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GAS-METAL ARC BRAZE WELDING OF
INGOT-SHEET BERYLLIUM

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GAS-METAL ARC BRAZE WELDING OF INGOT-SHEET BERYLLIUM

Richard J. Merlini and Walter L. Bush

Abstract. Discussed are studies on the Gas-Metal Arc welding of ingot-sheet beryllium produced at Rocky Flats. The results of a weld-porosity study indicate that radiographically porous-free welds can be made if the proper welding process parameters are used. Tensile-test data of welds showed that welds stronger than the base metal are easily produced if unbonding is avoided. The results of specimens tested for weld unbonding confirmed previous data from hot-pressed beryllium that a "fill factor"* of less than 10 must be used to prevent unbonding between the weld and the base metal. Graphs showing general process-parameter limits have also been constructed and are presented.

INTRODUCTION

The Rocky Flats Division of The Dow Chemical Company has been engaged in the joining of commercially available beryllium metal. The joining processes used for this task have ranged from oxy-acetylene flame welding to electron-beam techniques:

At Rocky Flats, Gas-Metal-Arc (GMA) braze welding is the process most often used for joining beryllium to beryllium. The most common type of beryllium used at Rocky Flats is the hot-pressed metal, manufactured using powder metallurgy techniques. Another type of beryllium metal used, which was developed at Rocky Flats, is ingot-sheet beryllium.⁽¹⁾ This material, manufactured by rolling cast ingots, has desirable properties not possessed by the hot-pressed beryllium.

Because of these desirable properties, ingot-sheet beryllium has been substituted for hot-pressed beryllium in numerous applications. However, many of these applications are predicated upon the ability to successfully join the ingot-sheet material.

Early attempts to GMA braze weld ingot-sheet beryllium produced two unacceptable conditions; weld porosity, and

weld-to-base metal unbonding. Unbonding is completely unacceptable in beryllium braze welds because of the loss in joint strength. An excess of weld porosity, on the other hand, is not necessarily detrimental to weld strength, but can result in other undesirable properties such as a decrease in weld-metal bulk density.

This report describes recent tests conducted to define some GMA braze welding characteristics of ingot-sheet beryllium produced at Rocky Flats. Wherever possible, these characteristics are compared to those for the hot-pressed beryllium.

COUPON CONFIGURATION

Two basic coupon configurations were used in this study. Flat coupons, as shown in Figure 1a, were used for the porosity study, and for obtaining weld strength and unbonding data. Two of these coupons were placed together to form a modified U-type weld groove. Cylindrical shaped coupons, such as shown in Figure 1b, were used for tests to determine weld arc stability limits. Two of these were placed together to form a weld joint similar to that for the flat coupons. All coupons were made from Rocky Flats produced ingot-sheet beryllium. For the flat coupons, the initial 3.5-inch-thick ingots were first rolled to approximately 0.265 inch and then machined to the final thickness shown in Figure 1a. The cylindrical coupons were rolled and formed to approximately 0.300 inch before machining.

WELD POROSITY STUDIES

Early attempts to GMA braze weld ingot-sheet beryllium produced very porous weld metal. For these first attempts, welding process parameters identical to those used for the hot-pressed beryllium had been used. The failure of these conditions to produce acceptable welds prompted a weld porosity study. The purpose of the study was to determine the effect of the weld process parameters on weld porosity.

For this porosity study, the three weld process parameters that appear in the weld energy input equation** were

*Fill factor is defined as the ratio of the filler wire feed rate to the welding rate. It is a relative indication of the volume of weld deposited for a given length of weld.

(1) J. L. Frankeny and D. R. Floyd, RFP-910, Rocky Flats Division, The Dow Chemical Company. [Report is subject to Department of Commerce Comprehensive Export Schedule Part 385.2 (c) (3) (v).]

