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**ELECTRON-BEAM, MULTIPASS, WIRE-FED
WELDING OF TYPE 5083
ALUMINUM**

J. L. Murphy

July 1976

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ELECTRON-BEAM, MULTIPASS, WIRE-FED WELDING OF TYPE 5083 ALUMINUM

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ABSTRACT

The versatility and advantages of electron-beam, multipass, wire-fed welding were demonstrated on 5.33 and 1.52-mm (210 and 60-mil)-thick Type 5083 aluminum cylinders by making full-penetration welds that had controlled inner distortion and minimum porosity.

A comparison was made between the mechanical properties of gas tungsten-arc welds; electron-beam, autogenous welds, and electron-beam, wire-fed welds. The yield strength of the electron-beam, wire-fed welds compared favorably with the yield strength of the arc welds and autogenous, electron-beam welds. The tensile strength of the electron-beam, wire-fed welds is reduced, because of the depletion of some magnesium from the weld, resulting in a weld-joint efficiency of approximately 74%. A determination was made of the loss of magnesium from the weld that resulted from electron-beam, multipass, autogenous and gas tungsten-arc welding.

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SUMMARY

Electron-beam, multipass, wire-fed welds were made on Type 5083 aluminum cylinders that had a 5.33-mm (210-mil) or 1.52-mm (60-mil) wall thickness. Preweld compensation for weld distortion was determined for the 5.33-mm-thickness aluminum cylinder. Mechanical properties of the multipass welds were obtained and related to the magnesium content in the welds. A comparison was made of the mechanical properties of gas tungsten-arc welds, electron-beam single-pass autogenous welds, and electron-beam wire-fed welds.

INTRODUCTION

Multipass, wire-fed, electron-beam welding makes it possible to achieve full-penetration welds in a variety of thicknesses and still maintain some control over material chemistry, distortion, backside temperature, and weld structure. Root defects, cold shuts, porosity, and variation in penetration are problems that can result from an autogenous, single-pass, electron-beam weld in aluminum and other metals.⁽¹⁻⁸⁾ It was previously described how incomplete fusion and spiking can be avoided by using a multipass welding method.^(5,9-11) Development of a dial-switch-programmed wire feeder and positioner for electron-beam welding has been reported.⁽⁹⁾ A computerized electron-beam and wire-feeding system has also been reported.^(11,12) In the present work, electron-beam, multipass, wire-fed welding has been evaluated on 5.33 and 1.52-mm (210 and 60-mil)-thick Type 5083 aluminum.

ELECTRON-BEAM, MULTIPASS, WIRE-FED WELDING

EXPERIMENTAL WORK

Techniques For Welding 5.33-mm (210-mil)-Thick Cylinders

Figure 1. JOINT GEOMETRY FOR ELECTRON-BEAM, WIRE-FED WELDING OF TYPE 5083 ALUMINUM. (Joint Compensated for Root Distortion)

The weld-joint details that were established for welding 5.33-mm-thick aluminum are outlined in Figure 1. Table 1 gives the welding parameters. The resulting welds are illustrated in Figure 2. View a, of Figure 2, shows root distortion of the weld while View b shows an improved root configuration brought about by using a 0.508 by 3.18-mm (20 by 125-mil) chamfer at the root of the joint illustrated in Figure 1. Table 1 shows that an autogenous weld was made on the 1.02-mm (40-mil) root width. Five wire-fed weld passes were used to complete the weld. Welding parameters were held constant for the five weld passes except for one change in the part travel speed and one change in wire feed rate.

Figure 3 shows a dimensional

distortion of a welded cylinder that had the joint preparation that is indicated in Figure 1. The cylinder was welded such that it would not be restrained from distorting. The dimensions would change with inside restraint.

