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WELDING THIN-WALLED URANIUM CYLINDERS

A Monograph By

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ABOUT THIS MONOGRAPH: The development of a satisfactory process for the fusion welding of thin-walled uranium cylinders is discussed. Optimum results were obtained using the inert-gas shielded-arc method without the use of filler metal. Uranium welded by this method was free from porosity, cracks, and oxide inclusions. The tensile strength and yield strength of welded joints exceeded the strength of cast metal. The ductility of the welded joints, however, was lower than that of cast metal. Surface condition and the purity of the inert gas used affected the weld soundness. Straight polarity direct current was used for welding to achieve maximum penetration and to provide arc stability. Welding must be done in the flat position.

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WELDING THIN-WALLED URANIUM CYLINDERS

E. L. Brundige, J. M. Taub, G. S. Hanks, and D. T. Doll*

Techniques for the fusion welding of thin-walled uranium cylinders have been under development at Los Alamos Scientific Laboratory. Several methods of fusion welding have been investigated. The inert-gas shielded-arc method using a tungsten electrode and no filler metal proved to be the most satisfactory.

The welding equipment used was standard commercial equipment. A 400-amp rectifier type power supply was employed. A tial slope control, used in conjunction with this power supply, aided considerably in eliminating the crater normally found in a weld where the arc is broken. A Heliarc HW-13 series 2 machine welding torch with a No. 6 ceramic cup was used for the majority of welding development. The work was positioned and rotated under the torch by the use of a welding jig. Rotation was achieved by a chain drive controlled by a Graham transmission. The face plates were mounted on ball bearings, and interchangeable aluminum chucks were bolted to the face plates. This jig could swing diameters up to 13 $\frac{1}{2}$ in. For welding uranium cylinders of larger diameters and lengths in excess of 15 in., a spinning lathe was modified and used as a fixture. The welding fixtures are shown in Figs. 1 and 2 with the torch in welding position. The torch was mounted directly above the jig center line and was adjustable in both the vertical and horizontal planes.

The inert gases used in the shielded-arc welding process were dried by passing them through a commercial drier and further purified by passing through a tube of uranium chips held at 600°C.

Depleted uranium was used in the majority of welding experiments. A typical analysis of the metal used showed it to contain the following impurities: carbon, 100 to 500 ppm; iron, 70 to 100 ppm; and silicon, 50 to 100 ppm. The total of all impurities was less than 1000 ppm.

*Authors are affiliated with the Los Alamos Scientific Laboratory, operated for the U. S. Atomic Energy Commission by the University of California.

Fig. 1—Welding fixture with torch in welding position.

Fig. 2—Welding fixture with torch in welding position.

Uranium metal (m.p. 1130°C) readily became molten in the electric arc and possessed a high degree of fluidity. The fluidity characteristic and high density of uranium required that the work be maintained in a near-horizontal position during welding. The low thermal conductivity of uranium was advantageous in welding. The low electrical conductivity was not harmful. The chemical activity of uranium was decidedly a troublesome factor during welding in that oxidation was very rapid and ever present unless the area was blanketed with inert gas during fusion, solidification, and cooling.

The transition temperature for uranium is approximately 150°C. Below this temperature uranium exhibits brittle metal characteristics. Above the transition temperature the metal is quite plastic and behaves in a ductile fashion.

The technique for welding uranium is very similar to that applicable to other nonferrous metals. A clean surface is the first prerequisite for welding of any metal. Relatively thick oxide or other adherent impurity precluded a successful weld. The relatively thin atmospheric oxidation present on previously cleaned or freshly machined uranium usually was not detrimental. The welding procedures covered in this paper were established using electrolytically cleaned metal except when freshly machined surfaces were available. The oxide surface that formed on a properly protected weld bead was thin and easily removed by wire brushing, leaving a clean smooth surface.

An insufficient flow of inert gas during welding caused a heavy oxide scale to form, resulting in weld failure. A black wrinkled appearance of the surface indicated this condition. A sound weld with a tight overlap could be produced on uranium cylinders when the weld area was initially clean and the formation of oxide was inhibited during fusion.

