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BRAZING OF BERYLLIUM FOR STRUCTURAL APPLICATIONS

COMPRESSION PANEL

COMPRESSION TUBE

by

J. W. VOGAN

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NO. NAS8-28029

SOLAR DIVISION OF INTERNATIONAL HARVESTER COMPANY

SAN DIEGO, CALIFORNIA 92138

FINAL REPORT

FOR

BRAZING OF BERYLLIUM FOR STRUCTURAL APPLICATIONS

CONTRACT NAS8-28029

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MARSHALL SPACE FLIGHT CENTER

HUNTSVILLE, ALABAMA 35812

SOLAR DIVISION OF INTERNATIONAL HARVESTER COMPANY

SAN DIEGO, CALIFORNIA 92138

FOREWORD

This final report details the work performed under NASA Contract NAS8-28029. Records on this program are filed under Solar Research Project Number 6-3913-7.

The contract was initiated by the National Aeronautics and Space Administration, Marshall Space Flight Center with the Solar Division of International Harvester Company, for fabrication of a brazed beryllium compression panel and a compression tube composite. The technical direction was supplied by Mr. C. N. Irvine of NASA Research Process Technology, Metals Joining Development Branch, Huntsville, Alabama.

Mr. J. W. Vogan, Solar Research Laboratories was the Project Manager and Mr. P. V. Nerger the Contracts Administrator.

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ABSTRACT

Progress made in fabricating a beryllium compression tube structure and a stiffened beryllium panel for delivery to the George C. Marshall Space Flight Center is discussed. The compression tube was to be 7.6cm (3") in diameter and 30.5cm (12") long with titanium end fittings. The panel was to be 203cm (80") long and stiffened with longitudinal stringers. Both units were to be assembled by brazing with BAg-18 braze alloy. The detail parts were fabricated by hot forming 0.305cm (.120") beryllium sheet and the brazing parameters established.

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INTRODUCTION

Structural beryllium panels and truss beams for the Space Shuttle and other aerospace applications offer a new potential for efficient materials utilization. Beryllium's unique properties may be realized by properly designed and carefully fabricated hardware. The objective of Solar's contract was to build one metallurgically bonded compression panel with stringers and one laminated beryllium tube with metallurgically joined titanium end fittings. Successful accomplishment of these structural brazements would contribute significantly to the manufacturing technology of beryllium.

The panel to be fabricated in this program was to be similar to one fabricated by Lockheed Missiles and Spacecraft under a separate NASA contract. It would differ primarily in that the Lockheed unit would have the stringers attached to the panel by lockbolts while the Solar panel was to be a brazed design. After completion of both panels NASA would then subject them to comparative testing and establish the relative merits of the two assembly methods.

A second piece of hardware was to be designed and fabricated by Solar to demonstrate the feasibility of producing a beryllium compression tube with titanium alloy end fittings attached by brazing. This would be a model Thrust Structure Truss Beam for future design. The brazed end fittings serve to transmit high compression and tensile loads uniformly into the tube.

Part way through the program a decision was made to incorporate heavier gauge stiffeners into the test panel. This entailed additional tooling and material requirements. To offset the added cost fabrication of the model compression tube was discontinued and the tooling redesigned to handle the heavier gauge material. The remainder of this report details the effort expended under this contract.

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PROCUREMENT AND PROPERTY DETERMINATION OF BERYLLIUM MATERIALS

Material for use on this program was ordered from Kawecki-Berylco Industries (KBI) and Brush-Wellman (BW). Certification as to chemical composition and tensile properties were supplied by the manufacturer.

Receipt of the materials, identification and their physical dimensions are tabulated in Table I below. Chemical analysis and mechanical properties are reported separately. With the exception of sheet 1497B, all materials were supplied by KBI.

TABLE I

BERYLLIUM MATERIAL IDENTIFICATION

	Date		Heat No.	Sheet No.
1)	12/16/72	One piece 1.65mm x .30m x 0.61m (.065" x 12" x 24")	4785 Lot	1497B(B-W)
2)	3/12/72	One piece 1.52mm x 0.61m x 1.3m (.060" x 24" x 50")	379P	HR-1513(KBI)
3)	4/02/72	Two pieces 6.32mm x .267m x .74m (.249" x 10.5" x 29")	633P	H-1573(KBI)
4)	4/11/72	One piece 2.90mm x .76m x 94m (.114" x 30" x 37")	690P	H-1575(KBI)
5)	4/18/72	Two pieces 2.90mm x .74m x 2.0m (.114" x 29" x 80")	690P	H-1574(KBI) H-1579(KBI)
6)	4/18/72	Two pieces 3.00mm x .76m x 2.0m (.118" x 30" x 80")	379P 690P	HR-1527(KBI) H-1577(KBI)
7)	4/25/72	One piece 3.00mm x .76m x 2.0m (.118" x 30" x 80")	690P	H-1578(KBI)

Chemical composition of the individual sheets is reported in Table II. None of the individual sheets were found to have excessive impurities and all were within acceptable limits. It may be observed that the percentages total more than 100 percent. This results from the beryllium content showing both as beryllium and again as part of the beryllium oxide content.

TABLE II

CERTIFICATION OF BERYLLIUM SHEET - CHEMICAL ANALYSIS

Vendor	Brush-Wellman	Kawecki	Kawecki	Kawecki	Kawecki	Kawecki	Kawecki	Kawecki	Kawecki
Sheet No.	1497B	HR-1513	H-1573	H-1575	H-1574	H-1579	HR-1527	H-1577	H-1578
Heat No.	4785	379P	633P	690P	690P	690P	379P	690P	690P
	%	%	%	%	%	%	%	%	%
Be Assay	98.4	99.0	99.01	99.05	99.05	99.05	99.00	99.05	99.05
Be O	1.6	1.04	1.04	.95	.95	.95	1.04	.95	.95
C	.09	.048	.064	.068	.065	.068	.048	.068	.068
Fe	.11	.095	.090	.090	.090	.090	.095	.090	.090
Al	.07	.042	.027	.026	.026	.026	.042	.026	.026
Mg	.03	.004	.012	.010	.010	.010	.004	.010	.010
Si	.03	.016	.016	.027	.027	.027	.016	.027	.027
Other	.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04

Mechanical properties of the individual sheets were also reported by the supplier to insure that the material would, in addition to the requirements of MIL-B-8964, meet the contractural specification of 10 percent minimum elongation in a 2.54 cm (1.0") gauge length. This data is reported in Table III.

