WASTE CANISTER CLOSURE WELDING USING THE INERTIA FRICTION WELDING PROCESS

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ABSTRACT

Liquid radioactive waste presently stored in underground tanks is to undergo a vitrifying process which will immobilize it in a solid form. This solid waste will be contained in a stainless steel canister. The canister opening requires a positive seal weld, the properties and thickness of which are at least equal to those of the canister material. This paper describes the inertia friction welding process and a proposed equipment design concept that will provide a positive, reliable, inspectable, and full thickness seal weld while providing easily maintainable equipment, even though the weld is made in a highly contaminated hot cell. All studies and tests performed have shown the concept to be highly feasible.

INTRODUCTION

Many gallons of liquid radioactive waste are stored in underground tanks at several sites around the country. Changing this waste into a solid vitrified, or glass, form and sealing the glass in a canister puts it in a safe form that requires little storage space. This is accomplished by mixing the liquid waste with glass formers and feeding the resultant slurry into a ceramic melter. The slurry is then converted into a molten glass which is drained into a canister. The canister selected for this purpose is made from Type 304L stainless steel and is 24 inches (61 cm) in diameter. The canister length is a nominal 10 feet (3.1 m). The filled canister weighs approximately 4650 pounds (2107 kg).

After filling, the canister opening must be sealed. A welding process is used to join a lid to the canister top. The weld is then inspected to provide assurance of a high-quality seal.

Because of the highly radioactive nature of the vitrified waste, all of the operations must be performed in a shielded or hot cell environment. The hot cell provides containment of radioactive particulate material and shields operating personnel from the high radioactivity.

The guidelines used for the canister closure welding project were:

- The canister material would be Type 304L stainless steel.
- The canister top opening would be 8 inches (20.3 cm).
- The wall thickness of the canister top at the weld joint would be 3/8 inches (9.5 mm).
- The weld would be inspectable by a nondestructive testing (NDT) method.
- The weld and canister top would have to pass waste repository impact testing criteria. The criteria are that the canister must be able to survive a drop (in this case onto the closure) of up to 30 feet (9.2 m) onto an unyielding surface. Survival is defined as the lack of a leak in excess of 10^{-5} atm-cc/sec.
- The welding process would produce a full 3/8 inch (9.5 mm) thick weld.
- The weld would be performed remotely inside a hot cell.

From the outset it was evident that some of the criteria required for the welding process would be:

- The welding machine would have to make welds in which the quality would be consistent from one weld to another.
- The welding process (and thus the weld) should not be greatly influenced by outside conditions such as part tolerances, constituents of the materials to be welded, accuracy of the equipment setup, variations in electrical input to the machine, and air currents that may affect shielding gas flow.
- The process should be capable of effecting a repair weld in the event of an unacceptable primary weld. The repair weld should be accomplished with minimal perturbations to the welding machine setup or facility operations.
- Proven technology and existing equipment and methods should be employed as much as possible.

A study was conducted to identify potentially applicable welding processes. One that appeared highly promising was inertia friction welding.

THE INERTIA WELDING PROCESS

The inertia welding process uses a flywheel that is revolved by a motor until a preset speed is reached. The flywheel rotates one of the pieces to be joined; the other piece is held stationary.

When the flywheel reaches the predetermined speed, the motor is disengaged and the parts to be welded are brought into contact with each other under a preset pressure. The force and rotational energy cause friction and subsequent heating of the faying surfaces. Softening of the metal occurs, upset begins; and as the flywheel comes to a stop, the weld is completed. The pressure is maintained after the flywheel stops until the weld partially cools. Coalescence of the two materials occurs at a temperature below their melting point. In this application, the rotating part is the lid and the stationary part is the canister.

Inertia welding was selected for a more detailed study because, in addition to meeting the aforementioned criteria, it affords several benefits.