**This refers to the theoretical equation for weld energy input per linear inch of weld.

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selected. These parameters: (1) welding arc voltage, (2) filler wire feed rate, and (3) welding rate, were arranged in a one-third factorial experiment. Three levels of each of these parameters (factors) were chosen for the experiment. The factor levels were selected over a relatively wide range so that some information about absolute process limits and unbonding might also be determined. The factors, the levels of these factors, and their arrangement are shown in Figure 2. The numbered squares represent conditions at which a coupon was welded.

A total of nine coupons must be welded for a one-third factorial plan. However, if some measure of the experimental error is desired, then the experiment must be repeated, or, at a minimum, one of the treatments must be repeated a number of times. For this particular case, three coupons were welded at the central square treatment, therefore three coupon numbers are listed at these conditions.

The factor levels at which the coupons were welded, can be determined from the test plan figure. Parameters that were constant are listed in Appendix A. The number of weld passes for each coupon is also given in Appendix A. Figure 3 is a photograph of a completed weld.

During welding, some difficulty was encountered with the welds at the 500 ipm wire feed rate. At the two higher voltages (22.5 and 24.0 Vdc), weld metal could not be deposited in the groove. Instead, because of the unstable welding arc, the metal was deposited at the groove edges. For the lower voltage (21.0 Vdc) the situation was marginal in that the arc was stable for a portion of the weld and unstable for the remainder. This condition did not prevent taking porosity measurements, but did preclude obtaining strength and unbonding data from these particular coupons.

Porosity measurements were taken after each weld pass by subjectively rating weld radiographs. A rating scale of from zero to four was used; four representing the best weld. Figures 4a and 4b represent positive prints of a four (best) and zero rated weld radiograph.

Experience has shown that porosity in GMA beryllium braze welds is largely determined by the porosity that occurs on the first weld deposit or pass. Therefore, the following porosity data represent results from the first weld pass.

FIGURE 1. Coupon Configurations Used for Weld-Arc Stability Studies of Ingot-Sheet Beryllium; (a) Flat Configuration, and (b) Cylindrical Configuration. Dimensions in Inches.

FIGURE 2. Factorial Test Plan Arrangement Used for Weld Porosity Studies of Ingot-Sheet Beryllium.

FIGURE 3. Typical Completed Weld Coupon.

FIGURE 4. Radiographs of GMA Welded Ingot-Sheet Beryllium.

After welding, analysis of variance was performed on the porosity ratings and process parameters. A significant linear effect of arc voltage on porosity was found. There was also a possible significant quadratic effect of filler wire feed rate upon porosity. Welding rate had no effect upon porosity. Table I summarizes the results of this variance analysis.

Significance is determined by comparing the F-Ratio value to the upper 0.05 probability point of the "F distribution" with 1 and 2 degrees of freedom.

Graphs showing porosity rating as a function of each of the variables are shown in Figure 5.

FLUORESCENT PENETRANT EFFECTS

Another cause of weld porosity, not previously recognized, was discovered during the coupon porosity study.

Fluorescent penetrant inspection of the completed weld coupons revealed macrocracks in the beryllium. These cracks were primarily transverse to the weld deposit and extended from the edge of the weld. The length of the cracks varied up to one-quarter inch.

Because a pre-weld penetrant inspection had not been performed on the coupons, we had no assurance that the cracks did not exist prior to welding. To determine if the

TABLE I. Analysis of Variance Table, Weld Porosity Experiment.

Parameter and Effect	Degrees of Freedom	Mean Square	F-Ratio
Arc Volts, Linear	1	2.041667	32.67
Arc Volts, Quadratic	1	0.125000	2.00
Wire Rate, Linear	1	0.093750	1.50
Wire Rate, Quadratic	1	0.281250	4.50
Weld Rate, Linear	1	0.041667	0.67
Weld Rate, Quadratic	1	0.125000	2.00
Residual	2	0.062500	

FIGURE 5. Ingot-Sheet Weld Porosity Ratings as a Function of the Investigated Variables.

cracks were a function of the welding, additional coupons were welded. This time, however, a pre-weld penetrant inspection was performed on the coupons. No cracks were detected on the unwelded coupons, but post-weld inspection again revealed cracks. Therefore, we determined that the cracking did occur as a result of the welding; however, another unexpected phenomena occurred. We discovered that we could not produce a low porosity weld on coupons that had been fluorescent penetrant inspected. Every weld, regardless of welding conditions, was extremely porous. Almost all of the welds had porosity ratings of less than two, with many zero ratings.