Beryllium tensile test specimens were prepared for room temperature testing of mechanical properties to verify vendor certifications. This entailed microscopic examination of sample edges, recording dimensions and scribing test elongation reference lines. As shown in Table IV all of the materials met minimum specifications for longitudinal tensile strength. The transverse tensile strength of sheet HR-1513 was slightly below the desired value but as the longitudinal values met the required minimum this was not considered cause for rejection. Generally the values obtained ran lower than those reported by the supplier.

Elongation of all but one sheet, HR 1513, met the required minimum of 10 percent. Average in longitudinal and transverse directions was 9.75 percent. Since the sheet was already in work it was accepted on the basis of vendor certifications.

TABLE III

SUPPLIER REPORTED MECHANICAL PROPERTIES

	Rolling*	$\sigma_{U.T.S.}$		$\sigma_{Y.S.}$ (.2%)		%**
Sheet No.	Direction	(10^8 N/m^2)	(ksi)	(10^8 N/m^2)	(ksi)	Elongation
1497B***	L	5.05	(73.2)	4.17	(60.4)	13.5
	T	5.47	(79.3)	4.02	(58.3)	21.5
HR-1513	L	5.15	(74.7)	3.48	(50.5)	12.0
	T	4.85	(70.3)	3.52	(51.0)	12.0
H-1573	L	5.17	(75.0)	3.50	(50.8)	27.0
	T	5.36	(77.7)	3.48	(50.5)	28.0
H-1574	L	4.97	(72.0)	3.81	(55.3)	11.0
	T	4.87	(70.6)	3.74	(54.2)	17.0
H-1575	L	5.15	(74.7)	3.81	(55.3)	15.5
	T	4.94	(71.7)	3.67	(53.2)	16.0
H-1579	L	5.48	(79.5)	4.08	(59.2)	19.0
	T	5.35	(77.6)	4.23	(61.4)	25.0
HR-1527	L	5.51	(79.9)	4.00	(58.0)	27.0
	T	5.28	(76.5)	4.00	(58.0)	34.0
H-1577	L	5.41	(78.4)	4.10	(59.4)	16.0
	T	5.10	(73.9)	3.84	(55.7)	29.0
H-1578	L	5.43	(78.7)	4.29	(62.2)	15.0
	T	5.31	(77.0)	4.14	(60.0)	27.0

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*L - Longitudinal, T - Transverse

**2.54 cm (1.0") gauge length

*** Brush-Wellman material, all other KBI material

The minimum specifications of 4.827 x 10^8 N/m^2 (70,000 psi) ultimate, 3.448 x 10^8 N/m^2 (50,000 psi) yield, and 10 percent elongation were met on all beryllium material received.

TABLE IV

MATERIAL VERIFICATION TENSILE TEST DATA(1)

Type	Cross Section cm	Cross Section in.	U.T.S. $10^8 N/m^2$	U.T.S. ksi	(.2%) Y.S. $10^8 N/m^2$	(.2%) Y.S. ksi	El. (%)(4)
Sheet HR-1513							
1L(2)	.906 x .137	.357 x .054	4.92	71.3	3.67	53.2	9.0
2L	.909 x .139	.358 x .055	4.90	71.1	3.68	53.3	8.0
1T(2)	.906 x .137	.357 x .054	4.74	68.7	3.50	50.8	11.0
2T	.907 x .137	.357 x .054	4.74	68.7	3.50	50.8	11.0
Sheet HR-1527							
1L	.912 x .264	.359 x .104	5.23	75.8	3.88	56.2	22.0
2L	.912 x .269	.359 x .106	5.12	74.2	3.81	55.2	21.0
3L	.907 x .264	.357 x .104	5.22	75.7	3.94	57.2	20.0
Sheet H-1574							
1L	.922 x .292	.363 x .115	4.96	71.9	3.80	55.1	9.0
2L	.922 x .299	.363 x .118	5.11	74.1	3.88	56.3	14.0
3L	.922 x .295	.363 x .116	5.20	75.4	3.81	55.2	15.0
Sheet H-1577							
1L	.917 x .318	.361 x .125	5.35	77.6	3.85	55.8	20.0
2L	.919 x .318	.362 x .125	5.30	76.8	3.85	55.8	20.0
3L	.914 x .318	.360 x .125	5.05	73.3	3.87	56.1	13.0
Sheet H-1579							
1L	.953 x .318	.375 x .125	5.25	76.1(3)	4.17	60.5	12.0
2L	.922 x .318	.363 x .125	5.44	78.9	4.14	60.1	14.0
3L	.904 x .302	.356 x .119	5.40	78.3	3.83	55.5	19.0
Sheet 1578							
1L	.917 x .307	.361 x .121	5.46	79.2	4.25	61.6	17.0
2L	.925 x .307	.364 x .121	5.42	78.6	4.19	60.7	17.0
3L	.927 x .307	.365 x .121	5.25	76.1	4.30	62.3	14.0

(1) Load Rates (ASTM E8-66)
.005"/min. to yield
.050"/min. yield to ultimate
(2) L-Longitudinal T-Transverse Rolling Direction
(3) Failed in grip area
(4) One inch gauge length

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DESIGN AND FABRICATION OF THE COMPRESSION TUBE COMPOSITE

The compression tube was to be approximately 7.62cm (3") internal diameter and to be fabricated from three brazed plies of 1.5mm (.060") gage beryllium with two (2) brazed titanium end fittings. The beryllium tube length was to be 0.3m (12") long. The tube was scaled down from known load requirements but design stress was calculated to be comparable to existing applications. This high strength composite tube was to demonstrate advanced fabrication technology of beryllium composites for load carrying structures.

Application of Solar's symmetrical "trapped joint" design, Figure 1, between the beryllium tube and the titanium alloy end fitting has evolved from in-house experiments with various design and materials combinations as end configurations to transmit loads efficiently into and from the tube proper. The double taper fit provides self-aligning action during assembly which, coupled with special fixturing, provides proper joint thickness and cool-down control. The latter factor is the key to brazed joint integrity as the resultant composite is not only precisely aligned but residual stresses are held to a minimum. High quality, high performance brazements are envisioned without further development.

Fabrication of the beryllium compression tube was to employ cross rolled beryllium sheet hot formed into cylindrical half-shells. Six individual sections would then be joined by brazing and laminating to provide the desired tube. Joints between tube halves would be spaced equally around the circumference to minimize their effects. Bonding of the sections into a single structural tube was to be accomplished using a silver base braze alloy. Joint thickness would be held to a minimum to obtain the maximum possible strength and load transmission through the individual sections.

The secondary brazing operation was to utilize a lower melting aluminum base braze alloy selected for compatibility with both the titanium and the beryllium components. The taper joint was selected to provide a large joint area with self-fixturing properties.