- It consistently produces high-quality welds.
- The welds are readily inspectable by ultrasonic NDT examination.
- It is less affected by surface contamination on the parts to be welded than some of the other welding processes because the contaminants flow out of the weld area in the weld flash.
- The welding system can be set up so that the welding machine can have "hands on" maintenance.
- It is a simple process--there are only two welding parameters, rotational speed of the flywheel and forging pressure.
- Welding parameters can be easily monitored.
- The welding machine parameters can be monitored before the weld is made.
- A secondary closure can be easily made in the case of an unacceptable primary closure.
- The welding process is forgiving to minor changes in part configuration and welding parameters.

THE INITIAL INVESTIGATION

The first phase of the work was to identify equipment suppliers. Two studies[1,2] were then performed by the equipment manufacturer. One investigated the nature of the loads and the areas of possible design difficulties associated with having the axis of the machine vertical or horizontal. The loads included the weld thrust, eccentric thrusts, the weld torque, and the transverse welding forces. Design considerations such as torsional stiffness and stability, spindle bearing and hydraulic seal design, axial movements, and weld thrusts were considered.

The second study investigated the problems associated with making a closure weld on a waste canister and performed a preliminary design to determine the welding machine's approximate physical characteristics, throughput, mounting concept, cost, etc. The results of the two studies provided assurance that, in using inertia welding equipment with a vertical axis, no problems would be encountered that could not be solved with present day technologies.

WELDER AND FACILITY DESIGN CONCEPT

At the same time the studies by the manufacturer were being performed, a preconceptual welder and facility design concept was emerging. This concept is illustrated in Fig. 1. The proposed sequence of operations begins with the transferring of the waste canister by an overhead crane with a grapple system from the storage rack to a receptacle or "thimble" attached to a swing arm. The thimble has guides in the bottom to center the canister. An electric motor drive mechanism under the direct control of an operator moves the swing arm with the canister on a rail along an arc and under the welder. The entire operation of the swing arm occurs in the heavily shielded hot cell area to protect the operations personnel from radiation. The swing-arm system is designed so that removal and replacement of the entire arm, parts of the arm, and/or the drive unit can be accomplished by the in-cell crane.

The pivot pin is also designed for remote replacement. The drive components have carbon steel housings with a protective coating.

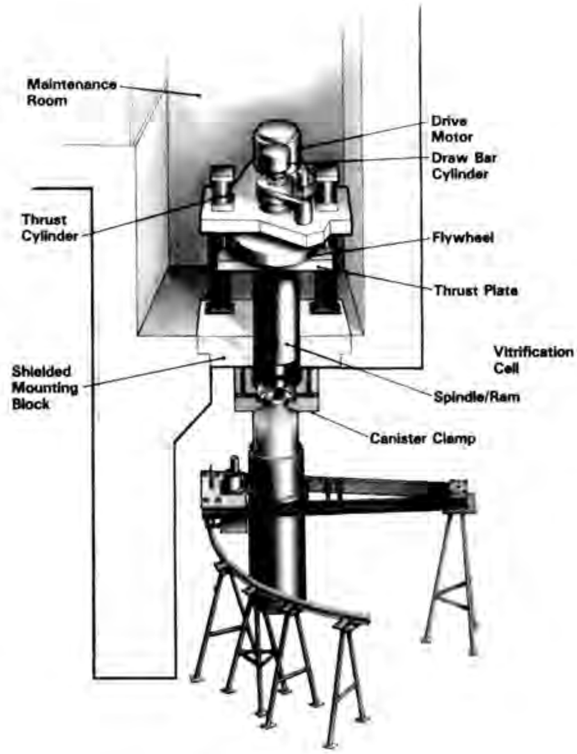

Fig. 1. Preconceptual Welder and Facility.

