December 6, 1961
DMIC Memorandum 140

REVIEW OF RECENT DEVELOPMENTS IN METALS JOINING

DEFENSE METALS INFORMATION CENTER
BATTELLE MEMORIAL INSTITUTE
COLUMBUS 1, OHIO

REVIEW OF RECENT DEVELOPMENTS IN METALS JOINING

J. J. Vagi, W. J. Lewis, and H. W. Mishler*

This memorandum summarizes major recent developments in the technology of metals joining within the scope of the Defense Metals Information Center. Information received during the period from July 30 to October 30 is covered.

Titanium-Base Alloys

Arc Welding

Fracture toughness studies are being made on titanium alloys which appear promising for solid-fuel rocket-motor cases.(1)** The Ti-13V-11Cr-3Al alloy was selected because strength-density ratios of over 1,000,000 can be obtained. The studies were conducted on (1) sheet cold rolled 20 per cent and then aged (yield strength 188,000 psi), (2) annealed sheets welded to simulate a girth weld (yield strength 125,000 psi), and (3) samples cut from a missile case which had successfully passed hydrotest (yield strength, 189,000 psi). The studies also included tungsten-arc weld metals, which had been chilled with helium during welding t reduce grain size. The conclusions drawn from this program were:

(1) Strengthening obtained by cold work is more beneficial to fracture toughness than the same strengthening obtained by aging.

(2) Fracture toughness of the weld joints exceeds minimum requirements.

(3) Chilling of the weld puddle during welding reduces grain size, but does not improve fracture toughness.

Several programs also are being conducted to investigate the suitability of titanium alloys for deep-diving submarine hulls. Willner and Sullivan(2) of the David Taylor Model Basin obtained explosion-bulge data on five high-strength titanium alloys: (1) Ti-5Al-2.5Sn, (2) Ti-6Al-4V, (3) Ti-13V-11Cr-3Al, (4) Ti-6Al-4Zr-1V, and (5) Ti-8Al-2Cb-1Ta. The Ti-8Al-2Cb-1Ta exhibited the least sensitivity to rate of loading and the greatest resistance to fracture as determined by Charpy vee-notch and explosion-bulge tests.

Also, information was received from Battelle Institute(3) and Republic Steel Corp.(4) on the metal-inert-gas welding of thick titanium-alloy plates for submarine hulls. The Battelle welding studies are being

*Metals Joining Division, Battelle Memorial Institute.
**References are listed at the end of this memorandum.

made with 2-inch-thick plate of the following alloy compositions: (1) A-70, (2) Ti-5Al-2.5Sn, (3) Ti-6Al-4V, and (4) Ti-13V-11Cr-3Al. Welding is being done automatically in an inert-gas welding chamber. Cracking has not been found in welding any of the alloys. The properties of the welds were found to be as good or better than those of the base plate. At Republic Steel, 2-inch-thick A-70 was welded in the open air. Satisfactory welds were obtained, but the tensile and impact properties of both the welds and the A-70 base plate were low and not satisfactory for hull weldments.

TMCA obtained weld cracking in automatic welding of 2-inch Ti-13V-11Cr-3Al in the open atmosphere.(5) Cracks were primarily transverse to direction of welding with a few fissures extending in the longitudinal direction. The cause of cracking was not reported, but crack-free welds were obtained by preheating at 450 F to 500 F.

Ultrasonic Welding

The feasibility of ultrasonically welding the all-beta Ti-13V-11Cr-3Al alloy is being studied by Aeroprojects, Inc.(6) Satisfactory welds could be made in sheet 4 to 11 mils thick. However, in sheet thicker than 4 mils, an interleaf of unalloyed titanium foil 0.0005 inch thick had to be used.

Electron-Beam Welding

The Alloyd Corporation(7) recently completed studies on the electron-beam welding of five titanium alloys: 6Al-4V, 4Al-3Mo-1V, 2.5Al-16V, 5Al-2.5Sn, and 13.5V-11Cr-3Al in thicknesses ranging from 0.084 to 0.125 inch. Welding was done at low voltages (14,000 volts). Various tests were made on these weld joints, including determination of welding parameters, flat-bar tensile tests, and subsize Charpy impact tests. The tensile specimens were photoetched with a grid so that incremental strains could be determined. The conclusions were:

(1) "Titanium alloys in thicknesses up to 1/8 inch can be electron-beam welded by a low-voltage gun in a single pass without excessive joint preparation.

(2) Weld widths varying from 0.050 to more than 0.300 inch are attainable with proper tooling and power density.

(3) Fusion zone strengths may match or exceed base-plate values.