Table 1

WELDING PARAMETERS FOR ELECTRON-BEAM, WIRE-FED
WELDING OF TYPE 5083 ALUMINUM
[Filler Metal was 0.76-mm (30-mil)-Diameter
Type 5356 Aluminum]

Weld Pass ⁽¹⁾	Beam Voltage (kV)	Beam Current (mA)	Weld Speed		Beam Focus ⁽²⁾ (mA)	Wire Speed	
			(ipm)	(mm/s)		(ipm)	(mm/s)
1	75	5	20	8.45	430	0	0
2	75	8	20	8.45	455	20	8.48
3	75	8	14	5.93	455	30	12.69
4	75	8	14	5.92	455	30	12.69
5	75	8	14	5.92	455	30	12.69
6	75	8	14	5.92	455	30	12.69

(1) An R-40 gun was used with the filament in the flush position.

(2) Sharp focus at the root of the joint at 1.0 mA was 390 mA.

(a) Root Distortion of Weld.

MS-72-0584-11

(b) Improved Root Configuration.

MS-72-0584-14

Figure 2. MULTIPASS, WIRE-FED, ELECTRON-BEAM WELDS IN 5083 ALUMINUM ALLOY. (View b Shows Root Shape Improved by Using Joint Geometry Detailed in Figure 1; 10X)

Figure 3. DIMENSIONAL-DISTORTION MEASUREMENTS OF A 152.4-mm (6-in)-DIAMETER TYPE 5083 ALUMINUM CYLINDER THAT WAS MULTIPASS WELDED. (A Minus Sign Represents Inward Diametrical Distortion)

Figure 4. The loss of magnesium in respective weld passes is shown. The autogenous weld in the root of the joint had an average of 2.5% magnesium, while the wire-fed welds had approximately 1.5% magnesium.

Mechanical Properties of Wire-Fed Welds

Table 2 lists the mechanical properties of electron-beam, multipass, wire-fed welds in Type 5083-0 aluminum. Compensated welds (see Figure 2, View b) had an ultimate tensile strength of 255.1 MPa (37 ksi) and a yield strength of approximately 134.5 MPa (19.5 ksi). The uncompensated welds (see Figure 2, View a) had an ultimate tensile strength of approximately 248.2 MPa (36 ksi) and a yield strength of approximately 141.4 MPa (20.5 ksi). Minimum tensile and yield strengths of arc welds have been reported as 275.8 and 165.5 MPa (40 and 24 ksi),⁽¹³⁾ respectively. The greater loss of magnesium in the electron-beam, multipass, wire-fed weld results in a reduction in strength.

Magnesium Content of Wire-Fed Welds

Electron microprobe values were taken from scans through the center of the electron-beam, multipass weld, as noted in

Table 2

TYPICAL AS-WELDED TENSILE PROPERTIES OF A MULTIPASS, ELECTRON-BEAM WELD IN TYPE 5083 ALUMINUM WITH TYPE 5356 ALUMINUM FILLER

Specimen ⁽¹⁾	Tensile Strength		Yield Strength ⁽²⁾		Elongation ⁽³⁾
	(ksi)	(MPa)	(ksi)	(MPa)	
1	37.0	255.1	19.4	133.8	11.0
2	37.0	255.1	19.9	137.2	12.0
3	37.1	255.8	19.1	131.7	13.0
4	36.9	254.4	21.1	145.5	11.0
5	35.1	242.0	19.9	137.2	10.0
6	35.9	247.5	20.4	140.7	10.0

(1) Type T4 specimens were transverse to the weld. Weld-root reinforcement was not removed from Specimens 1-3 (see View a, Figure 2); weld-root reinforcement was removed from Specimens 4-6 by premachined compensation (see View b, Figure 2).

(2) At 0.2% offset.

(3) In a 25.4-mm (1-in) gage length.