If the swing arm fails to operate while the canister is under the welder, the arm can be moved by a steel retrieval cable (attached to the arm) to a position accessible to the crane. When the cable bail is picked up and raised by the crane hook, the cable provides horizontal travel to the swing arm which will move it and the canister from under the welding head. The swing-arm drive wheel is smooth, not a cog, so a locked drive wheel will slide along the track during retrieval. Failure of the swing arm during weld inspection does not require cable retrieval since the arm would be directly accessible to the overhead crane. Once the canister has been transported from the storage rack and positioned under the welder, the welding operation can take place.

The inertia welder is mounted on the top of the cell in a machine room. It penetrates into the cell through an 18 in. (46 cm) thick steel plate that is an integral part of the machine but also part of the cell ceiling. Airflow is from the machine room to the cell to keep the machine room free from radioactive contamination. The machine room ceiling is to be high enough that the welder and the 18 in. thick steel ceiling plug can be raised by a hoist and removed as a unit if this is ever required. Contact maintenance of the welder can be performed in the machine room, which has been kept contamination free.

The canister holding mechanism, a device that lifts, positions, and holds the canister by the canister flange during welding, actuates from the machine room. If replacement of this device is required, it can be released into the cell from the machine room and replaced by remote means. The only portion of the welder itself that is in-cell is a short length of the spindle and the cap chuck that is located on the end of the spindle.

After the canister is placed in the swing-arm thimble, a lid is placed on the canister top. Wire positioning "spiders" on the inside of the lid hold the lid on the canister as the swing arm is moved, and will position the lid within the pickup tolerance of the welder chuck. The canister and lid then move into position under the welder. The canister flange-holding mechanism, which absorbs the welding torque, engages and locks onto the flange. This mechanism then slightly lifts the canister from the bottom of the thimble. This releases the bottom of the canister so that it is free-floating and allows the canister vertical axis to be essentially self-aligning. Once this has occurred, the welder spindle is lowered and the cap engaged in the welder chuck. At this point, a force check on the machine can be made to ensure that the set welding force is the force that will be delivered. The weld sequence is then initiated.

During the weld, the welder monitors the loss of length caused by the squeezed-out weld upset. This loss of length is an excellent indication of weld quality; if it falls within predetermined limits, it will indicate a good weld. Thus, even before swinging the canister from under the welder, the operator would have initial assurance of the weld quality. After the weld is completed, the chuck releases the lid and the spindle retracts to its preweld position. The swing arm then returns the canister to the initial position where the lid weld undergoes NDT.

THE WASTE CANISTER TOP AND LID DESIGN

The top "necked" portion of the waste canister and the canister lid require a design that facilitates the inertia welding process. These two parts would need to meet the following criteria.

- The canister must be able to be lifted and transported without the lid on it. After the lid is welded on, the canister should not be lifted by the lid.
- The canister top flange should be as short as possible so that the shearing forces of a drop test do not tend to tear it from the canister.
- The top flange should be designed so that the welder does not have to grip it with the force required to resist the torque of the weld.
- The top flange and primary (inner) lid should be designed so that a secondary (outer) lid could be welded onto the canister in the event of an unacceptable primary weld. This weld should be made with minimal perturbation to the welding machine, primary lid design, and flange design.
- Both the primary lid weld joint and the secondary lid weld joint should be designed in such a manner that they would be amenable to NDT.
- The primary and secondary lids should be designed to minimize the gripping force needed.
- Both lids should remain in position on the top flange without falling off in the pre-weld stages of operation.

Figure 2 shows the resultant design of the canister top flange, primary lid, and secondary lid.

The canister flange is machined from a standard Type 304L, 400-pound, (181 kg), 8-inch (20.3 cm) seamless, long welding neck flange. The two weld joints are machined onto the top surface of the flange and a flat is machined on each side of the flange. The flats provide the means to resist the machine torque and, at the same time, reduce the gripping requirement.