(4) Fusion zone strengths have been shown to be totally unrelated, over wide limits, to interstitial content.

(5) Fusion zone strengths were shown to be essentially independent of joint width within the wide range studied and to depend primarily on resolidified grain size.

(6) Fusion zone impact resistance values were found to be either similar to or higher than those of the base plates.

(7) Fusion zone impact resistance was found to increase as weld width increased.

(8) Fusion zone impact resistance was found to bear a general inverse relationship to hydrogen content.

(9) Weldment mechanical properties did not vary with chamber pressure or condition of surface prior to welding.

(10) Incremental strains were found to be independent of weld width.

(11) Incremental strains in welds were substantially lower than base plate values; however, fusion zone ductility occasionally approached that of the base plate fracture locations."

Columbium-Base Alloys

The Tapco Group of Thompson-Ramo-Wooldridge(8) has continued studies of the welding characteristics of columbium alloys FS82, D31, and F48.

Tungsten-arc welds were made in a vacuum-purged argon or helium-filled welding chamber to study the effects of 5, 15, and 36-ipm welding speeds, interstitial chemistry variations, and postweld heat treatments. Welds were evaluated by radiographic inspection, bend ductility, tensile strength, microstructure, and hardness.

The bend-ductility data for the FS82 tungsten-arc welds indicated that little benefit was achieved when welding speed was increased from 5 ipm to 15 or 36 ipm although the welds made at 15 or 36 ipm in helium possibly have lower transition temperatures than when the inert gas was argon. The effect of oxygen higher than normal in FS82 gave higher yield strength and lower elongation in tensile tests of welded specimens.

Tungsten-arc welds made on 0.060-inch-thick sheet of the D31 alloy gave results opposite to those reported previously for welds made on 0.040-inch-thick sheet. Increased welding speeds (to 36 ipm) on the 0.060-inch-thick sheet impaired the bend ductilities of welds. As-welded cracks, transverse to the weld and crossing into the heat-affected zone, frequently occurred. Welds made in helium at 5 ipm appeared to be more ductile than welds made in argon. At the higher welding speeds, there was no noticeable difference between the ductilities of welds made in either argon or helium. Postweld heat treatments of 2100 F and 2350 F in D31 alloy fusion welds lowered the transition temperatures of welds made at 15 ipm.

Limited fusion welds on the F48 alloy showed that welds made at 15 ipm with a 150-200 F preheat were crack-free. A postweld heat treatment of 2350 F for 24 or 74 hours lowered the transition temperature over that of as-welded material.

Resistance spot welding results on the FS82 and D31 alloys are summarized below:

		Electrodes		Welding Conditions		Tension-Shear
Alloy	Sheet Thickness, in.	Alloy	Dome Radius, in.	Force, lb	Time, Cycles	Strength, lb
FS82	.020-.020	Gr.A, Cl.1	4	730-850	3	480-530
	.060-.060	Ditto	12	1580	15	2100-2750
D31	.020-.020	"	4	910	6	630-740
	.060-.060	"	12	1420	12	1130-1390

Electrode sticking and expulsion were experienced with some of these welding conditions.

Tungsten

Electron-Beam Welding

General Electric Company has completed an investigation of the electron-beam welding of tungsten sheet.[9] Tungsten sheet, 0.020 to 0.060 inch thick, was welded with low-voltage electron-beam equipment to study the effects of voltage, current, travel speed, and beam focus on the weld-joint geometry. The depth of penetration was related to the total beam power. Increasing either the voltage or current increased the penetration. The best joint geometries (high depth-to-width ratios) were obtained at high voltages and high travel speeds.

Metallographic examination of butt welds in 0.040- and 0.060-inch-thick tungsten sheet showed that grain size of the fusion zone was quite large. Some of the joints contained fusion-line porosity caused by gaseous impurities that were trapped in the tungsten during solidification.

Elevated-temperature tensile and bend tests made on butt welds showed that, above 3000 F, the welds were as strong as roll-formed tungsten which had recrystallized during testing (10,000-psi ultimate). Between

1500 F and 3000 F, the welds were significantly weaker (20,000-psi ultimate for weld joints and 30,000-psi ultimate for the sheet) because of the coarse-grained, cast weld structure and recrystallized heat-affected zones. At room temperature, the tungsten welds were very brittle with low fracture strength.

The feasibility of butt welding the girth seam between two conical tungsten nozzle components and corner welding circular flanges to the ends of the nozzles was established. It was felt, however, that successful utilization of welded tungsten nozzle components is questionable because of room-temperature brittleness and low-fracture strength of tungsten fusion welds. Improvements in tungsten quality through higher purity or alloying are considered necessary to improve weld properties for applications where low ductility of present welds cannot be tolerated.

