The Need for a New Joining Technology for the Closure Welding of Radioactive Materials Containers - 9516

G.R. Cannell
Fluor Government Group
P.O Box 1000, Richland, WA 99352

G.J. Grant
Pacific Northwest National Laboratory
902 Battelle Blvd. Richland WA 99352

B.E. Hill
Department of Energy, Richland Operations
825 Jadwin, Richland, WA 99352

ABSTRACT

One of the activities associated with cleanup throughout the Department of Energy (DOE) complex is packaging radioactive materials into storage containers. Much of this work will be performed in high-radiation environments requiring fully remote operations, for which existing, proven systems do not currently exist. These conditions demand a process that is capable of producing acceptable (defect-free) welds on a consistent basis; the need to perform weld repair, under fully-remote operations, can be extremely costly and time consuming. Current closure-welding technologies (fusion welding) are not well suited for this application and will present risk to cleanup cost and schedule. To address this risk, Fluor and the Pacific Northwest National Laboratory (PNNL) are proposing that a new and emerging joining technology, Friction Stir Welding (FSW), be considered for this work.

FSW technology has been demonstrated in other industries (aerospace and marine) to produce near flaw-free welds on a consistent basis. FSW is judged capable of providing the needed performance for fully-remote closure welding of containers for radioactive materials for the following reasons:

- FSW is a solid-state process; material is not melted. As such, FSW does not produce the type of defects associated with fusion welding, e.g., solidification-induced porosity, cracking, and distortion due to weld shrinkage. In addition, because FSW is a lower-heat input process, material properties (mechanical, corrosion and environmental) often suffer less degradation than that seen in the heat affected zones of fusion welds. When compared to fusion processes, FSW produces extremely high weld quality.
- FSW is performed using machine-tool technology. The equipment is simple and robust and well-suited for high radiation, fully-remote operations compared to the relatively complex equipment associated with the fusion-welding processes.
- Additionally, for standard wall thicknesses of radioactive materials containers, the FSW process can perform final closure welding in a single pass (GTAW requires multiple passes) resulting in increased productivity.

The performance characteristics associated with FSW, i.e., high weld quality, simple machine-tool equipment and increased welding efficiency, suggest that this new technology should be considered for the upcoming DOE radioactive materials packaging campaigns.

FSW technology requires some development/adaptation for this application, along with approval from the governing code of construction prior to production operations. This paper addresses the need for a new joining technology, a description of the FSW process and why it may be well-suited for this application,

along several activities required for commercialization.

INTRODUCTION

Over the past five years, the U.S. Department of Energy (DOE), Richland Operations Office (DOE-RL), has completed several significant, radioactive materials packaging campaigns at the Hanford Site. Included are those for packaging Special Nuclear Materials (SNM) into some 2,000 DOE-3013 containers, packaging of Spent Nuclear Fuel (SNF) into more than 400 Multi-Canister Overpack (MCO) canisters, and overpacking of TRIGA research reactor fuel. A key element in packaging these materials was performing the final or container closure weld. Closure welding utilized the Gas Tungsten Arc Welding process (GTAW) – a fusion welding process. Operations were conducted under "semi-remote" conditions, i.e., the weld joint was accessible for equipment setup and repair (when needed), but actual welding was performed using a remote video console with cameras at the weld joint. Of the more than 400 MCO closures made, not a single weld failed an examination or test. This however, does not take into account the many "in-process" repairs (during welding operations prior to turnover to quality control) required to remove "stuck tungsten," dressing of weld beads resulting from arc wander, and other process upsets that can occur with the GTAW process. Without access to the weld joint, many of the completed closure welds would not have met the examination/test acceptance criteria. Direct access was critical to the overall success of the MCO welding campaign, as well as for the other campaigns.

Upcoming Hanford packaging campaigns will be performed in high-radiation environments and will require fully remote operations, thus making direct access to the weld joint for setup and weld repair unfeasible. These conditions will require a joining process that is capable of producing acceptable, defect-free welds on a consistent basis. Current fusion welding technologies are not well-suited for this environment/application and may present risk to project cost and schedule.

In terms of risk, the single greatest concern is that of producing an unacceptable weld and the resulting difficulty associated with evaluating, characterizing and repairing the defect(s). Significant effort, on the order of that needed to develop/qualify the original weld technique, may be required for successful repair.

Repair activities will include the following:

- Weld defect characterization
- Weld repair plan qualification, including process and equipment
- Defect removal
- Weld repair
- Weld repair examination/inspection.