The lids are machined from Type 304L plate. An octagonal shape is machined onto the top of both the primary and secondary lids. The dimensions of the octagon are identical for both. This shape also assists in reducing the welding machine gripping requirement. The lids are machined to produce the desired weld joint. A basic pipe-to-pipe butt weld joint is used for the primary weld and a pipe-to-plate joint is used for the secondary lid weld. If for some reason the primary lid weld is not acceptable, the secondary lid can fit over the primary lid. Four wire spiders are provided inside the primary lid to hold and position the lid in the canister flange before the weld is made. Figure 3 shows the as-machined parts. The primary lid shown in the figure has only three wire spiders. Initially, it was believed that three should be adequate, but experience showed that at least four would be needed to better position the lid on the canister top. Figure 4 is a graphic representation of the canister top, top flange, the two lids, and the welded closures.

DEMONSTRATION WELDS

Fifteen sets of the canister top flange and primary lid and four of the secondary lids were machined at PNL. These parts were sent to the vendor for welding. The purpose of this welding was to prove the principle, i.e., that on this type and size part the inertia welding process could make an acceptable primary closure weld. The primary welds would be tested to determine their integrity. Only four secondary lids were fabricated because their purpose was to demonstrate the design. If the process could make an acceptable primary closure weld, there was no doubt that it could also make an acceptable secondary weld.

The welding of the parts took place at the equipment manufacturer's plant on a laboratory machine. All of their lab machines are horizontal models; therefore, the welds were made in that position. Since these welds were proof-of-principle, it made no difference whether the welds were made in the horizontal or vertical position.

A force of 4000 psig was used at 1050 rpm to make the primary welds. This resulted in a pressure of 20,000 psi on the interface area during welding.

A force of 3300 psig, used on the secondary welds, resulted in a pressure of 20,500 psi. The speed was 855 rpm.

A primary and secondary weld can be seen in Fig. 5.

The loss of length on 14 primary welds varied from a low of 0.349 inch (8.86 mm) to a high of 0.359 inch (9.11 mm) for a total maximum variation of 0.010 inch (0.25 mm). The welded samples were returned to PNL for evaluation.

WELD EVALUATION

Because of the importance of weld integrity, the welds were evaluated using a number of testing techniques.

Five of the primary lid welds were examined by the ultrasonic NDT method. No indications of porosity or lack of fusion were found. These results were later confirmed with metallographic samples. Figure 6 is a typical weld cross section.

Four of the primary lid welds were helium leak tested to less than 2×10^{-10} standard cc/sec.