The Alloyd Corporation[7] also has electron-beam welded 1/8-inch-thick rolled and stress-relieved tungsten sheet. Wide welds were obtained with low voltages (18,000 volts) and narrow welds were obtained with high voltages (125,000 to 150,000 volts). Results show that tungsten sheet up to 1/16-inch thick can be welded in a single pass. Narrow fusion zones (0.020 inch wide) result in low tensile strength; wide fusion zones also have lower tensile strength than unwelded material but higher strength than narrow fusion zones. The welds had no appreciable impact resistance and no appreciable incremental strains in tension tests.

Molybdenum-0.5 Titanium Alloy

Electron-Beam Welding

Arc-cast Mo-0.5Ti alloy sheet 1/8 inch thick also was electron-beam welded at the Alloyd Corporation.[7] Weld joints with both wide and narrow fusion zones were made at low voltage (18,000 volts) and at high voltage (125,000-150,000 volts), respectively.

In thicknesses up to 1/8 inch, the Mo-0.5Ti alloy can be welded in a single pass at low voltages. Very thin fusion zones (0.020 inch wide) result in considerably lowered tensile strength, whereas wide fusion zones (0.320 inch wide) are almost of the same tensile strength as unwelded material. The wide fusion zones have substantially more impact resistance than is obtained with thin fusion zones or in the unwelded structure.

Rocket-Motor Cases

Electron-Beam Welding

An evaluation of electron-beam welds in rocket-motor-case steels is being conducted on H-11, Airsteel X-200, and MBMC-1.[10] Flat-bar tensile tests of heat-treated welded specimens were made. Specimens tempered at 1000 F had an ultimate strength of about 265,000 psi and a yield strength of 190,000 psi. Lowering the tempering temperature to 400 F increased the ultimate strength to 320,000 psi and the yield strength to 230,000 psi. Elongation of the latter specimens was 6 per cent in 2 inches. Half of these tensile specimens failed well away from the weld joint.

Heat distribution during welding was studied by the use of temperature-sensitive lacquers. Minimum heat-affected-zone hardness corresponded to a temperature of 1350-1400 F. The magnitude of the minimum hardness was affected by the preweld tempering temperature. The degree of softening in the heat-affected zone was the least at the lower tempering temperatures.

Also, the Alloyd Corporation[7] has reported on electron-beam welding of H-11 hot-work die steel and cold-worked Type 301 stainless steel. It was concluded that different types of steel in thicknesses up to 1/8 inch can be electron-beam welded with a low-voltage gun to produce weld widths of 0.100 to 0.185 inch in a single pass without excessive joint preparation and without preheat or cracking. H-11 die steel can be welded in the fully hardened condition to yield weldments having a minimum of 250,000-280,000-psi ultimate tensile strength. No appreciable strength or strain difference between air-melted and vacuum-melted H-11 stock was observed. Fusion-zone impact values for air- and vacuum-melted material were at least equal to those of the unwelded metal. Fully cold-worked austenitic stainless steel loses one third of its strength when welded with fusion-zone widths of 0.100 to 0.185 inch. Incremental strains match and impact values substantially exceed those of unwelded stock.

Armor Steels

A final report[11] was issued by Rennselaer Polytechnic Institute on a test to obtain the sensitivity of armor steels to cold cracking and on an investigation of cold cracking. This work was supported by the Ordnance Corps, because of the large variation in cracking obtained by armor-plate fabricators in welding plate from different heats of steel with essentially identical composition, properties, and hardenability. Significant work done on cold cracking of weldments is reviewed in the report, and a test is described for evaluating heat-affected-zone cracking in armor steels. The test is reported to be highly sensitive to differences in cracking tendency, and its reproducibility is excellent. Data are presented to show that the primary cause of variations in cold-cracking sensitivity among steels with identical composition and properties is a difference in the tendency of carbides to dissolve during the welding cycle.

