Development of Resistance Welding Methods for Tritium Containment

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Abstract

A resistance welding process was developed early in the history of the Savannah River Site (SRS) for the critical application of sealing reservoirs filled with tritium gas. Resistance welding again became the welding method of choice for attaching new stems to reservoirs to allow their reuse after tritium decay necessitated removing the reservoir from service. The successful application of these two welding processes put SRS in the forefront of resistance welding technology. These successes, with no failures during service, provided the basis for future non-reservoir applications, the largest of which is the 5-inch diameter defense waste canister closure weld. The success of the pinch and reclamation welding processes also led to developing resistance welding to join the two halves of reservoirs, with potential to replace fusion welding processes altogether for reservoir fabrication.

Introduction

During the early months of 1956, a project was initiated at the request of the then Atomic Energy Commission to design and build a new tritium facility. This facility was to provide the necessary equipment to fill and seal capsules (reservoirs) designed by Los Alamos Scientific Laboratory (LASL) (as it was known in 1956). This project was the beginning of a unique engineering task to develop a technique that would seal tritium in capsules at high pressures.

Engineers at LASL and Du Pont Atomic Engineering Division (AED) in Wilmington, Delaware, investigated five methods for sealing the capsules:

- Ball check
- Projectile closure
- Conventional packed valve
- Ball expansion seal
- Pinched tube

The first two options were abandoned for either failure to obtain the required leak rate or for not producing consistent results. By the end of July 1956, development of the conventional packed valve closure, method 3, was abandoned because of more pressing work, the expense required for testing, and the cumbersome valve that would remain with the capsule.

The fourth method, the ball expansion seal, was developed during the investigation of the other methods. This method required a steel ball to be driven into a tapered plug tube, expanding it to seal the annulus through which the tritium passed during loading. In early July 1956, it was decided that the capsules for the startup would contain the ball expansion seal and initial capsules were fabricated by ACF Industries Atomic Energy Section in Albuquerque, New Mexico. However, this method was also abandoned because of time and cost restraints, leaving a pinched tube as the only viable option.

Pinch Welding Development

The challenge of loading and sealing reservoirs was therefore met by developing pinch welds to close the tube through which reservoirs are loaded. Prior to this time, there was no history of sealing tubing containing pressures much higher than 100 psi. The development criteria required sealing a tube containing gas at pressures orders of magnitude higher that previously accomplished .

The pinch weld is a type of resistance weld initially unique to SRS for high pressure closures. During pinch welding the tube is sealed by applying a force and an electrical current through electrodes that impinge on the tube. Initially these tubes were 1/80-inch OD by 1/16-inch ID and were made of 304 stainless steel. These dimensions are used today for most reservoirs. Tube material became 304L when the low carbon grade became available, and most reservoirs today are made from this material.

The early pinched tube welds were made by DuPont at the Mechanical Development Laboratory in Wilmington, Delaware, and at the TNX Facility at the Savannah River Plant. In October 1956, development of the pinch welding of tubes was assigned to the Weld Development Group of the Engineering Assistance Section in Building 723-A. Development of the pinch welding process was completed by mid 1957.

The initial welds were made using a manual (foot operated) spot welder. The electrodes used initially were made of copper with either spherical- or cylindrical-shaped tips. The production welding equipment was designed by Du Pont and fabricated at the Site. This equipment was unique in that the reservoir tubes were held between the horizontal floating electrode rams.

Pinch welding process refinement and improvement continued for many years. The process was adapted to reservoirs with tubes of different sizes, materials, and strengths. A capacitor discharge welder was used to seal tubes as small as 0.040-inch O.D. by 0.010-inch I.D. Tubes as large as 0.250-inch O.D. by 0.083-inch I.D. were welded on the production design pinch welders. Processes to achieve a hotter weld interface were developed, including the confined tube welding process that was initiated in production in 1974. This process minimizes the diameter of the pinched tube and produces melting in the center of the weld to minimize the effect of tube bore cleanliness.

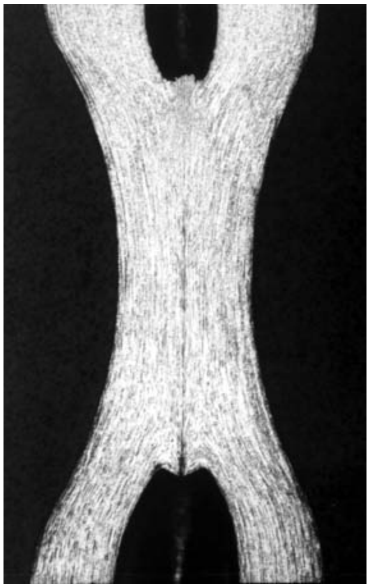
Developing the pinch welding solved a critical production problem at SRS and initiated a lasting technical expertise in resistance welding at the Site. Production pinch welding was carried out in loading lines in Building 234-H until 1994 when the loading mission was transferred to the new Tritium Facility in Building 233-H.