In an effort to address this risk, Fluor and PNNL are proposing that a new welding technology be considered for closure of radioactive materials containers, one that has proven capable in other industries of making nearly flaw-free welds on a consistent basis. The technology is Friction Stir Welding (FSW). FSW is a solid-state process (material is not melted) and as such, is not subject to fusion-related defects, e.g., porosity, cracking and distortion, etc., all associated with weld-solidification and shrinkage. It is a low heat-input process and tends to preserve material properties (mechanical, corrosion and environmental), whereas the higher-heat fusion processes can degrade such properties. FSW is performed using simple, robust machine-tool technology making it well-suited for fully-remote, high-radiation environments.

FSW TECHNOLOGY

Scientific Principles of FSW

FSW is a revolutionary joining technology that employs severe plastic deformation processes to create solid-state joints between a wide variety of materials. FSW, invented by TWI, Ltd. (1), is now well demonstrated on aluminum alloys, and is capable of producing welds as good or better than fusion welds in terms of joint efficiency, mechanical properties, and environmental robustness. FSW weld properties, in many material systems, have been found to be improved over those produced using current fusion joining processes.

A typical FSW butt joint is depicted in Figure 1. The weld is created by clamping the materials to be joined, and plunging a spinning tool into the joint. The spinning tool is then translated down the joint line leaving behind a weld zone characterized by a fine-grained, dynamically recrystallized microstructure. Initially, friction between the tool shoulder and work surface provides heat to lower the flow stress of the base materials. A vertical load is then applied sufficient to create a plasticized region below the tool shoulder, and the tool is translated along the joint. As the tool rotates and translates, complex flow patterns develop in the base material creating an intimate mixing of materials from both sides of the weld joint. Heat input during plastic deformation generally creates a temperature in the weld between 0.6 and 0.8 of the absolute melting temperature, so no liquid phase is generated. Characteristic flow patterns are set up beneath the spinning and translating tool that are directly related to process variables such as X, Y, and Z machine forces or loads, tool rotation speed, and forward tool travel speed.

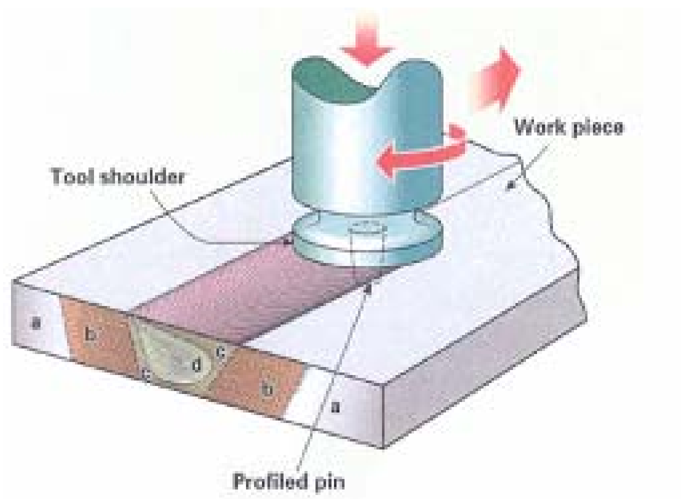

Fig. 1. Schematic of the Friction Stir Joining Process. The pin tool is rotated and translated along the joint resulting in the plasticizing of the base metals and their subsequent mechanical intermixing.

Friction Stir Welding Process Advantages

FSW technology presents several features that provide distinct advantages for closure welding of radioactive materials containers, under fully-remote operations.

- Process and Equipment Robustness

  As noted in the introduction, the single greatest risk to production closure-welding operations is that of producing an unacceptable weld and the resulting difficulty associated with repair. The ability to produce defect-free closure welds, on a consistent basis will be critical to the success of upcoming Hanford radioactive materials packaging campaigns. FSW has proven to be a high-quality joining process using standard, simple machine-tool technology. Together, these two features are expected to significantly increase confidence in meeting production operations cost and schedule.

- Weld Deposition Efficiency

  FSW welds are accomplished in a single pass. Typical radioactive materials container wall thickness is 9.5 mm. The Hanford MCO SNF canister (9.5 mm wall) required 6 – 8 passes for completion.

- Avoidance of Post-Weld Processing

  A primary concern in closure welding is long-term performance, especially with regard to the effects of corrosion and environmental degradation. Two significant advantages of FSW over fusion welding techniques, with respect to these effects, is the reduction in residual stress and improved microstructure. The former may reduce/eliminate the need for post-weld processing to relieve residual stresses and the latter reduces susceptibility to corrosion at the weld area.