Why such a condition should occur was not immediately apparent. All of the coupons had been thoroughly cleaned after penetrant inspection, ensuring that no penetrant or penetrant developer remained on the coupon surface. (The cleaning procedure used throughout this weld study is listed in Appendix B).

The apparent paradox was ultimately explained upon closer inspection of the coupon surfaces. Inspection revealed that the surfaces contained extensive microcracking. We reasoned that the microcracking had the effect of creating minute reservoirs for the penetrant, which was not removed during cleaning. Upon welding, the penetrant was released and vaporized to form weld porosity. After suspension of the pre-weld penetrant inspection, porosity ratings returned to normal levels.

TENSILE AND ROOT-BEND SPECIMENS

We had originally planned to machine the porosity study coupons into tensile and root-bend specimens to obtain weld strength and unbonding data. Unfortunately, all but three of the eleven welded coupons either exhibited the aforementioned cracking phenomena or were from the 500 ipm filler wire feed level. As a result, strength specimens were machined from only three coupons. From each of these three coupons, two tensile and two root-bend specimens were removed. As shown in Figure 6, the tensile specimens were removed from the center of the coupon and the bend specimens from the ends. After removal from the coupon, the tensile specimens were machined to remove the unwelded butt portion of the weld joint. That is, the notch was removed. The bend specimens were left notched and only the surface weld bead was removed. Each specimen was numbered according to its coupon number and its position within the coupon. That is, if the specimen was taken from the first half of the coupon its number would be suffixed by an "s" for start, and conversly a specimen from the second half was labeled "f" for finish.

The purpose of the root-bend specimens was to determine if the welding conditions of the test plan produced

weld-to-base metal unbonding. As mentioned, the unwelded or notched portion of the specimens was left intact for testing. Experience has shown that if deleterious unbonding exists in a beryllium braze weld, a notched specimen will fracture along this unbonded interface when subjected to a root-bend test. Such a failure both locates and permits examination of the unbonded region.

The testing procedure for the root-bend specimens involved a two point loading technique to produce a constant bending movement across the weld with tensile stresses at the root of the weld. This testing technique is shown diagrammatically in Figure 7. When tested, the root-bend specimens exhibited two basic failure patterns. The failure was either near the weld-to-base metal interface or through the weld deposit. Figures 8a and 8b show these failure patterns. Generally speaking, the particular failure pattern had no significance as specimens from the same coupon had both types of failures. Table II lists the results from the root-bend specimens. As seen in Table II, one of the root-bend specimens from coupon number 1 had an unbonded region at the weld-to-base metal interface.

Experience with tensile specimens of GMA braze welded hot-pressed beryllium has shown that such specimens tend to fail in the beryllium away from the weld deposit. In an attempt to circumvent this condition with the ingot-sheet beryllium, a tensile specimen configuration with the smallest cross section at the weld was used. We had hoped that such a design would cause failure through the weld deposit so that the strength of the weld might be determined. However, when tested, none of the tensile specimens failed through the weld deposit. With one exception, the specimens failed in the beryllium away from

FIGURE 6. Outline of Tensile and Root-Bend Specimen Positions on Completed Weld Coupon.