Reclamation Welding Development

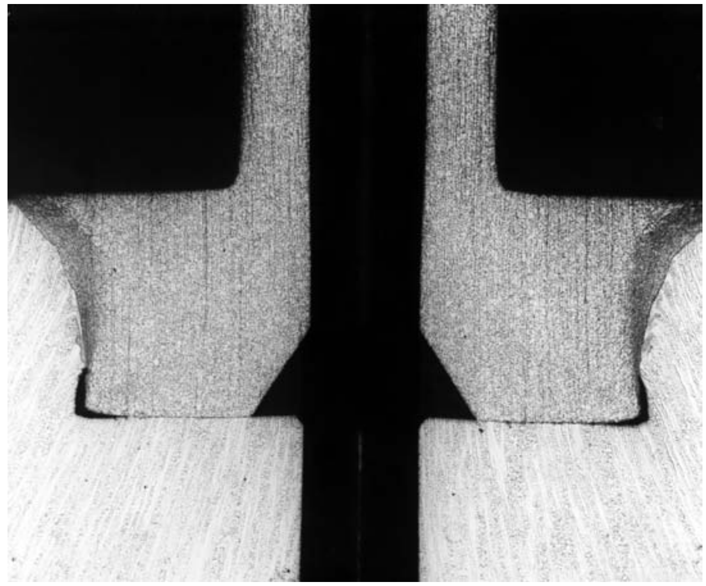
The useful life of reservoirs is determined by tritium decay, which renders the weapon non-functional. Used reservoirs can be discarded and replaced. However, a large cost saving was realized by recycling, or reclaiming, reservoirs. Reclamation has been done in Building 238-H since its construction in 1969 by replacing the fill stem using a "reclamation" resistance weld. This method reuses reservoirs by filling the reservoir through a tube and pinch welding the tube.

The reservoir reclamation process was developed in the 1960s by Equipment Engineering in Building 723-A. Three processes were initially investigated during the developed program to reclaim reservoirs. Fusion (gas tungsten arc) welding, brazing, and resistance welding were all successfully developed for reclamation. These processes included both tube-to-tube welds and tube-to-base welds. The tube-to-base resistance welding process was chosen for production.

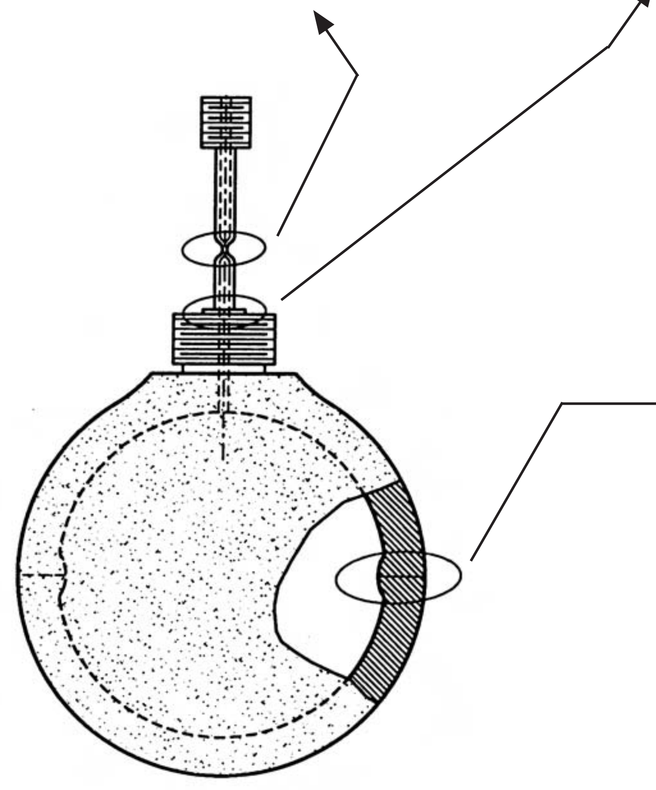
Reclamation by resistance welding was a novel process for attaching tubes to a part. The process requires machining and resistance welding capability in a glovebox facility. The old stem from the reservoir and a counterbore at the base of the stem location are machined and a new stem is resistance welded into the counterbore. The new stem has a "foot" that is oversized to the counterbore diameter by about 0.024 inch. During welding, force and electrical current are used to push the stem foot, which becomes hot from resistance heating, into the counterbored hole. A metallographic cross section of the reclamied stem is shown in Figure 1. Significant cost savings were realized by using the reclamation welding process.