Techniques for Welding 1.5-mm (60-mil)-Thick Cylinders

Electron-beam, multipass, wire-fed welding of 1.52-mm (60-mil)-thick aluminum was evaluated to determine if an improved root contour and reduced porosity could be achieved when compared to one-pass, autogenous, electron-beam or gas tungsten-arc welds. (The multipass welding method also offers precise control of the energy input to the root weld pass.) A root width that could successfully be welded was selected and the remainder of the joint was filled with welding wire. Figure 5, Joint Geometry A, shows the weld-joint details that were developed. The welding procedure is given in Table 3; a typical wire-fed weld is shown in Figure 6. The first autogenous weld was followed by two wire-fed welds using 380- μ m (15-mil)-diameter wire. Techniques and equipment were developed to feed the small-diameter wire.^(9,10) It may be noticed in Table 3 that the electron beam was oscillated longitudinal to the welding direction during the autogenous weld and transverse to the weld during the wire-fed welds. Electron-beam oscillation for the root weld helped to prevent burn through and resulted in a smoother inside weld surface. Transverse oscillation was useful on the thin aluminum to sweep the electron beam wide enough to fuse the side walls of the groove of the weld joint.

Figure 5. JOINT GEOMETRIES FOR ELECTRON-BEAM WELDING OF TYPE 5083 ALUMINUM.

Electron Microprobe Scan through the Center of the Weld

Pass 1 Welded at 28,600 J/mm (1125 J/in) of weld.
Passes 2 - 6 Welded at 65,200 J/mm (2570 J/in) of weld.

Weld Pass	Magnesium Content (%)	Comments
1	2.5 $\pm$ 0.05	Average of 10 electron microprobe values for each weld pass.
2, 3, 4, 5	1.5 $\pm$ 0.05	
6	1 $\pm$ 0.25	
Base Metal Average	4.6	

Figure 4. AVERAGE VALUES FOR THE MAGNESIUM CONTENT OF AN ELECTRON-BEAM, MULTIPASS, WIRE-FED WELD IN TYPE 5083 ALUMINUM WITH TYPE 5356 ALUMINUM WIRE.

Comparison of Mechanical Properties to the Welding Method

Mechanical properties of one-pass, autogenous, electron-beam and gas tungsten-arc welds were obtained for comparison to electron-beam, wire-fed welds. Figure 7 shows a cross section of a gas tungsten-arc weld that was made on a joint that had a square-butt geometry. Copper chill rings were used at the weld joint, and they were spaced a total of 3.18 mm (125 mils) on the cylinders. A cross section of an autogenous, electron-beam weld that was made on a joint that had a square-butt

Table 3

WELDING PARAMETERS FOR ELECTRON-BEAM WELDING OF TYPE 5083 ALUMINUM
[1.52-mm (60-mil) Wall Thickness]

Welding Method ⁽¹⁾	Weld Pass	Beam Voltage (kV)	Beam Current (mA)	Weld Speed		Beam Focus ⁽²⁾ (mA)	Wire Speed ⁽³⁾		Beam Oscillation ⁽⁴⁾	Joint Geometry (see Figure 5)
				(ipm)	(mm/s)		(ipm)	(mm/s)		
Multipass, Wire-Fed	1	75	3.0	35	14.8	370	0	0	Harmonic Y 2.54 mm (100 mils)	A
	2	75	2.5	10	4.2	370	25	12.7	Harmonic X 1.0 mm (40 mils)	
	3	75	2.5	10	4.2	370	25	12.7	Harmonic X 1.0 mm (40 mils)	
One-Pass, Autogenous	1	75	5.0	35	14.8	370	0	0	Harmonic Y 2.54 mm (100 mils)	B

(1) An R-40 gun was used with the filament in the flush position.

(2) Sharp focus at the root of the joint at 1.0 mA was 370 mA.

(3) Type 5356 aluminum wire, 0.38 mm (15 mils) in diameter, was used.

(4) Electron-beam oscillation is 60 cps. Dimensions are the length or width of the oscillated beam.