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the Al-Si weld deposit. Figure 9 is typical of the tensile specimen fracture location. The exception, specimen number 1f, failed primarily along the weld-to-beryllium interface. Examination of this interface revealed unbonding near the weld groove root. (Note that this unbonded tensile specimen was from the same coupon that had the unbonded root-bend specimen). Table III lists the ultimate tensile strengths (UTS) for the six specimens. If the unbonded specimen strength is omitted, the sample UTS mean and 95% confidence limits are as follows:

Sample UTS mean 34.9 ksi
95% lower confidence limit 33.1 ksi
95% upper confidence limit 36.7 ksi

This compares favorably with the following data for identical tensile specimens of GMA welded hot-pressed beryllium:

Sample UTS mean 39.1 ksi
95% Lower confidence limit 35.9 ksi
95% Upper confidence limit 42.3 ksi

FIGURE 7. Drawing Showing General Testing Technique for Ingot-Sheet Beryllium Weld Root-Bend Specimens.

FIGURE 8. Fractures of Root-Bend Specimens; (a) Weld Centerline Fracture, and (b) Fracture near Interface of Root-Bend Specimen.

TABLE II. Root-Bend Specimen Test Results for GMA Welded Ingot-Sheet Beryllium.

Weld Coupon Number	Root Bend Specimen No.	Failure Path	Unbonding Detected
1	1s	Interface	No
1	1f	Interface	Yes
3	3s	Interface	No
3	3f	Weld Metal	No
4	4s	Weld Metal	No
4	4f	Interface	No

FIGURE 9. Tensile Specimen Configuration and Typical Failure Location for Ingot-Sheet Beryllium Weld Specimens.

PROCESS PARAMETER LIMITS

When GMA braze welding ingot-sheet beryllium, a higher welding arc voltage is needed to produce the same arc length as when welding hot-pressed beryllium. This condition is graphically shown in Figure 10. Figure 10 is a plot of welding arc short-circuit frequency (SCF) as a function of arc voltage. (A high SCF represents a short arc length while a low SCF represents a longer arc length. In general, the SCF is a measure of the number of times an arc is extinguished per unit time as a result of weld metal transfer from the filler wire electrode to the workpiece.)

TABLE III. Tensile Specimen Test Results for GMA Welded Ingot-Sheet Beryllium.

Weld Coupon Number	Tensile Specimen No.	Ultimate Tensile Strength (ksi)*	Failure Location
1	1s	32.8	Base Metal
1	1f	27.6	Interface
3	3s	36.1	Base Metal
3	3f	36.3	Base Metal
4	4s	35.2	Base Metal
4	4f	34.2	Base Metal

*Strengths were calculated using the minimum specimen cross-section in lieu of the cross-section at the failure location.

FIGURE 10. Plots Showing Difference in SCF as a Function of Arc Voltage for Ingot-Sheet and Hot-Pressed Beryllium; GMA Braze Welding.

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Examination of the plots of Figure 10 shows that for a given average arc length, a higher voltage drop exists across the arc for the ingot-sheet beryllium. The difficulty with this situation is that at the higher voltage, the arc tends to melt the weld groove edges. This produces an unstable oscillatory arc length condition and generally results in inferior weld deposits.

There are two probable causes for groove edge melting. The arc column is either too long or too large in diameter. Since SCF measurements indicate that the arc is not excessively long, the arc column diameter appears to have increased.

There are a number of solutions to the problem of groove edge melting. One is to use a wider weld groove. However, this is generally objectionable because of the increase in the volume of foreign weld metal. Another solution is to modify the actual arc column. That is, reduce the size of the arc column and restrict the arc plasma cathode to the groove root. One technique for accomplishing this is to alter the composition of the arc shielding gas.

When GMA braze welding hot-pressed beryllium, an arc shielding gas ratio of 5 parts helium to 1 part argon is normally used. After some experimenting, we determined that a shielding gas ratio of 8 helium-to-1 argon reduced groove edge melting.