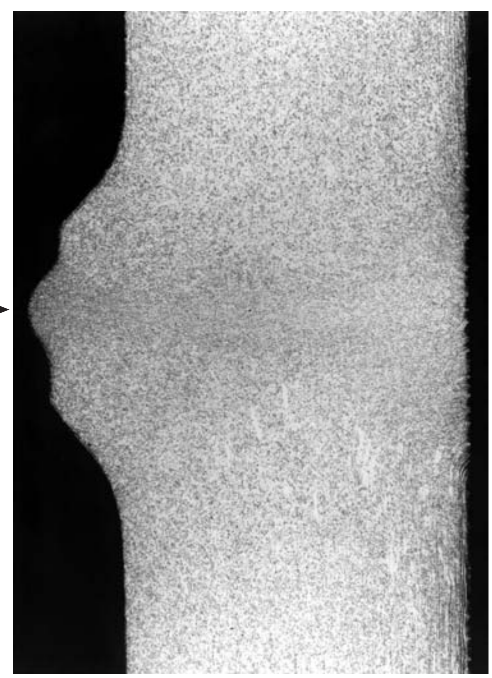
A
Tube closure (pinch) weld
(production since 1957)



B
Side-bonded tube attachment
(reclamation) weld
(production since 1967)



C
Simulated reservoir



D
Girth weld
(currently in development)

Figure 1. Reservoir fabrication resistance welding processes
(weld cross section)

In recent years, the manufacturing process for new reservoirs has incorporated the reclamation process to attach stems. The reclamation process is more cost effective, and stems are resistance welded to new reservoir bodies rather than machine stems as an integral part of the body. The past practice of drilling of the small hole through the stem when it is an integral part of the reservoir was very costly, and rejects were frequent. However, if stems are separate from the reservoir when they are machined, the most that will be lost from machining errors is the stem itself.

The production reclamation process has been very successful over the years with no failures during deployment. The first, and now preferred, reclamation process is called side-bonded because the weld forms along the sides of the stem foot. Other reclamation welds have been developed. For instance, a projection weld that requires no counterbore was developed with advantages in simplicity, minimal machining, and superior strength. Considerable tritium experience now exists for the projection tube attachment weld without a counterbore. This weld was applied in production using a shallow counterbore and was called a bottom-bonded reclamation weld.

A reclamation process combining a braze with a side-bonded resistance weld was developed and patented. The weld-braze technique created a weld that is much stronger than the side-bonded reclamation weld, but the technique was not applied to production since the projection weld has the same strength without the complication of a braze. An alternative reclamation process that uses a combination of laser drilling/welding with resistance welding was developed more recently and may find future application.

Reservoir Fabrication Development

Solid-state resistance welding is being developed to fabricate reservoir bodies. The production applications will be used at the DOE Allied Signal Federal Manufacturing & Technology plant in Kansas City, Missouri, where reservoirs are fabricated. The Kansas City plant purchased and installed large resistance welding equipment that will be used for reservoir fabrication. Initial development of girth welds to fabricate cylindrical and spherical shapes was carried out at SRS and continues today in support of applications at Kansas City.

Resistance welding has advantages of stronger welds, a simple process, fewer defects, and less sensitivity as compared to the fusion welding processes currently used to join the two halves of reservoir bodies. A simple butt weld joint around the circumference of the body components is all that is needed to form the weld. The girth weld is made by applying force on the weld joint and then passing a high electrical current through the weld joint. Fixturing is used to apply the force, to channel the current flow through the weld joint, and to align the two halves of the reservoir body during welding. Resistance to the electrical current at the weld joint, combined with resistance heating of nearby metal, increases the temperature at the weld joint to create a bond at the weld interface. No metal melting occurs. Welds up to 2.5 inches in diameter with a 0.3-inch wall have been produced. These welds are stronger and easier to make than the fusion welds they are designed to replace.

Beginning in 1984, vessels fabricated using solid-state resistance welding were placed in tritium storage in the Materials Test Facility, Building 232-H. The long-term compatibility of the fabrication welds for tritium service is being demonstrated with the storage tests. Vessels maintained their integrity during accelerated (71°C) storage for periods up to 12 years. Ten vessels were removed from storage and evaluated with no detrimental effects of the tritium observed. Over 170 vessel-years in storage were successfully completed.