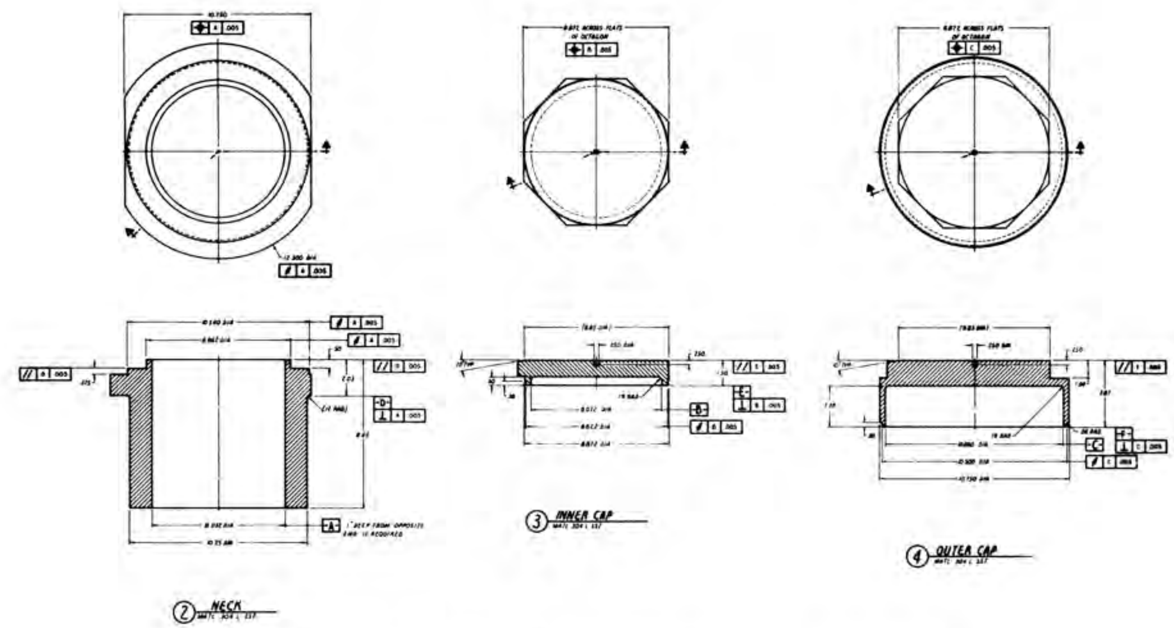

Fig. 2. Canister Top Flange & Primary and Secondary Lid Details.

Fig. 3. Machined Flange & Lids.

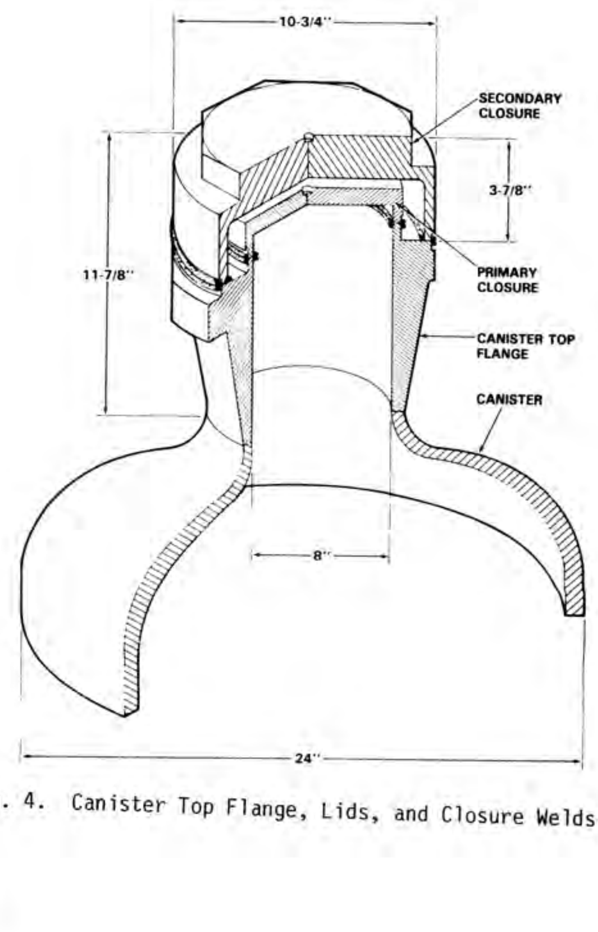

Fig. 4. Canister Top Flange, Lids, and Closure Welds.

