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ELECTRON BEAM WELDING OF REFRACTORY METALS

Problem Assignment No. C 10 RMA 23-21 under Bureau of Naval Weapons WEPTASK RRMA 02 018/200 1/R007 05 01

A. Purpose

To study the electron beam welding process as applied to the welding of the 0.5 Ti-Mo alloy.

B. Details and Test Procedure

1. Electron Beam Welding Equipment

Operation of the equipment was interrupted for a period of approximately five weeks due to maintenance of the vacuum pumping system.

2. Electron Beam Welding of Test Assemblies

Electron beam welded assemblies of the 0.5 Ti-Mo alloy sheet material in gage thicknesses of 0.030", 0.060" and 0.125" were prepared using welding schedules developed in preliminary studies. Welding schedules were chosen which would produce a vee-shaped weld zone configuration and a narrow parallel-sided weld zone configuration respectively, in each gage thickness of material.

3. Sectioning and Machining of Test Specimens

Due to the inherent brittleness of the 0.5 Ti-Mo alloy material and the embrittlement induced during the welding operation, special techniques were required to section the welded assemblies and machine specimens. During shearing or saw-cutting, cracks developed which propogated into the sheet at approximately 45° to the line of cutting or shearing. Cracking was not encountered in friction cutting but burning of the edges was unavoidable and the cuts that were made were usually not straight. Sectioning was accomplished using a high speed cut-off wheel with a modified clamping fixture to accommodate the flat welded assembly. Tensile specimen blanks sectioned in this manner were subsequently finished to size by a grinding operation.

4. Tensile Tests

Tensile tests were conducted on electron beam welded specimens of the 0.5 Ti-Mo alloy in three gage thicknesses of sheet material. Similar tests were conducted on base metal specimens. The results of the tests are given in Tables 1 and 2. A comparison of the results are given in Table 3.

C. Discussion of Results

In preparing welds having a narrow weld zone configuration, alignment of the electron beam and the seam to be welded was critical. Alignment was even more critical on lighter gage material when low beam-currents and a finely focused beam were used. A five inch seam misaligned with the beam by 1/16" at the end of the weld resulted in lack of fusion on one face for almost one third of the seam.

Examination of cross-sections of the electron beam welds in the .030" gage material revealed vee-shaped weld configuration at both the high and low power densities. The narrow, parallel sided weld configuration appears to be limited to the heavier gage materials.

A more realistic appraisal of the tensile properties of electron beam weld in the 0.5 Ti-Mo alloy material was gained by excluding strength values of those welded specimens which were badly undercut or only partially fused. With the exclusion of these [illegible] strength values, weld strength variation was found not to exceed 15% and joint efficiencies for the three gage thicknesses was greater than 60%. The vee-shaped weld configuration provided higher joint efficiency and lower variation in strength in the two lighter gages of material, .030" and .060". The higher joint efficiency, 77.6%, was obtained with the narrow weld zone configuration in the 0.125" gage material.

D. Conclusions and Recommendations

Sectioning of molybdenum alloy sheet material is best accomplished with the use of high speed cut-off wheels utilizing excess coolant. This mode of sectioning is recommended for molybdenum and its alloys and other inherently brittle materials.

Of the welding parameters necessary to produce a narrow weld zone in the .030" and .060" material alignment is very critical and partially fused or undercut welds may result when the beam is only slightly off the seam. In order to insure sound electron beam welds, the wider, "vee"-shaped weld configuration is recommended for the lighter gages, .060" and lower. The narrow, parallel sided weld zone configuration is much easier to obtain in the heavier gage material because of the high beam power density required for complete penetration and the wider beam at these power levels. Because of the higher joint efficiency obtained with the narrow weld zone, this weld zone configuration is recommended for sheet thickness .060" and over.

E. Future Work

Investigative efforts on the 0.5 Ti-Mo alloy will be curtailed in favor of a newly developed alloy of molybdenum identified as the TZM alloy. Until the TZM alloy is received, the electron beam welding properties of specially fabricated tungsten will be determined. This material has been received in gage thicknesses of .010", .060", .100", and .250". Initial work on the tungsten sheet will be concerned with establishing schedules for electron beam welding each thickness of material.

