

A weld that lasts for 100,000 years

Friction Stir Welding to seal 5 cm thick copper canisters containing Sweden's nuclear waste

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After nearly thirty years of research and development, one of the most important pieces of the puzzle has been laid in the method proposed by SKB for safe and permanent disposal of spent nuclear fuel. The technique that will be used for sealing the copper canisters is friction stir welding. SKB will present the results from the development during the DVS Grosse Schweisstechnische Tagung connected to the Schweissen & Schneiden fair in September 2005.

In 1983, SKB proposed that Sweden's high-level nuclear waste should be deposited in copper canisters at a depth of 500 metres in the Swedish bedrock – the so-called KBS 3 method. High power electron beam welding was the only viable method available at that time for welding thick section copper. In 1997, SKB started to investigate friction stir welding (FSW) as a possible joining method. The results to date, 12 years before the first canister will be sealed and disposed of in the deep repository, show that FSW is a stable and tolerant process that can repeatedly produce defect-free welds.

The barriers

The copper canister is one of the barriers in the Swedish method for final disposal of spent

nuclear fuel (Figure 1). The canister (length 5 m, diameter 1 m) containing the nuclear waste needs to remain intact for 100,000 years and a corrosion barrier of 5 cm thick copper and a cast iron insert for mechanical strength are used to meet this requirement. The 5 cm thick cylindrical body with an outer diameter of 105 cm can be produced in seamless form by extrusion, forging or the pierce and draw technique.

The canister manufacturing process requires that a bottom and a lid are sealed using a method that produces extremely high joint integrity. Two methods, FSW and electron beam welding, are being developed at SKB's Canister Laboratory in Oskarshamn. In May 2005 SKB chose FSW, due to the robustness and reliability of the process

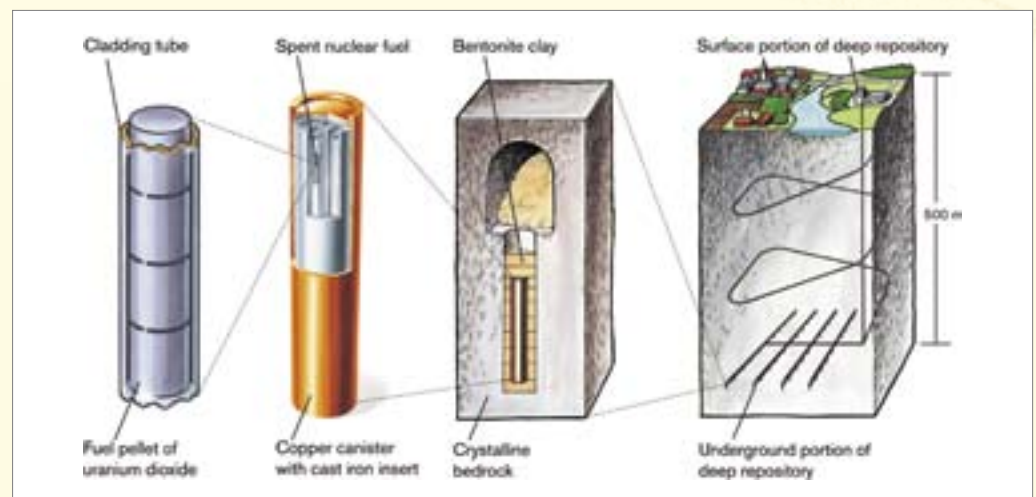


Figure 1. The barriers in the Swedish method for final disposal of spent nuclear fuel.

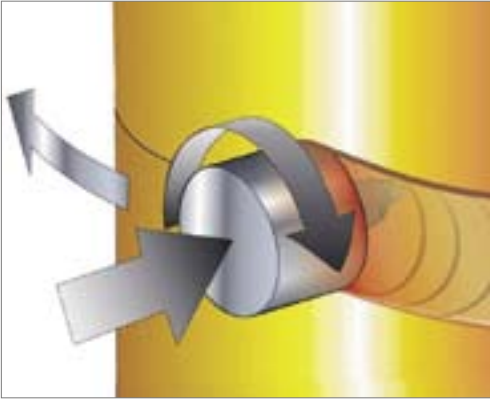


Figure 2. Scheme of the FSW-process.



Figure 3. The tool probe and shoulder.

and the machine, as the main welding method for the Encapsulation Plant application, which will be submitted to the Swedish authorities in mid-2006.