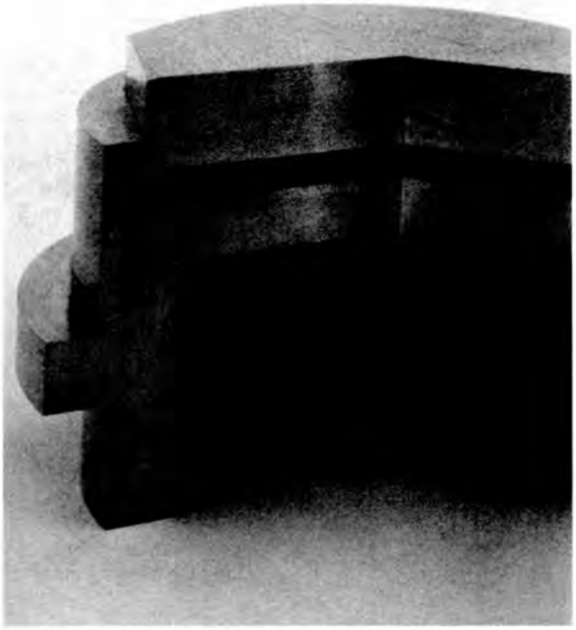

Fig. 5. Cross Section of the Canister Showing Primary and Secondary Welds

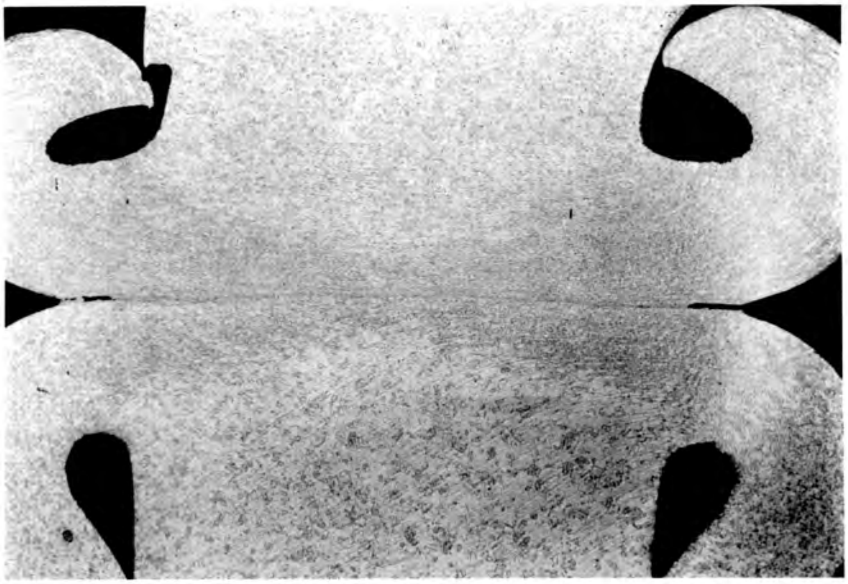

Fig. 6. Typical Weld Cross Section

Tensile samples were made from three different primary lid welds. At least three tensile tests were made on each weld. The tests were conducted in accordance with ASTM E 8-81, "Tension Testing of Metallic Materials." It was found that the weld area material is as strong as the unwelded parent material.

To determine the corrosion properties of the welds, ten samples were machined from one primary lid weld. Five samples were exposed to a test environment of refreshed tuff water at 300°F (1490°C). The water was air-sparged to ensure an abundance of oxygen. The other five samples were used as control specimens. The specimens were removed from the canister weld, machined with ground surfaces, and run in an autoclave to a total exposure of 1,944 hours. The water chemistry was continuously monitored throughout the test. The parameters used during this test (temperature and liquid used) were selected because they appeared at the time to be the most representative (or a worst case) of the environment in which the canister might be found. The appearance of the test samples after they were removed from the autoclave showed no adverse reaction.

Even though a number of different tests have been performed, impact testing to the waste repository criteria needs to be done to fully qualify the welds. This test has not been performed to date.

CONCLUSION

All of the studies and testing performed to date on the utilization of the inertia welding process to make the waste canister closure welds indicate that the process can make both primary and secondary welds of acceptable quality.

Only a small portion of the welding machine (the end of the spindle and the lid chuck) would need to be inside of the hot cell. The remainder of the machine can be accessible for contact maintenance in a separate room that is kept contamination free. The equipment would be a special design for this particular purpose, but only state-of-the-art technology would be used.

REFERENCES

1. Manufacturing Technology, Inc., "Analysis of a Vertical vs Horizontal Inertia Welding Machine," Mishawaka, Indiana (June 30, 1983).

2. Manufacturing Technology, Inc., "Study Report on Utilizing the Inertia Welding Process for Waste Canister Closures," Mishawaka, Indiana (September 30, 1983).

ACKNOWLEDGMENTS

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