Initially, sections 7.62cm (3") long were to be formed and brazed into short columns. The required brazing and forming parameters for the final 30 cm

(12") unit would be established during this portion of the program.

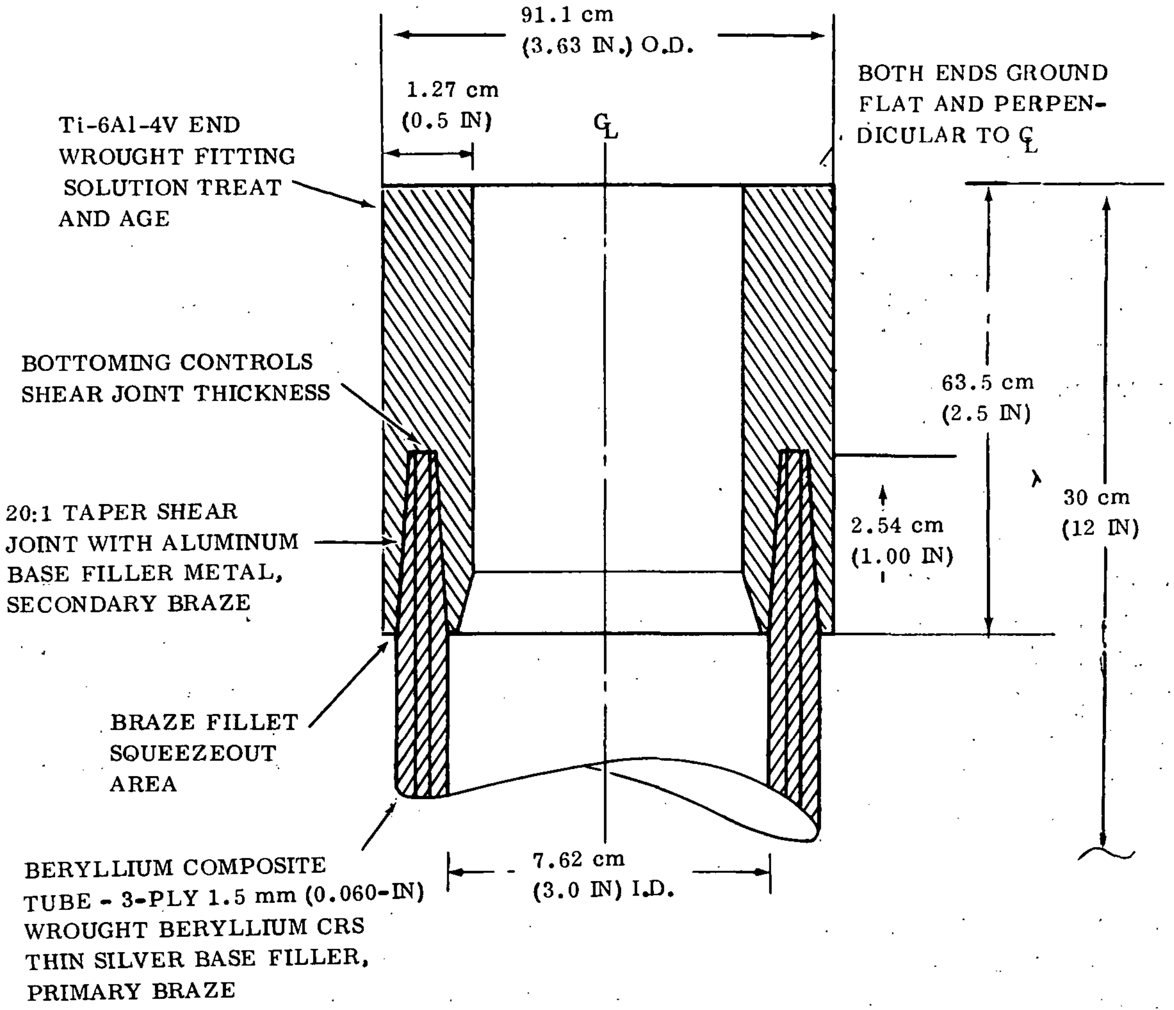

FIGURE 1. TYPICAL END CONFIGURATION FOR BRAZED BERYLLIUM COMPRESSION TUBE

The first set of details for the 76mm (3") long compression tube forming process was completed. Tooling required for forming of the short compression tube was designed and fabricated. A Solar forming process is used to provide the required degree of precision at forming temperatures of 705° C (1300° F) to 732° C (1350° F). Blanks for this compression tube demonstration sample were cut and one complete set (6 pieces) of beryllium sheet 1.52mm (.060 in) thick was successfully formed. The three ply, laminated tube components were formed with ± 0.5mm (.002") diametrical tolerances to meet brazing requirements. These details are shown in Figure 2 and are ready for brazing into a test compression tube.

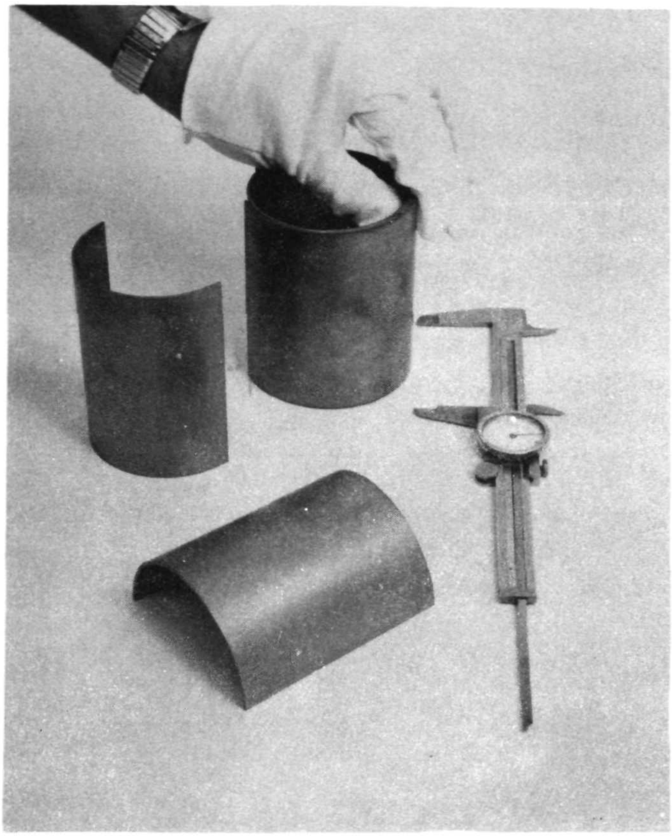

FIGURE 2

COMPRESSION TUBE,
FORMED BERYLLIUM DETAILS

At this point work on the compression tube was discontinued. The NASA furnished, compression panel design had been received as LMSC drawing #SKJ201002, Rev. B. The gages of material were substantially heavier than those on the preliminary print #SKS-100125. Also, the size of the doublers had been increased. The basic changes were increasing the U-channel and skin thickness from 1.93mm (.076") minimum to a 2.79mm (.110") minimum (45 percent increase). Also the height of the doublers increased from 11.1cm (4.4") to 26.7cm (10.5"). These changes increased the program scope and it was decided to delete the compression tube requirement. No further work was conducted in this area.