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LIST OF TABLES

TABLE 1

TENSILE PROPERTIES OF 0.5 Ti-Mo ALLOY

Gage	Grain Direction	Strain Rate	Ultimate Stress	% Elon. (G.L = 2")
.030	Transverse	.0066 in/in/min	151,333	6.0
.030	Transverse	.0066 in/in/min	150,666	7.0
.030	Longitudinal	.0066 in/in/min	141,333	11.0
.030	Longitudinal	.0066 in/in/min	140,000	12.5
.060	Transverse	.0057 in/in/min	141,333	11.5
.060	Transverse	.0057 in/in/min	135,830	10.5
.060	Longitudinal	.0057 in/in/min	127,333	18.0
.060	Longitudinal	.0057 in/in/min	127,666	19.0
.125	Transverse	.005 in/in/min	110,880	10.5
.125	Transverse	.005 in/in/min	108,480	11.5
.125	Longitudinal	.005 in/in/min	106,080	17.5
.125	Longitudinal	.005 in/in/min	104,640	16.5

TABLE 2

TENSILE PROPERTIES OF ELECTRON BEAM WELDED JOINTS IN 0.5 Ti-Mo ALLOY SHEET

Gage	Weld Parameters			Strain Rate	Ultimate Tensile Strength	Weld Zone
	E	I	s/t			
.030	24 KV	80 ma	90 psi	.0025 in/in/min	79,100	Narrow
.030	24 KV	80 ma	90 psi	.0025 in/in/min	92,000	Narrow
.030	24 KV	80 ma	90 psi	.0025 in/in/min	83,500	Narrow
					Average - 84,500	
.030	27 KV	40 ma	40 psi	.0050 in/in/min	82,000	Vee
.030	27 KV	40 ma	40 psi	.0050 in/in/min	71,300	Vee
.030	27 KV	40 ma	40 psi	.0050 in/in/min	81,000	Vee
					Average - 78,300	
.060	21 KV	170 ma	70 psi	.0050 in/in/min	82,200	Narrow
.060	21 KV	170 ma	70 psi	.0050 in/in/min	75,700	Narrow
.060	21 KV	170 ma	70 psi	.0050 in/in/min	74,300	Narrow
					Average - 77,400	
.060	21 KV	110 ma	50 psi	.005 in/in/min	90,000	Vee
.060	21 KV	110 ma	50 psi	.005 in/in/min	84,300	Vee
.060	21 KV	110 ma	50 psi	.005 in/in/min	80,100	Vee
.060	21 KV	110 ma	50 psi	.005 in/in/min	85,700	Vee
.060	21 KV	110 ma	50 psi	.005 in/in/min	83,300	Vee
.060	21 KV	110 ma	50 psi	.005 in/in/min	80,300	Vee
.060	21 KV	110 ma	50 psi	.005 in/in/min	83,300	Vee
					Average - 83,860	
.125	28 KV	260 ma	80 psi	.005 in/in/min	73,800	Narrow
.125	28 KV	260 ma	80 psi	.005 in/in/min	83,700	Narrow
.125	28 KV	260 ma	80 psi	.005 in/in/min	85,300	Narrow
.125	28 KV	260 ma	80 psi	.005 in/in/min	84,500	Narrow
					Average - 81,800	
.125	24 KV	210 ma	35 psi	.005 in/in/min	68,400	Vee
.125	24 KV	210 ma	35 psi	.005 in/in/min	70,100	Vee
.125	24 KV	210 ma	35 psi	.005 in/in/min	70,800	Vee
.125	24 KV	210 ma	35 psi	.005 in/in/min	73,800	Vee
.125	24 KV	210 ma	35 psi	.005 in/in/min	63,600	Vee
					Average - 69,600	

TABLE 3

COMPARISON OF BASE METAL AND WELD JOINT STRENGTHS OF 0.5 Ti-Mo ALLOY

Gage	Weld Zone	Average Weld Joint Tensile Strength	% Variation	Average Base Metal Tensile Strength, psi	Joint Efficiency
.030	**Narrow**	84,900	15.0	140,700	60.3
	"V"	98,300	12.6	140,700	69.9
.060	**Narrow**	77,400	10.2	127,500	60.8
	"V"	83,760	11.0	127,500	65.7
.125	**Narrow**	81,800	13.9	105,400	77.6
	"V"	69,200	9.4	105,400	65.6