Although the increased helium accomplishes the desired effect of reducing groove edge melting, there is an attendant disadvantage. That is, with the higher helium-to-argon ratio there are more parameter combinations that produce an unstable weld deposition condition. Unstable, in this case, refers to a phenomena whereby gaps are formed in the weld metal. This gapped condition is shown in Figure 11.

To more thoroughly define the limits at which these unstable welds occur, a series of welds were made on the cylindrical coupons described earlier. The welds were made at two different shielding gas ratios. A number of filler wire feed rates and arc voltages were used along with a constant welding rate of 100 ipm.

Figure 12 summarizes the results of these welds. Again, with the exception of the arc-shielding gas ratio, conditions as listed in Appendix A were used.

Interpretation of Figure 12 indicates that if welds are made at welding parameters that intersect below the curves, depending on the shielding gas ratio, the gapped weld condition of Figure 11 will probably occur. (It should be noted that the curves of Figure 11 are applicable only for the welding groove configuration of Figures 1a and 1b.)

DISCUSSION

Weld Porosity

The results of the weld porosity study clearly indicate that weld arc voltage is the parameter that must be controlled if low porosity welds are to be produced. In general, the results shown in Figure 4 indicate that an average arc voltage in the range from 22.5 to 24.0 Vdc is required to produce a low porosity weld. This voltage is approximately 1.0 to 2.0 Vdc higher than needed to produce a similar weld in hot-pressed beryllium. A low porosity or acceptable weld has a rating of 3.5 or higher.

There are probably two basic reasons for the significance of the arc voltage parameter on porosity. Equation I is a relationship for the heat input per unit volume of deposited weld metal. In examining this equation

$$\frac{\text{Heat Input}}{\text{Unit Volume}} \left(\frac{\text{joules}}{\text{in}^3} \right) = \frac{E \times I \times C}{\text{WFR} \times A}$$

FIGURE 11. Photograph Showing Gapped Weld Deposit Caused by Unstable Weld Arc Condition.

Where: E = Weld Arc Voltage
I = Weld Arc Current
C = Conversion Factor (seconds/unit time)
WFR = Filler Wire Feed Rate (per unit time)
A = Filler Wire Cross-sectional area

it is seen that weld arc voltage is the only member of the equation that changes the heat input in a directly proportional manner. This means that a linear increase in arc voltage results in a linear increase in the amount of energy per given quantity of weld metal deposited. Such a

condition will slow the overall weld-cooling rate and produce less porous welds.

The other reason for the strong effect of arc voltage upon weld porosity is related to the arc short-circuit frequency. As seen in Figure 10, the arc SCF for ingot-sheet beryllium increases rapidly below 24.0 Vdc. As the SCF increases, the amount of "arc time" steadily decreases. As a result, the weld cooling rate again increases preventing the release of gases from the molten weld puddle. Although data on weld cooling rate as a function of SCF are not available, examination of arc voltage oscillographic traces reveal that a significant decrease in energy input occurs as the SCF increases. Thus, in addition to a high arc voltage, a low SCF (less than 50/second is considered low) is also needed to produce low porosity welds.

A possible explanation for the increase in arc voltage required for GMA braze welding of ingot-sheet beryllium is related to the chemical composition of the ingot-sheet material. Compositionally speaking, the prime difference between ingot-sheet and hot-pressed beryllium is the BeO

content. Typically, the hot-pressed beryllium has between 1.5 - 2.0 wt% BeO while the ingot-sheet has less than 0.01 wt% BeO. When electron beam welding ingot-sheet beryllium, a low BeO content is a decided asset for the reduction of porosity. However, for GMA braze welding this lack of oxygen appears to produce somewhat undesirable welding arc characteristics. Although specific information could not be located on the arc column voltage gradients for beryllium vapor and oxygen, the data by Suits⁽²⁾ indicate that elements with higher atomic numbers (such as oxygen relative to beryllium) will produce a higher arc column voltage gradient and therefore a shorter arc length for a given arc voltage.