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BRAZING PROCESS DEVELOPMENT

A silver base braze alloy, BAg 18, (60% Ag 30% Cu 10% Sn) was selected for joining the stiffeners to the compression panel. This selection was based on a previous Solar program evaluating the relative merits of braze alloys for use in beryllium joining.

A test program was established to determine the best time-temperature-pressure parameters for use in the panel brazement. Initial evaluation of these parameters was based on a simple shear test. The sample configuration and test fixture are sketched in Figure 3.

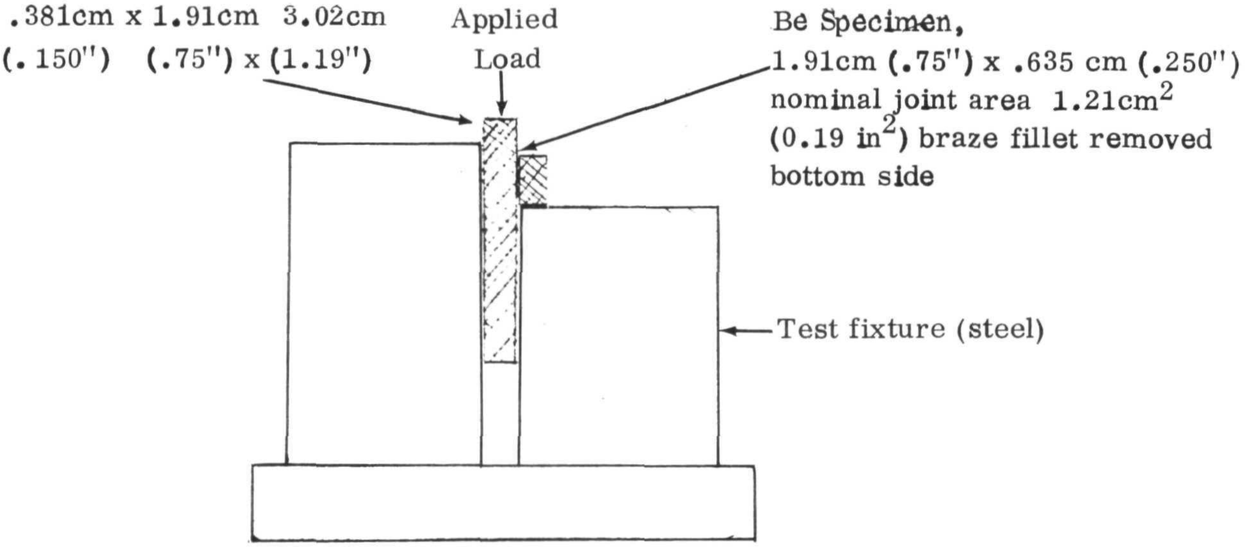

FIGURE 3. LAP SHEAR TEST SPECIMEN AND TEST FIXTURE

Past experience has indicated that .076mm (.003") brazing foil is the most suitable for applications involving joints of the type encountered in the compression panel and the majority of the tests were based on this braze alloy thickness. A test matrix, Table V, was established prior to initiating the test program. Two sets of samples, 9a and 10a, used .002cm (.001") braze alloy for comparison with the preferred foil thickness.

TABLE V

TEST MATRIX FOR LAP SHEAR TEST SPECIMENS

Test Number	Quantity of Specimens	BAg18 Alloy Thickness mm	(in.)	Time (Min.)	Brazing Temperature (°C)	(°F)	Clamping Pressure $10^5 N/m^2$	(psi)
1	4	.076	(.003)	6	648	(1200)	1.0	(15)
2	4	.076	(.003)	6	648	(1200)	3.4	(50)
3	4	.076	(.003)	6	675	(1250)	1.0	(15)
4	4	.076	(.003)	6	675	(1250)	3.4	(50)
5	4	.076	(.003)	6	705	(1300)	1.0	(15)
6	4	.076	(.003)	6	705	(1300)	3.4	(50)
7	4	.076	(.003)	60	648	(1200)	1.0	(15)
8	4	.076	(.003)	60	648	(1200)	3.4	(50)
9	2	.076	(.003)	60	675	(1250)	1.0	(15)
9a	2	.025	(.001)	60	675	(1250)	1.0	(15)
10	2	.076	(.003)	60	675	(1250)	3.4	(50)
10a	2	.025	(.001)	60	675	(1250)	3.4	(50)
11	4	.076	(.003)	60	705	(1300)	1.0	(15)
12	4	.076	(.003)	60	705	(1300)	3.4	(50)

The results of these brazing tests are given in Table VI. As expected the .025mm (.001") foil gave weaker joints than the .076mm (.003") foil when brazed by the same process. This difference is seen when comparing sample 9 with 9a and sample 10 with 10a in Table VI. The parts brazed with the thinner foil gave weaker joints. This is particularly evident in the low pressure joints where joint strengths varied by a factor of 3.

Photomicrographs of a typical braze joint from this series of tests are reported as Figures 4 and 5. The test numbers refer to test conditions given in Table V. This joint is considered to be representative of the joints expected in a full size panel. The filler metal is reduced to in thickness about 16 percent. On each interface is a diffusion zone approximately 0.0012cm (0.0005") thick accounting for the loss in braze alloy thickness. The affects of this diffusion zone have not been fully evaluated at the present time. The amount of diffusion shown in Figure 4 is considered to be the minimum that can be achieved when producing a reliable structural joint.

The excellent wetting and flow of braze alloy can be seen in Figure 5. The large fillet adds to joint strength slightly but is of greater value in reducing edge stress concentration preventing the development of fatigue cracks in the brittle diffusion layer.