L399-4

Figure 6. THREE-PASS, ELECTRON-BEAM WELD IN 1.52-mm (60-mil)-THICK TYPE 5083 ALUMINUM. (Root Pass was Autogenous Followed by Two Wire-Fed Passes Using Type 5356 Aluminum Wire; Weld-Joint Details are Shown in Figure 5, Geometry A; 10X)

L308-1A

Figure 7. ONE-PASS, AUTOGENOUS, GAS TUNGSTEN-ARC WELD IN 1.52-mm (60-mil)-THICK TYPE 5083 ALUMINUM. [Weld was Made with Direct Current, Straight Polarity, Using Helium Shielding at 130 A and a 12.7-mm/s (30-ipm) Part Travel Speed; 10X]

geometry is seen in Figure 8. Table 4 gives the mechanical properties that resulted from the welding methods and also the base-metal properties. The yield strength of the welds is not significantly different nor reduced from the base-metal value. The tensile strength of the autogenous, gas tungsten-arc and electron-beam welds compares favorably with the value for the base metal. Weld-joint efficiency of the arc weld is 93%; that of the autogenous electron-beam weld is 97%. The electron-beam, multipass, wire-fed weld-joint efficiency drops to approximately 74%. All the specimens were tested in the as-welded condition, with no dressing of the top and bottom surfaces.

Comparison of Magnesium Losses to the Welding Method

The effects of electron-beam and gas tungsten-arc, multipass, autogenous welds in deleting magnesium in Type 5083 aluminum was determined for comparison to electron-beam, wire-fed welds. Full-penetration welds were made on 2.03-mm (80-mil)-thick plates. Two to four weld passes were then staggered on top of each other. The electron beam welds were made in an approximate vacuum of 13 mPa (10^{-4} mm) Hg, while the arc welds were made at

L410-3

Figure 8. ONE-PASS, AUTOGENOUS, ELECTRON-BEAM WELD ON 1.52-mm (60-mil)-THICK TYPE 5083 ALUMINUM. (The Beam was Oscillated Longitudinal to the Direction of the Welding; 10X)

Table 4

COMPARISON OF WELDING METHODS TO RESULTING MECHANICAL
PROPERTIES FOR 1.52-mm (60-mil)
TYPE 5083 ALUMINUM

Welding Method	Tensile Strength ⁽¹⁾		Yield Strength	
	(ksi)	(MPa)	(ksi)	(MPa)
Base Metal	46.3	319.5	21.2	146.3
GTA (one-pass, autogenous) ⁽²⁾	43.0 ⁽³⁾	296.7	22.0	151.8
Electron Beam (one-pass autogenous)	45.0 ⁽³⁾	310.5	21.4	147.7
Electron Beam (one-pass, autogenous; two wire-fed passes)	34.0 ⁽⁴⁾	235.6	20.0	138.0

(1) Specimen dimensions were 12.7 mm (1/2 in) in width and 50.8 mm (2 in) in length, except base-metal specimens which were machined T4 specimens.

(2) GTA weld was direct current, straight polarity using helium shielding.

(3) Failure was in the weld or at the bond line.

(4) Failed in the weld.

atmospheric pressure. Figure 9 reports the magnesium losses in the welds. A one-pass, electron-beam weld had approximately a 1% loss in magnesium. At the tie-in or overlap area in a weld, the loss in magnesium resulting from two weld passes could be approximately 2.5%. The weld on the 1.02-mm (40-mil) root land that was used for the wire-fed weld in the 5.33-mm-thick aluminum, that was previously discussed, had an average of 2.5% magnesium, which is a deletion of magnesium greater than 2%. By comparison, a small percentage of magnesium is deleted by autogenous arc welding. Figure 10 provides a comparison of the mechanical properties to the magnesium content of arc welds in Type 5083 aluminum. The curves peak at approximately 5% magnesium. The curves show a reduction in mechanical properties with a corresponding reduction in the magnesium content.

Figure 9. EFFECT ON THE ALLOY CONTENT OF AUTOGENOUS, MULTIPASS WELDS IN TYPE 5083 ALUMINUM ALLOY PLATE OF 2.03-mm (80-mil) THICKNESS.