If an approximation of the results of the porosity study are added to the arc instability limits of Figure 12, conditions that produce unacceptable welds are further defined. Figure 13 shows the result of this addition.

(2) Suits, C. G., *Phys. Rev.*, 55, 561, 1939.

FIGURE 12. Plots Showing Arc Instability as a Function of Filler Wire Feed Rate, Average Arc Voltage, and Arc-Shielding Gas Ratios for GMA Welding Ingot-Sheet Beryllium.

This new addition can be interpreted to mean that welds made with conditions that intersect to the left of the substantially vertical line will contain unacceptable weld porosity.

Fluorescent Penetrant and Coupon Cracking

The results of the fluorescent penetrant incident seem relatively self explanatory. It should be added that additional experiments on this subject have shown that surface condition is the most important factor. That is, the penetrant produces weld porosity only if abnormal surface roughness or microcracking exists. When such a surface exists, then the penetrant is trapped and released during subsequent welding to produce weld porosity.

The cracking condition that led to the penetrant inspection was at first thought to be anomalous. However, review of previous data revealed that coupons of hot-pressed beryllium of the same general configuration also cracked when they were GMA braze welded.

Strength and Unbonding Specimens

The results of the strength data from the tensile specimens show that high ultimate tensile strengths can be generated in unnotched GMA welded ingot-sheet beryllium coupons. (This assumes that no weld-to-base metal unbonding exists.) Although the UTS of the actual weld deposit was not determined, it apparently exceeds the UTS of the beryllium for the particular thickness and rolling direction tested. (Recall that the mean UTS for the tensile bars was 34.9 ksi). The mean UTS of the unwelded beryllium as determined by two tensile bars from the same transverse rolling directions was 33.9 ksi. Statistically speaking, these two values are the same which indicates that the welding had no measurable effect on the uniaxial tensile strength of the ingot-sheet beryllium.

The strength of the unbonded tensile specimen (1f) clearly shows the effect of unbonding upon UTS. Most important, however, is an analysis of the welding conditions used for joining this specimen. As can be seen from the test plan of Figure 2, the coupon from which tensile specimen 1f came

FIGURE 13. Plot Showing Addition of Weld Porosity: Results to the Arc Instability Limits of Figure 12.

was welded at the slow welding rate of 70 ipm. If this welding rate is divided into the wire feed rate, a dimensionless number which we shall call the fill factor is obtained.

Experience has shown that when GMA welding hot-pressed beryllium, fill factors of approximately 10 or over will probably produce unbonding. This same limit appears to be valid for ingot-sheet beryllium since tensile specimen 1f has a fill factor of 10. As seen in Table II, the unbonded condition of tensile specimen 1f was further substantiated by root-bend specimen 1f.

Both of these specimens were from the same welded coupon and clearly demonstrate the tendency for unbonding at this fill factor.

Fill factor limits also exist for the lower end of the spectrum. That is, we have determined that when welding hot-pressed beryllium, fill factors of approximately 5 or lower also result in unbonding. Although the lower end of the fill factor spectrum has not been determined for ingot-sheet beryllium, it would probably fall below the arc instability region of Figure 12 and therefore be of no consequence.

If a fill factor upper limit of 10 is added to Figure 13, the region of acceptable welds is further bracketed. Figure 14 shows this addition. This unbonding limit means that welds made with conditions that intersect above this line will probably contain weld-to-base metal unbonding. (We suspect that this unbonding limit will vary as a function of welding rate. Therefore, the fill factor value of 10 is only applicable for a welding rate of 100 ipm.)

Process Limits Chart

The acceptable weld region can be completely bracketed by considering the effect of high arc voltage. In general, excessive arc voltages result in deposition of the filler metal at the groove edges in lieu of deposition at the groove root. Such deposition can result in unbonding. In general, groove edge deposition decreases as the wire feed rate is increased. Adding this final limit to the graph of Figure 14 completes the process limits chart as shown in Figure 15. The lined area represents a region that will produce acceptable welds in ingot-sheet beryllium if an arc-shielding gas ratio of 8 parts helium to 1 part argon is used. This region would be similar for hot-pressed beryllium. The prime difference would be an extension of the area to the lower helium-to-

FIGURE 14. Plot Showing Addition of Weld-To-Base - Metal Bonding Limit to Figure 13.