- Reduced Need for Skilled and Qualified Welding Operators

  Once a qualified FSW process is established, a typical weld is initiated by starting a computer controlled sequence. At no time does the process require intervention from an operator nor is there a requirement for the operator to have specialized skills to perform the weld. The current availability of skilled fusion Welding Operators is limited, which could impact operations were conventional fusion systems to be used for closure-welding operations.

- Reduced Energy Costs

  Reduction in energy cost is realized through the single pass nature of the process, the lower temperatures required (no melting), and lack of the consumables (weld filler material) resulting in the savings of the total embedded energy costs to make the consumed materials.

- Environmental Benefit

  One of the highest impact pollutants released in the weld fumes from conventional fusion welds in 304L, is hexavalent chrome. OSHA regulation CRF 29 1910.1026, which became law in 2006, changes the permissible exposure level of hexavalent chrome from 52 micro g/m3 to 5 micro g/m3 with an “action level” at 2.5 micro g/m3. This requirement reflects the seriousness with which Cr will be controlled in the future and will be a significant cost increase to manufacturers involved in the welding of these steels. In hot cell environments, disposal of these chrome bearing vapors will complicate waste streams and could add significant cost to the project.

  FSW welding produces no measurable fumes.

COMMERCIALIZATION

The following describes several activities that will be required to prepare and qualify the FSW technology for closure-welding of radioactive materials containers, i.e., commercialization.

Process Development

Some development is needed to gain the applied technical understanding necessary to produce robust joints in 9.5 mm thick 304L stainless steel; conditions representative of radioactive materials container closure configurations. Weld microstructure, mechanical behavior of the joined materials and residual stress characterization will be required.

Welding Machine and Process Evaluation

The developed process will require evaluation using a prototypic, fully-automated FSW orbital welding machine to assess potential impact on process conditions resulting from differences between lab-grade development equipment and the orbital machine. Equipment issues, including dimensional compliance, fit-up, etc., could affect process performance and may require additional process development (tweaking). Equipment modification/improvement opportunities would be identified at this time.

Additional Considerations Preparatory to Field Deployment

Currently, commercial FSW systems for the closure of radioactive materials containers do not exist. The following activities will be required or at a minimum, should be considered in preparation of FSW technology for field deployment:

- Obtain governing code of construction acceptance and certification for the FSW process

  Radioactive materials container closure is typically performed in accordance with the American Society of Mechanical Engineers (ASME) B&PV, Section III code. ASME does not presently recognize FSW technology nor does it provide rules and practices for its use. Preparation of a code case, identifying the FSW process variables and prescribed limits necessary to ensure code design and safety function(s) can be met, for ASME consideration will be required.

- Demonstration that current, standard weld inspection and examination techniques are suitable for FSW weld quality evaluation

  The ASME code typically specifies both volumetric and surface examination, radiographic testing (RT) and liquid penetrant testing (PT), respectively, for acceptance of critical welds. Demonstration that current NDE methods, including RT and PT, are suitable for FSW weld evaluation should be performed. Sample FSW welds, typical of those for radioactive materials containers, should be prepared and evaluated for acceptability in accordance with ASME code requirements.

- Design/Development of Suitable Strategies and Techniques for the Repair of Unacceptable Welds

  As noted above, the FSW process is very robust and is expected to produce nearly flaw-free welds on a consistent basis. However, there remains the possibility that a weld will be made that does not meet acceptance criteria and will require repair. Design and development of a repair strategy(s) should be considered.

CONCLUSION / RECOMMENDATION

DOE-RL has identified a need for a new joining technology for the closure of radioactive materials containers when performed under fully remote operations. FSW technology, having been proven capable in other industries of making nearly flaw-free welds on a consistent basis, has been proposed for this application. Several activities, including process adaptation, equipment evaluation and construction code certification are either required or recommended as part of preparing FSW technology for field deployment.

It is recommended that the proposed FSW technology and activities outlined above, be considered as part of the effort to address identified DOE-RL packaging needs.

REFERENCES

1. W.M. THOMAS, E.D. NICHOLAS, J.C. NEEDHAM, M.G. MURCH, P. TIMPLESMITH, C.J. DAWES, G.B. Patent Application No. 9125978.8, December 1991; US Patent No. 5460317, October 1995.