Figure 10. TENSILE PROPERTIES OF GAS TUNGSTEN-ARC WELDS IN TYPE 5083-H113 ALUMINUM ALLOY USING FILLERS WITH VARIOUS MAGNESIUM CONTENTS. (From *Welding Kaiser Aluminum*, First Edition, Page 9-4; Kaiser Aluminum, Oakland, California)

Porosity in Multipass, Wire-Fed Welds

The electron-beam, multipass, wire-fed welds generally had less porosity compared to single-pass, autogenous, electron-beam and arc welds. A typical wire-fed weld in 5.33-mm-thick aluminum, using Type 5356 aluminum wire, might have several 508- μm (20-mil)-diameter pores and several pores in the 254 to 381- μm (10 to 15-mil)-diameter range, as determined by radiographic inspection. The base metal and wire were cleaned by, first, degreasing; followed by a scrubbing with steel wool; followed by a wipe with a cloth moistened with alcohol. Good results were also obtained using chemically cleaned welding wire. Experience with electron-beam, multipass, wire-fed welding the 1.52-mm-thick aluminum has shown that porosity is extremely small [generally $< 127 \mu\text{m}$ (5 mils) in diameter] and therefore not readily detectable by radiographic inspection. Occasionally, porosity up to 254 μm (10 mils) in diameter will occur. By comparison, gas tungsten-arc welds in the 1.52-mm-thick aluminum had up to seven pores that were up to 635 μm (25 mils) in diameter in 25 mm of weld. Many single-pass, autogenous, electron-beam welds contain no detectable porosity, while other welds will contain numerous pores in the 254- μm (10-mil)-diameter range, with occasional larger pores up to 635 μm (25 mils) in diameter. Several reasons for reduced porosity in multipass welds are apparent: (1) the depth of weld that is deposited in each weld pass can be controlled, thereby controlling the maximum pore size; (2) a part of each preceding weld pass is remelted and refined in the vacuum of the electron-beam machine; (3) it is postulated that hydrogen is liberated from the welding wire when it is melted and allowed to escape; (4) the weld is deposited into an open groove, and this may also be beneficial to permit hydrogen to escape from the molten weld.

DISCUSSION OF RESULTS

Electron-beam, multipass, wire-fed welding is presented as a useful process to weld thick or thin aluminum. The advantages resulting from using this process are: (1) reduced distortion inside the root face and base metal, and high-quality welds; (2) the process is useful in controlling porosity to a minimum number and size; (3) electron-beam welding offers precise control of the energy input to the root weld and subsequent fill passes. The principal disadvantage of the process is the reduction in weld-joint efficiency that results from the deletion of magnesium from the welding wire and base metal. The yield strength is not significantly affected by the deletion of magnesium, as was noted in Tables 2 and 4; however, the tensile strength is reduced to a value ranging from 234.6 MPa (34 ksi) (see Table 4) to 255.3 MPa (37 ksi) (see Table 2). It may be possible to develop welding wires that have particular chemistries to increase the as-deposited strength of electron-beam, wire-fed welds in Type 5083 aluminum alloy. Faster welding speeds during the wire-fed fill passes, combined with faster wire feed rates, may also improve the welds. The wire-fed welds have mechanical properties comparable to the arc welds that have a magnesium content close to 4% (see Figure 10). Therefore, some deletion of magnesium does not seriously degrade the tensile strength of electron-beam autogenous or wire-fed welds. Table 4 shows that the electron-beam autogenous weld had a higher tensile strength than the arc weld, while Figure 9 shows that the electron-beam weld had a magnesium content of approximately 3.6%. A judgment of the importance and amount of the deletion of magnesium from electron-beam welds should be based on the particular welding procedure and application for the weld. The data presented in this work show that weld-joint

efficiency can be reduced in Type 5083 aluminum with improper electron-beam welding techniques.

Cold shuts are not generally a problem in electron-beam, multipass welds because the deep-penetration welds that are typically done in one weld pass are replaced by numerous weld passes. However, the prevention of cold laps requires attention in electron-beam, multipass welds as it does in any multipass welding method. Cold laps are not a problem if the welding procedure is directed toward adequate interpass fusion. The depth-to-width ratio of multipass welds compare favorably to a one-pass weld. The weld that is shown in Figure 2 has a depth-to-width ratio approaching 3 to 1.

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