Two types of power supply were investigated. High frequency stabilized alternating current offered two advantages when welding uranium: (1) it had a slight cleaning effect on the surface to be welded, and (2) the lower heat input aided substantially in welding light-gauge uranium (0.020 in. and thinner). The disadvantages of a-c welding included the production of shallow welds because of the low heat input, poor arc stability, and pronounced electrode pickup. Reverse polarity direct current was found unsatisfactory because of the very low heat input, poor arc stability, excessive electrode deterioration, and extensive oxidation. Direct-current straight polarity (electrode negative) proved the most successful. Straight polarity d-c welding produced greater penetration at lower amperages, a more stable arc, and higher surface speeds during welding. Reproducibility of welds was good, and the weld beads were smooth. A welded uranium cylinder is shown in Fig. 3.

Welded cylindrical components ranged in thickness from 0.010 to 0.250 in. They were mounted in aluminum chucks, and the joints were aligned under slight pressure. A straight butt joint was employed in all cases unless alignment was extremely difficult because of excessive weight or length of the parts to be welded. In these cases a step type

Fig. 3—Welded uranium cylinder.

butt joint was utilized. A surface rotational speed of 18 to 23 in./min past the torch was established as the result of extensive experimentation. The optimum speed was dependent on the penetration desired and the thickness of the section. The thinner the section, the faster the speed.

Determination of approximately correct welding amperages for sections 0.060 in. thick can be made using the equation $A = 1.5T + T/5$. In this equation A is the welding amperage, and T is the thickness in thousandths of an inch for the penetration desired. T would equal the section when full penetration is desired; otherwise T equals the depth of penetration desired. The equation becomes $A = 1.3T$ when the weldment is less than 0.060 in. thick. The amperage value derived from these equations is only approximate, and refinements must be made to achieve optimum results. The equation values are most valid at a surface speed of 18 in./min.

Experimentation indicated that thoriated tungsten electrodes offered longer electrode life than plain tungsten electrodes. Optimum electrode life was obtained using 2.0 wt.% thoriated tungsten electrodes. Tungsten pickup in the weld was not a factor in the selection of the type of electrode. Average pickup in a representative weld was less than 250 ppm. An arc gap of 0.050 in. using a flat-end $\frac{3}{32}$ -in.-diameter electrode was standard procedure. To obtain proper weld technique, the welding torch was positioned about 10 deg off the vertical plane with the weld being made at 12 o'clock in relation to the rotational direction of the cylinder.

The use of a slope greatly aided in the production of sound welds. The slope control attachment automatically decreased the weld current over a predetermined length of time. This current decay successfully eliminated weld cratering when the arc was broken.

Helium, when used as the inert shielding gas, gave considerably better results than argon. The type of inert gas used and the flow rate employed were both determining factors in the strength and appearance of the resulting weldment. Pure helium, used as the shielding gas, produced a weld bead that was smoother, wider, and more penetrating than that made using pure argon. Owing to its higher density, argon tends to flow across the arc gap quicker and ionizes more rapidly. To take advantage of these properties, 10 vol.% argon was added to the helium for welding uranium, causing a slight decrease in penetration. This addition substantially aided arc starting, and the helium-10 vol.% argon mixture was adopted as the standard shielding gas mixture. Neither gas was satisfactory for use as bottled. Both helium and argon were dried by passing through commercial driers and further purified by passing through uranium chips held at 600°C. Sounder welds were produced using the purified gas. Shielding gas flow rates as high as 60 cu ft/hr were employed to inhibit oxide formation during fusion. The beneficial aspects of the shielding gas were dissipated almost instantly owing to the rotation of the cylindrical section past the torch. This loss of shielding protection resulted in weld failure in the overlap area and excessive oxide inclusion in the weld proper. To alleviate this condition, the entire weld area was blanketed with a protective cover of inert gas, which was maintained during fusion and cooling. The resulting weld was clean with no oxide inclusions, and the overlap area was free from porosity. Optimum results were obtained using a blanket consisting of a mixture of equal parts of helium and argon totaling 60 cu ft/hr. When this gas blanket was used, additional weld passes could be successfully made.