TABLE VI

SHEAR STRENGTH RESULTS VARYING BRAZE TIME, TEMPERATURE AND PRESSURE

Test No.	Temp. °C °F	Pressure $10^5 N/m^2$	(psi)	6 Min. Shear Strength $10^8 N/m^2$ (ksi)	Test No.	60 Min. Shear Strength $10^8 N/m^2$ (ksi)
1	648 (1200)	1.0	(15)	.99 (14.3)	7	.79 (11.4)
	648 (1200)	1.0	(15)	.98 (14.2)		1.20 (17.4)
	648 (1200)	1.0	(15)	1.16 (16.8)		1.31 (19.0)
	648 (1200)	1.0	(15)	.85 (12.4)		1.42 (20.6)
				Avg. .99 (14.4)		Avg. 1.18 (17.1)
2	648 (1200)	3.4	(50)	1.47 (21.3)	8	1.11 (16.1)
	648 (1200)	3.4	(50)	1.37 (19.9)		1.10 (16.0)
	648 (1200)	3.4	(50)	1.65 (23.9)		1.34 (19.4)
	648 (1200)	3.4	(50)	1.69 (24.5)		.74 (10.8)
				Avg.1.54 (22.4)		Avg. 1.07 (15.5)
3	675 (1250)	1.0	(15)	1.37 (19.8)	9	1.23 (17.9)
	675 (1250)	1.0	(15)	1.59 (23.1)		.91 (13.2)
	675 (1250)	1.0	(15)	1.52 (22.0)		Avg. 1.08 (15.6)
	675 (1250)	1.0	(15)	1.27 (18.4)	9a*	.41 (5.95)
				Avg.1.43 (20.8)		.22 (3.25)
						Avg. .32 (4.7)
4	675 (1250)	3.4	(50)	1.07 (15.5)	10	.50 (7.25)
	675 (1250)	3.4	(50)	.97 (14.0)		.59 (8.60)
	675 (1250)	3.4	(50)	.97 (14.0)		Avg. .55 (7.93)
	675 (1250)	3.4	(50)	.56 (8.1)	10a*	.48 (6.9)
				Avg. .89 (12.9)		.32 (4.6)
						Avg. .39 (5.6)
5	705 (1300)	1.0	(15)	1.13 (16.4)	11	.15 (2.18)
	705 (1300)	1.0	(15)	1.38 (20.0)		.22 (3.16)
	705 (1300)	1.0	(15)	.68 (9.8)		.11 (1.60)
	705 (1300)	1.0	(15)	1.83 (26.5)		.19 (2.75)
				Avg.1.26 (18.2)		Avg. .10 (1.50)
6	705 (1300)	3.4	(50)	.67 (9.7)	12	.28 (4.00)
	705 (1300)	3.4	(50)	1.38 (20.0)		.31 (4.45)
	705 (1300)	3.4	(50)	.84 (12.2)		.24 (3.50)
	705 (1300)	3.4	(50)	.44 (6.4)		
				Avg. .83 (12.1)		Avg. .23 (3.37)

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* 25.4 x 10^{-3}mm (.001") BAg18 Braze Alloy - All Others 76.2 x 10^{-3}mm (.003")

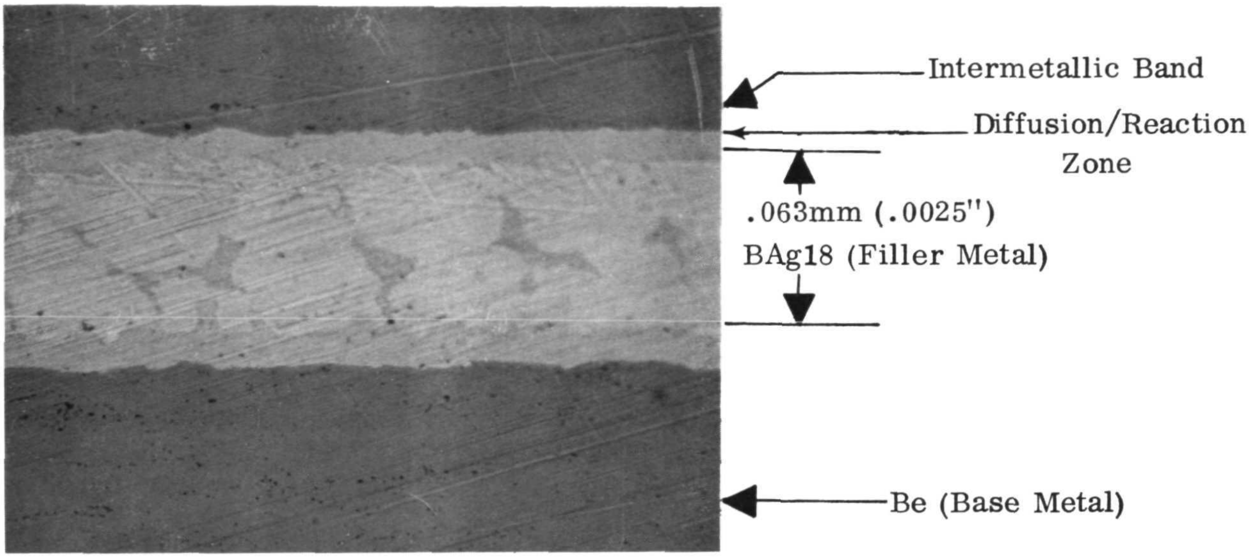

FIGURE 4. PHOTOMICROGRAPH OF TYPICAL BAg18 BRAZE JOINT (Test No. 3) Magnification: 500X

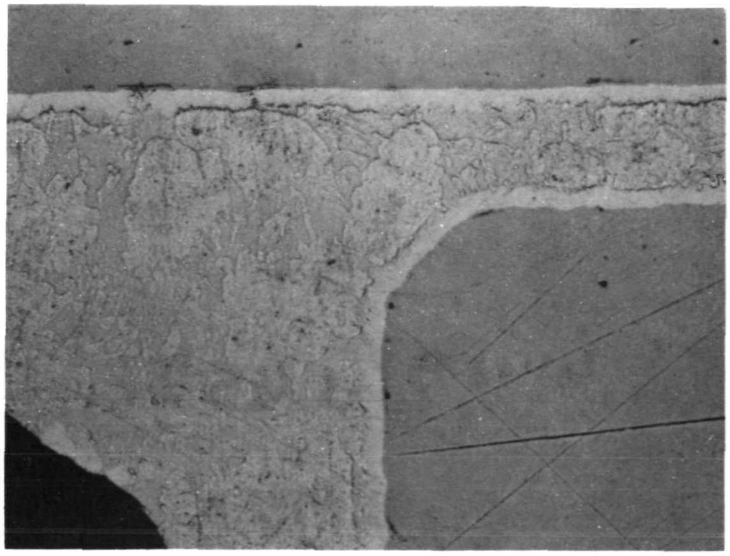

FIGURE 5. PHOTOMICROGRAPH OF TYPICAL BAg18 BRAZE JOINT FILLET AREA (Test No. 3) Magnification: 250X

For brazing of the panel assembly a procedure using a $1.0N^5/m^2$ (15 psi) joint load at 675° C (1250° F) for six minutes was selected. Longer times or higher temperatures would increase the diffusion zone while the use of higher pressures would lead to problems in design of adequate tooling for the full size panel.