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argon shielding-gas ratio and a general shift of the entire area to the left.

It should be remembered that the chart of Figure 15, along with the preceding charts represent approximations that are based upon the single welding rate of 100 ipm and the specific weld groove configuration discussed earlier. Other factors such as the beryllium BeO content, will also alter the results of these graphs. Generally speaking, deviations from the test conditions of this report will change the specific shape of the presented graphs; however, the basic concepts and general outline will be retained.

CONCLUSIONS

1. Acceptable weld porosity levels, such as encountered in GMA braze welds of hot-pressed beryllium, can be produced in Rocky Flats' ingot-sheet beryllium with the proper weld process parameters. Specifically, a relatively high welding arc voltage that produces a low SCF is needed. However, excessive arc voltage can produce weld unbonding for a given weld-groove configuration.
2. Weld-to-base-metal unbonding in GMA braze welds of ingot-sheet beryllium can be avoided if a fill factor of less than 10 is used. This same fill factor is applicable for braze welds of hot-pressed beryllium. (This assumes that the proper weld arc voltage exists in both cases.)
3. Fluorescent penetrant, such as used for surface crack detection, can be a significant cause of weld porosity in ingot-sheet beryllium braze welds. This condition can be particularly severe if the surface contains irregularities capable of trapping the penetrant. The penetrant is released during welding to form porosity.
4. Ultimate tensile strengths greater than the strength of the beryllium can be produced in ingot-sheet beryllium braze welds with the proper GMA process parameters.
5. Weld arc stability can be improved and groove-edge melting reduced, when GMA braze welding ingot-sheet beryllium, if a helium-to-argon shielding-gas ratio of 8 parts helium to 1 part argon is used. Use of the 5 parts helium to 1 part argon ratio, used for hot-pressed beryllium, requires a wider weld-groove configuration.

FIGURE 15. Plot Showing Completed Process Limits Chart for GMA Braze Welding of Ingot-Sheet Beryllium.

APPENDIX A.

GMA Weld Process Parameters.

Welding power supply	d.c., reverse polarity with horizontal V-I characteristics, 3-phase full wave rectified with inductive output filtering.	Coupon No.	No. of Passes	Coupon No.	No. of Passes
		1	2	7	1*(3)
		2	3	8	3
		3	2	9	3
		4	2	10	3
Filler wire alloy	— 718 aluminum alloy (Al-12 wt% Si) of 0.030 inch diameter.	5	1*(4)	11	3
		6	1*(4)		

Filler wire stick-out distance — 5/16 inch.

Arc shielding gas — 80 scfh He + 10 scfh Ar.

Shielding gas cup diameter — 3/4 inch.

Ambient arc pressure — approximately 11.7 psia.

*Because of the unstable weld deposition characteristics encountered when welding these coupons, only the first weld pass was made. The number in parenthesis represents the number of weld passes that would be required had these weld conditions been acceptable and the coupons completed.

APPENDIX B.

Coupon Cleaning Procedures.

Prior to welding, each coupon was subjected to the following cleaning procedure in the listed sequence:

1. Initial cleaning — Trichloroethylene or acetone ultrasonic, bath for 15 minutes.
2. Surface etch — Acid bath for 3 minutes. Acid composition by volume:
 - (a) 2 parts Hf
 - (b) 3 parts Malonic
 - (c) 5 parts HNO₃
 - (d) 90 parts H₂O
3. Water rinse — preferably distilled
4. Acetone rinse — for removing water
5. Ethyl alcohol — cloth soaked with ethyl alcohol is used to wipe weld joint area.