Distortion encountered in welding uranium was found to be a function of several variables, the most important of which were (1) degree of restraint, (2) intensity of the current, (3) geometry of the section, (4) number of passes to be made, and (5) residual stresses in the uranium. Unrestrained cylindrical uranium components will distort

longitudinally to be a noticeable degree during welding. In most cases circumferential distortion can be considered negligible.

The main difficulty encountered in welding uranium was the ease with which oxide could be included in the weld metal. Finely divided and/or light oxide particles usually floated to the surface, but heavy oxide particles rapidly formed a crust that could be entrapped within the weld metal. The oxide resulted from poorly cleaned surfaces or from an inadequate inert gas blanket during welding. Weldments may be cold-worked as much as 40 per cent without failure. The limits of weld deformation have not been investigated. Uranium welds possess greater strength than as-cast metal.

A uranium weld is comprised of a fusion zone and heat-affected zones on either side of the fusion zone. The fusion zone is that area where the uranium has exceeded the melting point. The heat-affected zones are those areas where the temperature gradient decreases from the melting point to some lower value where the internal structure of the metal was not affected.

A number of structural changes occur in the parent uranium metal because of welding. Three regions where the uranium parent metal has undergone changes can be considered in addition to the fusion region:

1. The region, adjacent to the fused area, which has been heated to a temperature above 760°C but below the melting point. During welding, this region exists in the gamma phase. Upon cooling, the metal passes through the gamma and beta phases and ends up in the alpha phase. A residual gamma structure can be seen.

2. Adjacent to the gamma transformed region is an area that has been subjected to temperatures between 660 and 760°C . This beta-transformed material reverts to the alpha phase during cooling. The beta grain outline is retained in the structure.

3. The area subjected to temperatures within the high alpha temperature range during welding. This metal was exposed to temperatures between 660 and 450°C . The 450°C temperature is here assumed to be the lowest temperature at which recrystallization of the worked uranium will occur.

The fusion zone in welded uranium had the appearance of a cast structure and contained grains as large as 500μ . Cast uranium grains run as high as 2500μ ; worked and annealed uranium contains grains averaging 30μ . In addition to this grain refinement, there is an absence of large carbide particles in welded uranium structures. These carbides, so noticeable in as-cast structures, appear to have broken up into finely divided particles during welding and are uniformly distributed throughout the fused area. Typical microstructures of uranium welds are shown in Fig. 4. Microstructures of as-cast as well as worked and annealed uranium have been included for comparison purposes and are shown in Fig. 5.

BRIGHT FIELD

0.060 SHEET

0.040 SHEET

NO BACKUP

Fig. 4a — Typical weld microstructures. (Magnification 250 ×.)

BRIGHT FIELD

0.060 SHEET

0.040 SHEET

GRAPHITE BACKUP

POLARIZED LIGHT

0.060 SHEET

Fig. 4b—Typical weld microstructures. (Magnification 250 ×.)

0.060 SHEET

AS-ROLLED

0.060 SHEET

ROLLED AND ANNEALED

625°C

Fig. 5a—Uranium microstructures. (Polarized light, magnification 250 ×.)

0.060 SHEET

ROLLED AND ANNEALED

900°C

AS-CAST

Fig. 5b—Uranium microstructures. (Polarized light, magnification 250 ×.)

Average physical properties of welded uranium sections are compared with the properties of as-cast metal and rolled and annealed metal in Table 1.

From the data in Table 1, it may be concluded that welded uranium is stronger than as-cast material but is slightly lower in ductility.

Table 1—PHYSICAL PROPERTIES OF WELDED, AS-CAST, ROLLED AND ANNEALED METAL

Material	Tensile strength, psi	Yield strength, psi *	Elongation in 2-in. gauge, %
Welded	87,000	43,000	6-7
As-cast	52,000	21,000	8
HR-74% WR-86%			
As-rolled	205,000	105,000	4
Salt annealed (600°C)	145,000	48,000	7
Vacuum annealed (600°C)	140,000	69,000	14

*Yield strength at 0.2 per cent offset.

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