Verification of the brazing parameters were demonstrated by a trial braze of two 30.5cm (12") stiffener sections to a test panel. The test braze was conducted in an evacuated retort using atmospheric pressure applied through conventional steel tooling to the joint area. No problems were encountered and an excellent joint was achieved except that filleting was less than desired. A photomicrograph of the test joint is presented as Figure 6. The reaction zone between the BAg-18 braze alloy and the beryllium is clearly shown.

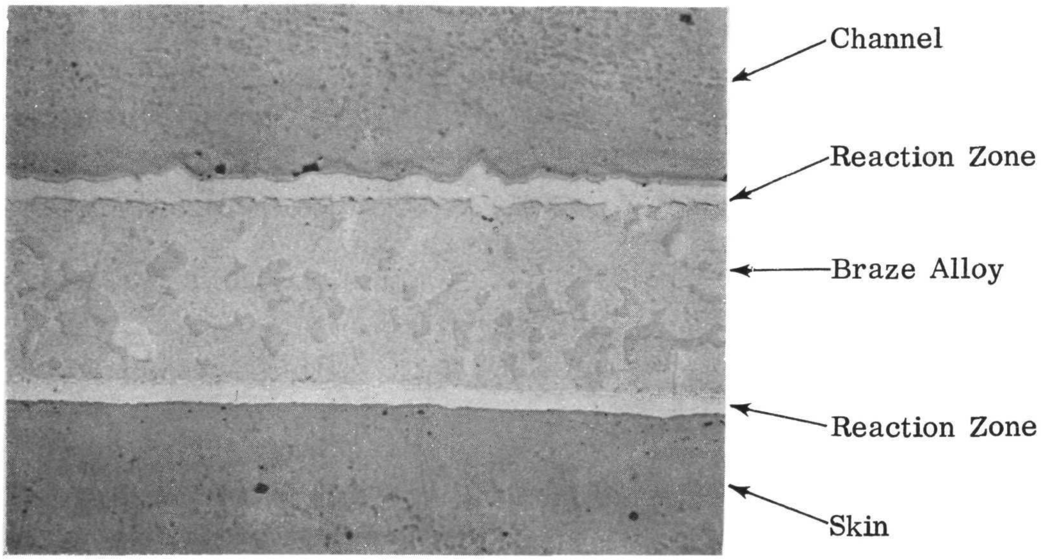

FIGURE 6. BRAZE OF TEST STIFFENER TO PANEL
(Magnification: 500X, Unetched)

Review of the data from the braze run showed that heat up was slower than planned. and the requirement for six minutes at 675° C (1250° F) was not met. Power input was increased on a second trial run and as a result of these tests no significant problems were anticipated in the final assembly braze.

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BERYLLIUM CHANNEL STIFFENER FORMING

Forming of the channel stiffeners for brazing to the beryllium panel was considered to be the most critical phase of the program. Unlike the lockbolted panel, shimming could not be used to compensate for irregularities in the brazed joint. An in-house requirement was established for a flatness on the brazed flange of 0.013 cm (.005") over the 203 cm (80") length. This precision is required to insure proper fit up of the components for brazing and minimum residual stress in the final assembly. Other tolerances on the channels were set at ± 0.076 cm (±.030") as required by the assembly drawing.

Early in the program the stiffener material thickness was changed from 0.193 cm (.076") to a minimum of 0.280 cm (.110"). This increase required a major modification of forming parameters and tooling requirements. The Solar forming process and tooling was primarily intended for light gauge materials, less than .229 cm (.090"), and process development work plus a tooling redesign was required.

Initial forming was conducted on 7.6 cm (3") channel lengths to evaluate forming pressure requirements and springback or underform problems that might develop in the heavier gauge material. Forming was conducted in the 690° C (1275° F) to 760° C (1400° F) range using moderate pressure. These tests demonstrated that the capacity of the pressure equipment had to be doubled to insure satisfactory forming of the full size channels. The required modifications were incorporated.

When modification of the equipment had been completed tests were conducted to establish the minimum forming temperature required with the equipment. It was determined that a temperature of 718° C (1325° F) ± 8° C (15° F) was optimum. Higher temperatures are deleterious and forming below this temperature led to problems in underforming the flanges.

Once forming parameters were established four separate 7.6 cm (3.0") channels were formed from 0.30 cm (.120") thick material. Each was made in a different area of the heated die to check for variations over the 203 cm (80") length of the heated platens used in forming. One of these test channels is shown as Figure 7. All of these test parts were well within drawing and brazing tolerance requirements.

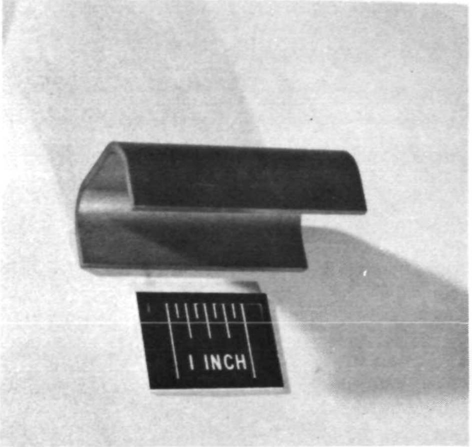


FIGURE 7

THREE INCH "C" CHANNEL
.305 cm (0.120") MATERIAL

With the forming requirements and die allowances established full size tooling was fabricated. Final tooling proof test runs were conducted using 61 cm (24") long channel sections. These sections were checked dimensionally and found to meet all dimensional requirements. As a final process check these 61 cm (24") stiffeners were cut to 30.5 cm (12") and brazed to a test panel using tooling designed for the full scale unit and the braze schedule previously established. A photograph of one of these panels is shown as Figure 8. As reported, the brazing trials were successful and the development portion of the program was completed.