Friction Stir Welding

FSW was invented at The Welding Institute, Cambridge, UK in 1991 and is a solid-state thermo-mechanical joining process which is a combination of extruding and forging. A cylindrical, shouldered tool with a profiled probe is rotated and slowly plunged into the material. For thick sections, a pilot hole has to be drilled to



Figure 4. The welding machine at the Canister Laboratory.

make the plunge sequence possible without probe wear. Frictional heat is generated between the wear-resistant tool shoulder and the material, causing the material to soften without reaching the melting point, and allowing the tool to traverse the joint line (Figure 2).

Due to the high welding temperature (up to 900°C), the high welding forces and the duration of the weld cycle (up to 1 hour), the requirements on the tool (Figure 3) are rigorous when welding 5 cm thick copper canisters. Currently, the nickel-based superalloy, Nimonic 105, and the sintered tungsten alloy, Densimet, are used as probe and shoulder material, respectively. The welding temperature is measured using a thermocouple inside the tool probe which gives an excellent indication of the state of the process. Currently, this temperature has to be restricted in order to protect the tool probe.

The welding machine

In order to develop a full-scale welding process, SKB ordered a purpose-built machine (Figure 4) from ESAB, in January 2002, that was commissioned at the Canister Laboratory in April 2003. The welding head on the machine rotates up to 425°, while the canister is clamped with 3,200 kN and the lid pressed down with 400 kN. The machine has a maximum capacity of 110 kW,

which makes it one of the most powerful welding machines in the world. However, in order to control the heat input, only 40 kW is used. The machine automatically keeps the welding temperature constant throughout a weld cycle by controlling the heat generation. Other advantages include:

- Ability to adjust all process parameters during welding excluding tool angle.
- Facility to automatically accelerate to the steady-state welding speed as a function of the welding temperature.
- Facility to start and park above the joint line.

Weld cycle

The pilot hole is drilled 75 mm above the joint line in order to eliminate the risk of defect formation at the joint line. In addition, no overlap region to remove possible start defects is needed and consistent weld microstructure, resulting from steady state welding conditions, will be present at the joint line. The start sequence could also be aborted if it does not converge towards a stable process. A new pilot hole could then be made and the weld could be started again and completed without rejecting the canister or the lid. After the start sequence the tool is moved downwards to the joint line at a specified angle and at the steady-state welding



Figure 5. The start sequence and the exit hole above the joint line.

speed (Figure 5). At the joint line, welding conditions are kept constant for process stability and reproducibility. After 360° of steady-state joint line welding, the tool is moved upward 75 mm to a position where the exit hole will be machined away when the canister is machined to its final dimensions (Figure 5).

Non-destructive testing

Two methods are currently being developed and evaluated at the Canister Laboratory.

Radiographic inspection is performed by a digital X-ray system with 60 times the power of medical diagnostic X-ray. The radiographic testing method will find volumetric flaws but has limited sensitivity for non-volumetric flaws.

Figure 6. Parking of the tool during the bottom weld of a full size canister.



For ultrasonic testing of FSW, SKB use the phased array technique. Ultrasonic inspection is a more suitable method than X-ray inspection for the detection of non-volumetric flaws.

Welding results

After 48 lid welds at the Canister Laboratory, the process can be summarized as being robust and stable, but not fully automated. Despite this limitation, the welds are made with excellent repeatability and reliability, since the parameter windows are relatively large.

An important milestone was reached in May 2004 when a complete full size canister with a cast iron insert was sealed (Figure 6). No defect indications except deflection of the joint line were found in the bottom weld and the lid weld.

Another milestone was reached, in January 2005, when a series of 20 lid welds was completed in production-like forms. The series demonstrated that the process and the machine are reliable and feasible for production.

In addition to non-destructive testing, various destructive testing methods are carried out to assess the long-term properties of the welds. The welds show similar properties to the base metal in tensile, creep and corrosion tests.

The excellent properties of the welds derive from the fact that FSW is a solid-state welding process that produces a fine grained microstructure.

Summary

The results from the lid welds at the Canister Laboratory show that FSW can be used to seal 5 cm thick copper canisters with repeated production of high integrity joints.

Future work will focus on developing a fully automated weld cycle to minimize the human factor, and to satisfy SKB's quality requirements regarding rejected canisters - less than 1 in a 100 - and to support the Encapsulation Plant application.

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LARS CEDERQVIST, MSc., DEVELOPED FSW LAP JOINTS UNDER A NASA CONTRACT AT UNIVERSITY OF SOUTH CAROLINA FOR TWO YEARS, THEN IMPLEMENTED FSW ON THE ECLIPSE 500 JET AT MTS SYSTEMS CORP., BEFORE JOINING SKB IN 2002 AS PROJECT MANAGER AND DEVELOPMENT ENGINEER FOR FSW IN THE ENCAPSULATION TECHNOLOGY GROUP.

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