Resistance Welding Fixtures, Controls, and Instrumentation

Mechanical and instrument development by the Equipment Engineering Department was an important part of the progress made on resistance welding. Successful application of unique welding processes required distinctive mechanical and instrument development.

Fixtures for pinch, reclamation, and girth welding all required adaptation to the unique configurations being welded. Copper alloy pinch welding electrodes were tipped with tungsten having a cylindrical radius that impinged on the tubes. Developing the confined tube pinch weld required fixtures with the added restraint on the sides of the tubes. Restraint was achieved using anvils made from Waspalloy in a fixture to align the tube with the electrodes and anvils. Reclamation fixtures required positioning the tube and reservoir to seat the tube in the counterbore while applying appropriate force and current. This was accomplished using a split electrode in an insulated sleeve for alignment. Girth welding uses large copper alloy electrodes in an insulating sleeve to align the two reservoir halves.

Advances in resistance welding controls and instrumentation were implemented throughout the history of resistance welding at the Savannah River Site. Data acquisition and weld control systems unique to SRS were developed, tested, and qualified in Building 723-A prior to installed in H-Area production lines. Emphasis over the years evolved from the early vacuum tube technology to the current computer-based data acquisition and control systems. During the 1990s, real-time digital sampling of resistance welding process electrical and physical parameters was introduced. This instrumentation provides accurate control and monitoring of process parameters during the welding operation. The technology was exported to Los Alamos National Laboratory to use with their resistance welding equipment. Additionally, feedback controls for welding current were tested, yielding a tenfold improvement in weld current variability. This progress has enabled production personnel to create more consistent and repeatable welds.

Historical Impact

The development of the pinch welding process in the early 1950s provided a robust method to seal tubes at high internal pressures. This technology was previously unavailable. Application of force with a shaped electrode and the passage of an electrical current through the tubes allowed sealing tubes with a range of sizes and materials. This closure method allowed the reservoir design laboratories great latitude in designing reservoirs. Pinch welding in its various forms has been used to produce reservoirs for 42 years without a field failure.

Both reclamation and pinch welding are unique applications of resistance welding. Developing tube attachment technology enhanced the Site expertise in resistance welding and provided a low-cost alternative to discarding used reservoirs. Technology and equipment for pinch and reclamation welding were transferred to other DOE sites over the years, in particular to Sandia National Laboratory, Los Alamos National Laboratory, the Rocky Flats Plant, and more recently, the Allied Signal facility at Kansas City.

Offshoots from the Site's resistance welding technology for tritium containment have been considerable. The largest spin-off is the plug weld used to close the canisters in the Defense Waste Processing Facility. The DWPF weld is 5 inches in diameter, the largest known application of resistance welding in the world. Additional SRS applications that relied on the resistance welding technology developed at the Site include the closure of Rabbit Capsules. These aluminum capsules were initially closed using a fusion welding process that exhibited many problems. These capsules, which contained iodine samples for irradiation in SRS reactors, were made routinely during the 1980s using the large resistance welder in Building 723-A. Another application was fabricating charging vessels that were used to expose mechanical test samples to tritium.

Work is ongoing in the area of resistance welding for containment of tritium. The development of large welds for fabrication of reservoir bodies continues. New equipment was recently installed at the DOE Kansas City Plant, the production site for reservoir fabrication, for applications using the large resistance welding processes developed at the Savannah River Site.

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Biographies

William R. Kanne, Jr.

William Kanne is a senior fellow engineer at the Savannah River Technology Center where his current work includes the use of resistance welding for tritium containment. He has 30 publications and one patent on topics that include welding of irradiated materials, welding heat source capsules, corrosion, and resistance welding. Mr. Kanne is a graduate of the Johns Hopkins University with a B.A. in physics. He received a Ph.D. in metallurgical engineering from the University of Wisconsin in 1968, and he has been at Savannah River since that time. He is currently on the Board of Directors of the International Metallographic Society, and is active with the American Welding Society, ASM International, TMS and ANS.

Robert J. Alexander

Robert Alexander is a principal engineer at the Savannah River Site in the Defense Program Tritium Engineering Division. His present work includes mentoring loading and welding system engineers and the development of new loading and welding processes for the Tritium Facilities. During his early years at Savannah River, he was a major part of the pinch weld development team. He later played a major role in the development of the reclamation welding process, and he holds a patent on resistance-braze welding. Mr. Alexander attended Florida State University and University of South Carolina at Aiken. He has worked at SRS for 46 years.