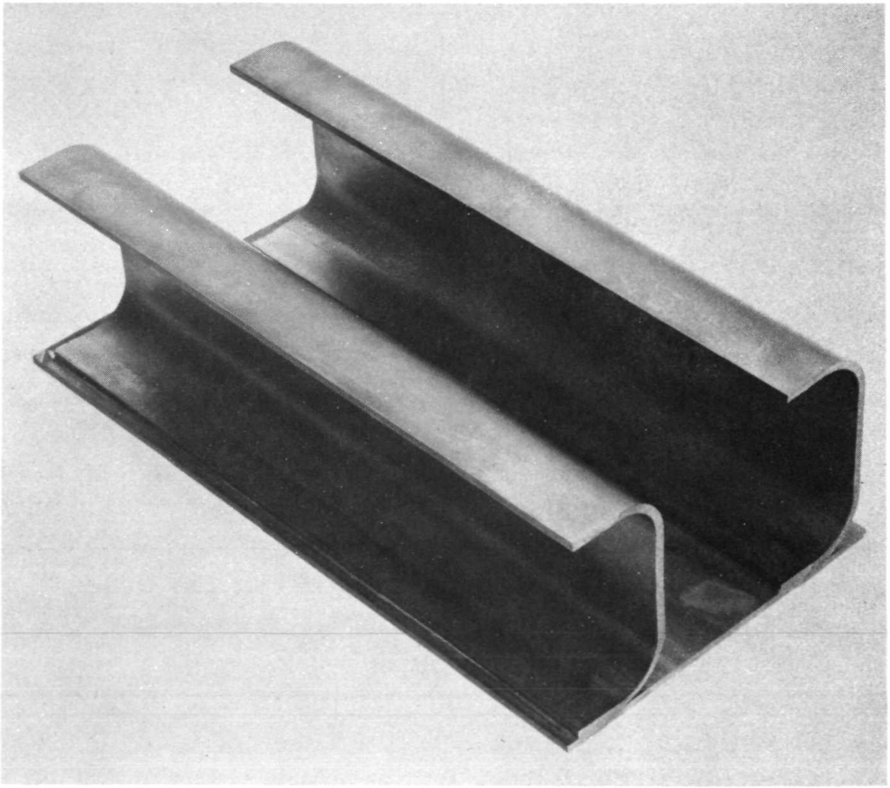
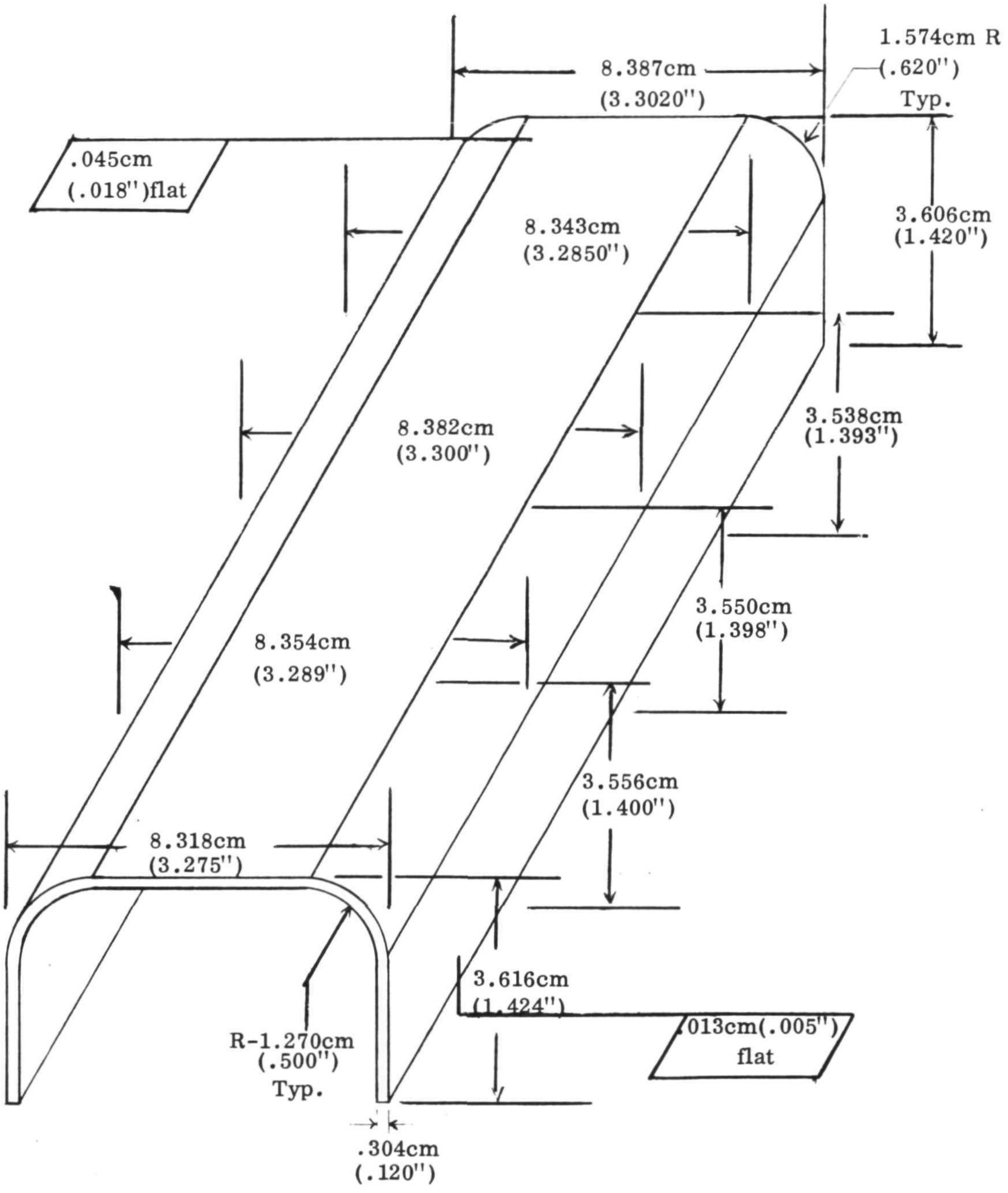


FIGURE 8. TEST PANEL WITH BRAZED 30.5 cm (12") STIFFENERS

Prior to initiating forming of the full size channel stiffeners the blanks were cut to size. No allowance was required for trimming after forming since the previous tests had demonstrated that the channels could be formed net. With one exception no problem was encountered in cutting the forming blanks to a ± .025 cm (.010") width tolerance and straight within ± 0.013 cm (.005").