Weight Saving by Flash Welding

The flash welding of a variety of high-strength, high-temperature materials at the Dresser Manufacturing Division for aerospace applications is described in a recent American Society of Tool and Manufacturing Engineers Seminar paper.[12] Examples of materials that can be flash welded and properties that can be obtained are reported as follows:

Material	Cross Section, inches	Joint Efficiency[a], per cent	Elongation, per cent of P.M.	Heat-Treat Condition
Multimet N-155	1-1/2x2-1/4	9.95	106.0	Solution anneal
8740	5/8x1-3/8	101.1	91.0	Normalize
8630	1-9/16x2-3/16	98.7	90.9	Normalize
A-286	1-7/8x4-11/16	99.8	90.7	Solution anneal
403	1-3/8x1-3/4	100	96.2	Hardened and tempered minimum hardness
321	3/4x2-1/8	102.7	96.1	Solution anneal
314	1-9/32x3	100.6	98.2	Ditto
309	1-1/16x4-5/16	100.3	100.0	"
304	7/8x1-1/8	101.2	101.2	"

(a) Joint efficiency = $\frac{\text{UTS of weld}}{\text{UTS of base metal}} \times 100$.

The majority of parts flash welded from these materials are lower in weight than those produced by other methods. For example, a weight reduction of over 650 pounds was realized by fabricating a ring from an extruded Type 321 bar-cruciform shape, using flash welding and cold expanding to obtain flatness; a jet engine part of Greek Ascaloy (AMS 5616) was reduced in weight from 356 pounds to 227 pounds by flash welding a channel-shaped-section ring; a weight reduction of 43 pounds was realized by flash welding a Hastelloy "X" angle section ring.

REFERENCES

(1) Romine, H. E., "Fracture Toughness Tests on Welded Titanium Alloys Being Considered for Chambers of Solid Propellant Rockets", NWL Report No. 1749 (April 21, 1961).

(2) Willner, A. R., and Sullivan, V. E., David Taylor Model Basin, preliminary information obtained under a Navy contract.

(3) Koppenhofer, R. L., et al., Battelle Memorial Institute, preliminary information obtained under a Navy contract.

(4) Savas, J., "Development of Fusion Welding Techniques for 2-Inch-Thick A-70 Titanium Plates", Republic Steel Corp., Final Report, Contract NOas 60-6091-F (May, 1961).

(5) Mitchell, D. R., Titanium Metals Corporation, preliminary information obtained under a Navy contract.

(6) Jones, J. Byron, McKarg, H. L., Thomas, John G., "Investigation of Ultrasonic Welding of All-Beta Titanium Alloy", Aeroprojects, Inc., Final Report, Contract NOw 60-0643 (FBM) (September, 1961).

(7) Lander, H. J., Hess, W. T., Bakish, R., and White, S. S., "A Study of Electron-Beam Welding", The Alloyd Corporation, Cambridge, Massachusetts, Final Summary Report No. WAL 401. 54/2-1, USA, Contract DA 19-020-ORD-5246 (July 21, 1961).

(8) Faulkner, J. M., and Gerken, J. M., Tapco Group of Thompson-Ramo-Wooldridge, preliminary information obtained under an Air Force contract.

(9) Kearns, W. H., General Electric Company, preliminary information obtained under an Air Force contract.

(10) Adams, C. M., Jr., Massachusetts Institute of Technology, preliminary information obtained under a Navy contract.

(11) Nippes, Ernest F., Savage, Warren F., and Levine, Earl D., Rensselaer Polytechnic Institute, Final Technical Report on Weld-Crack Sensitivity of Armor Steels, Contract DA 20-089-ORD-38859 (February, 1961).

(12) "Flash Welding of Space Age Metals", R. D. Johnson, Technical Paper SP62-10, American Society of Tool Engineers, Detroit (1961).

LIST OF DMIC MEMORANDA ISSUED

DEFENSE METALS INFORMATION CENTER
Battelle Memorial Institute
Columbus 1, Ohio

Copies of the technical memoranda listed below may be obtained from DMIC at no cost by Government agencies and by Government contractors, subcontractors, and their suppliers. Others may obtain copies from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

A list of DMIC Memoranda 1-90 may be obtained from DMIC, or see previously issued memoranda.