The exception was sheet H-1574 supplied by KBI. During cutting of this sheet the abrasive wheel tended to deflect and produce out of tolerance cuts. No reliable explanation was produced for this behavior. The cutting operation is automatic once the initial set up is made and changes in feed and wheel speed had no appreciable effect. The beryllium sheets cut immediately before and immediately after, using the same procedures and equipment were cut without difficulty. Reference to mechanical and chemical property data also failed to reveal any probable cause for the anomaly. As a result 40 percent of this sheet was lost during cutting. No losses were incurred in the remaining sheets during the cutting operation. After cutting the forming blanks were etched to eliminate edge stresses, inspected and set aside for the forming operation.

Forming of the 203 cm (80") channels proceeded as planned during the closing phases of the program. Due to schedule limitations it was not possible to complete all of the required channels and braze the final assembly. However, sufficient channels were formed to demonstrate that forming problems had been eliminated and that channels can be readily produced meeting the rigid requirements of a brazed panel assembly. Figure 9 is a sketch of a typical channel and the measured dimensions. As can be seen a slight variation in width exists over the channel length. The maximum variation in width was ± 0.034 cm (0.014") which is well within drawing requirements. Flatness on the brazing flange was better than 0.013 cm (0.005") which is also suitable for producing a reliable brazed joint. A photograph of these channels is included as Figure 10.



Length not to scale - 203.2cm (80.00")

FIGURE 9. DIMENSIONAL CHECK RESULTS ON A TYPICAL 203cm (80") HOT FORMED BERYLLIUM PANEL STIFFENER

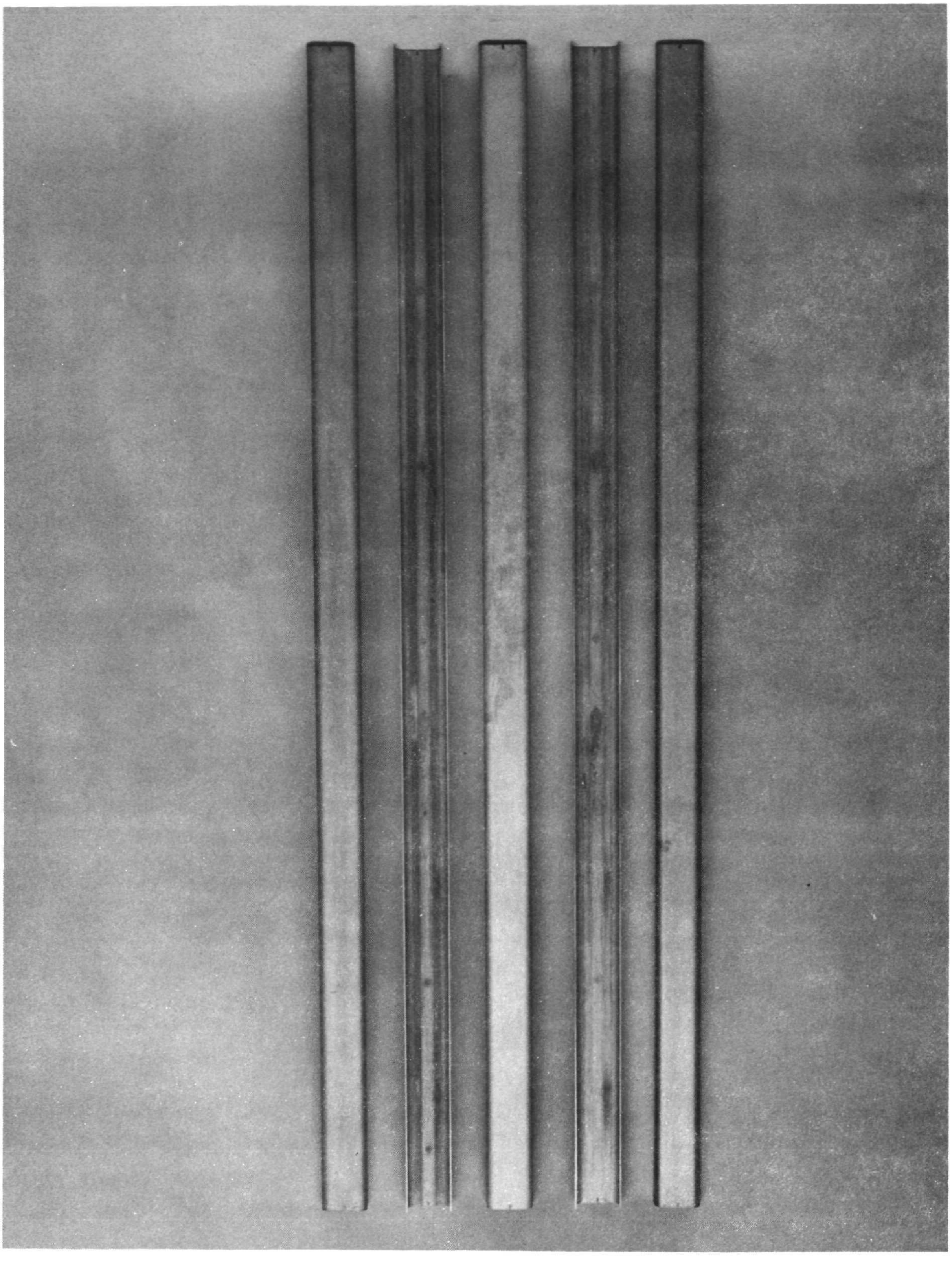


FIGURE 10. BERYLLIUM CHANNELS AS HOT FORMED

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CONCLUSIONS

Fabrication of a beryllium panel using hot formed beryllium stiffeners is a practical approach to current needs for lightweight rigid structures. Joining these panels to the stiffeners by brazing can be readily accomplished using current state-of-the-art techniques. Joint strengths to be expected in this structure are in the $10.4 \times 10^8 N/m^2$ (15,000 psi) range. With further development of brazing techniques higher strengths can be achieved.

In this program brazing of stiffeners to the test panel was readily accomplished with BAg-18 alloy. Test joints produced had a shear strength of $1.4 \times 10^8 N/m^2$ (20,000 psi). The low joint pressure $1 \times 10^5 N/m^2$ (15 psi) makes large assemblies practical with a minimum of tooling.

Forming the final design stiffeners was difficult due to their heavy gauge. The requirement to rebuild tooling and revise forming schedules created delays that prevented completion of the program within the allotted time span.

However, the scale up of the methods required to produce precise hot formed beryllium sections from heavy gauge materials were fully evaluated and sufficient channels formed to prove it practical. With the Solar forming techniques used, size of the channels is limited only by available sheet size and hat or Z sections can be produced with equal facility.

This program has demonstrated the feasibility of producing the brazed, stiffened beryllium panel with existing technology. It is recommended that further development be pursued in fabricating brazed structures from hot formed beryllium components for advanced structural applications.