DMIC Memorandum Number	Title
91	The Emittance of Titanium and Titanium Alloys, March 17, 1961, (PB 161241 $0.50)
92	Stress-Rupture Strengths of Selected Alloys, March 23, 1961, (AD 255075 $0.50)
93	A Review of Recent Developments in Titanium and Titanium Alloy Technology, March 27, 1961, (PB 161243 $0.50)
94	Review of Recent Developments in the Evaluation of Special Metal Properties, March 28, 1961, (PB 161244 $0.50)
95	Strengthening Mechanisms in Nickel-Base High-Temperature Alloys, April 4, 1961, (PB 161245 $0.50)
96	Review of Recent Developments in the Technology of Molybdenum and Molybdenum-Base Alloys, April 7, 1961, (PB 161246 $0.50)
97	Review of Recent Developments in the Technology of Columbium and Tantalum, April 10, 1961, (PB 161247 $0.50)
98	Electropolishing and Chemical Polishing of High-Strength, High-Temperature Metals and Alloys, April 12, 1961, (PB 161248 $0.50)
99	Review of Recent Developments in the Technology of High-Strength Stainless Steels, April 14, 1961, (PB 161249 $0.50)
100	Review of Current Developments in the Metallurgy of High-Strength Steels, April 20, 1961, (PB 161250 $0.50)
101	Statistical Analysis of Tensile Properties of Heat-Treated Mo-0.5Ti Sheet, April 24, 1961, (AD 255456 $0.50)
102	Review of Recent Developments on Oxidation-Resistant Coatings for Refractory Metals, April 26, 1961, (AD 255278 $0.50)
103	The Emittance of Coated Materials Suitable for Elevated-Temperature Use, May 4, 1961, (AD 256479 $2.75)
104	Review of Recent Developments in the Technology of Nickel-Base and Cobalt-Base Alloys, May 5, 1961, (AD 255659 $0.50)
105	Review of Recent Developments in the Metallurgy of Beryllium, May 10, 1961, (AD 256206 $0.50)
106	Survey of Materials for High-Temperature Bearing and Sliding Applications, May 12, 1961, (AD 257408 $2.00)
107	A Comparison of the Brittle Behavior of Metallic and Nonmetallic Materials, May 16, 1961, (AD 258042 $0.50)
108	Review of Recent Developments in the Technology of Tungsten, May 18, 1961, (AD 256633 $0.50)
109	Review of Recent Developments in Metals Joining, May 25, 1961, (AD 256852 $0.50)
110	Glass Fiber for Solid-Propellant Rocket-Motor Cases, June 6, 1961
111	The Emittance of Stainless Steels, June 12, 1961
112	Review of Recent Developments in the Evaluation of Special Metal Properties, June 27, 1961
113	A Review of Recent Developments in Titanium and Titanium Alloy Technology, July 3, 1961

LIST OF DMIC MEMORANDA ISSUED
(Continued)

DMIC Memorandum Number	Title
114	Review of Recent Developments in the Technology of Molybdenum and Molybdenum-Base Alloys, July 5, 1961
115	Review of Recent Developments in the Technology of Columbium and Tantalum, July 7, 1961
116	General Recommendations on Design Features for Titanium and Zirconium Production-Melting Furnaces, July 19, 1961
117	Review of Recent Developments in the Technology of High-Strength Stainless Steels, July 14, 1961
118	Review of Recent Developments in the Metallurgy of High-Strength Steels, July 21, 1961
119	The Emittance of Iron, Nickel, Cobalt and Their Alloys, July 25, 1961
120	Review of Recent Developments on Oxidation-Resistant Coatings for Refractory Metals, July 31, 1961
121	Fabricating and Machining Practices for the All-Beta Titanium Alloy, August 3, 1961
122	Review of Recent Developments in the Technology of Nickel-Base and Cobalt-Base Alloys, August 4, 1961
123	Review of Recent Developments in the Technology of Beryllium, August 18, 1961
124	Investigation of Delayed-Cracking Phenomenon in Hydrogenated Unalloyed Titanium, August 30, 1961
125	Review of Recent Developments in Metals Joining, September 1, 1961
126	A Review of Recent Developments in Titanium and Titanium Alloy Technology, September 15, 1961
127	Review of Recent Developments in the Technology of Tungsten, September 22, 1961
128	Review of Recent Developments in the Evaluation of Special Metal Properties, September 27, 1961
129	Review of Recent Developments in the Technology of Molybdenum and Molybdenum-Base Alloys, October 6, 1961
130	Review of Recent Developments in the Technology of Columbium and Tantalum, October 10, 1961
131	Review of Recent Developments in the Technology of High-Strength Stainless Steels, October 13, 1961
132	Review of Recent Developments in the Metallurgy of High-Strength Steels, October 20, 1961
133	Titanium in Aerospace Applications, October 24, 1961
134	Machining of Superalloys and Refractory Metals, October 27, 1961
135	Review of Recent Developments in the Technology of Nickel-Base and Cobalt-Base Alloys, October 31, 1961
136	Fabrication of Tungsten for Solid-Propellant Rocket Nozzles, November 2, 1961
137	Review of Recent Developments on Oxidation-Resistant Coatings for Refractory Metals, November 8, 1961
138	Review of Recent Developments in the Technology of Beryllium, November 16, 1961
139	Review of Recent Developments in the Technology of Tungsten, November 24, 1961