**ABSTRACT**

The Finnish disposal solution is based on packing of the spent nuclear fuel in copper-nodular iron canisters in the encapsulation plant, and on the isolation of canisters deep underground into repository tunnels surrounded by bentonite clay in the bedrock at Olkiluoto. The internal canister of nodular cast iron will withstand the mechanical stress acting on the canister in the bedrock. The external copper canister tightly encloses the internal nodular cast iron canister, and protects it from the corrosive influence of groundwater.

Posiva Oy is an expert organization responsible for the final disposal of spent nuclear fuel of the owners; Teollisuuden Voima Oyj (TVO) and Fortum Power and Heat Oy (Fortum). Posiva is responsible for the research targeted into the final disposal and for the construction, operation and eventual decommissioning and dismantling of the final disposal facility. Fortum Nuclear Services (FNS) is nuclear engineering company. In this case, FNS is supporting Posiva by delivering and manufacturing reference specimens for copper components and electro beam (EB) weld.

Copper material is a new challenge for NDE. Investigation of inspection methods was needed for optimising a proper manufacturing testing of copper components and EB weld of the lid to the canister. Reference specimens are used for NDE investigation and testing trials of pre-fabricated components and welds. Reflectors of reference specimens are used for calibration of inspection systems, for simulation of fabrication flaws, for demonstration and optimisation of inspection capability of different inspection systems for detection and sizing of different flaw types. The basic ideas for reference specimens, reflector design and fabrication methods are described in the paper.

The real size components are used as reference specimens. Pre-trials were utilised for fabrication of narrow electrodes and optimising of sparking parameters for copper to minimise the wear of electrode. Special arrangements and tools were needed to handle large and heavy test specimens and fabricate unusual reflectors and directions for machining and EDM. The population of the reflectors of reference specimens were designed together with Posiva and inspection specialists. The role of reflectors of reference specimens for NDE investigation and testing are presented in the paper.

The NDE investigations of Posiva are targeted to testing of manufactured components and welds. The final aim is to qualify the inspection systems for manufacturing inspections for copper components and EB weld following the ENIQ Methodology, Recommendations and Finnish qualification rules. The input information for qualification of manufacturing inspections is collected and the drafts of inspection procedures are written based on the inspection trials of pre-fabricated components. An expert team supports Posiva to proceed toward the qualification.
INTRODUCTION

In the Finnish disposal solution the spent nuclear fuel canisters are sealed with electron beam welding in the encapsulation plant, and on the isolation of canisters deep underground into repository tunnels surrounded by bentonite clay in the bedrock at Olkiluoto, see Figure 1.

The nodular cast iron insert will withstand the mechanical stress acting on the canister in the bedrock. The external copper canister tightly encloses the internal nodular cast iron insert, and protects it from the corrosive influence of groundwater, see Figure 2.

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The designed reference specimen will be used also in case of qualification and information provided will be used for technical justification like improving and justifying inspection techniques. The specimen reference content is designed so that they will fulfil the requirements of qualification needs. But this will be checked of course by the qualification body according to the recommendations of ENIQ /1, 2/ and Finnish qualification practices /3, 4/. The reference specimen should contain all relevant aspects consideration the inspection sets for qualification.

Figure 1 - Repository layout and vertical positioning of canisters in the repository.

Figure 2 - Structure of spent nuclear fuel canister
STATUS OF THE INSPECTIONS FOR COPPER COMPONENTS AND EBW WELD

Posiva is investigating the usage of ET, UT, VT methods for copper tube and copper lid. EBW weld of copper tube to lid is tested with ET, UT, RT and VT methods. Reference specimens and artificial defects are needed for those NDT activities.

Copper material is a new challenge for NDT. Investigation of above mentioned inspection methods are going on for working out their basic capabilities for detection and sizing of typical defects of copper components.

Development of inspection technology of UT, ET, VT and RT methods were needed to improve detection and sizing capability. The final goal is to qualify the manufacturing inspection systems according to ENIQ Methodology, Recommended Practices and Finnish qualification rules for disposal of spent nuclear fuel.

Method specific inspection studies are going on and partly realized with pre-fabrication components, welds and reference specimens and their defects. Those studies will be used as evidence documentation for qualification and for preparing method specific POD curves.

Posiva is collecting input data for qualification and defining the acceptance criteria for copper components and EBW weld. Posiva will define the proper inspection methods and techniques and their combination for each copper component and weld. The pre-qualification is targeted to carry out in 2012 and final qualification in 2017. The commissioning of the encapsulation plant will start in 2019 and operation in 2020.

REFERENCE DEFECTS

During manufacturing in the components there will be generated defects depending on the manufacturing process and component. The main idea to develop reference specimen is to simulate the similar defects as can be produced in the manufacturing. This has been realized in different cases for copper reference specimen - copper lid, copper tube and copper weld.

For each NDT methods have to be found similarity for response of used defect type. For radiography the intensity variations coming different possibilities like geometrical changes, generated defect in the welding process, beam divergence are coming from possible presence of defects. In ultrasonic testing the acoustic response reacts to phase, amplitude or frequency changes. Likewise have to take into account also geometry of material, focus point, probe active element size, wave mode, material properties etc. These effects have to be taken into account in the design of reference defects similarly like defect types originated from the manufacturing. For eddy current testing, the electrical and magnetic properties of material as well the defect effect on these properties. The probe positions versus defect positions in the material - defect near the corner for instance, are important.

![EDM arrangements inside the copper tube specimen](image)
REFERENCE SPECIMENS OF COPPER COMPONENTS AND EBW WELD

Reference specimens are used for NDT investigations and testing trials of pre-fabricated components and welds. Reference defects of specimens are used for calibration of inspection systems, for simulation of fabrication flaws, for demonstration and optimisation of inspection capability of different inspection systems for detection and sizing of typical flaw types. One of these different inspection systems used for copper components and EB-weld inspection - eddy current application is reported in presentation /5/.

The basic idea is to use full size components as reference specimens to allow flexible applications and space for later, additional reference defects, if needed. The reference defects are designed together with Posiva and inspection companies participating in inspections. Axial and circumferential EDM notches (narrow notches, V-grooves) with depth variation and axial planar flaw simulations are typically used for copper tube, in addition to reference defects simulating manufacturing defects of copper tube. Large and heavy reference specimens need careful lifting and proper handling devices, see Figure 3.

Figure 4 - EDM arrangements outside the copper tube specimen

Figure 5 - Machining of SDH and FBH into copper tube specimen
Fabrication of reference defects into copper tube

Copper tube was the first reference specimen delivered by FNS to Posiva. EDM pre-trials were utilised for fabrication of narrow electrodes and optimising of sparkling parameters for copper to minimise the wear of electrode. The basic problems were: How to manufacture electrodes from copper wolfram? How to minimize the wear of electrodes? How to finish the EDM notches to wanted shape? How to control and report the real depth of reference defect? Copper material was found soft and many shallow surface damages were present after EDM and machining of reference defects.

Special arrangements and tools were needed to position large and heavy test specimens and fabricate unusual defect types and directions for machining and EDM. The pool of EDM machine cannot be used and so the reference specimen is used as a pool. The circuit has to be wired up separately on the specimen like in Figures 3-4. The vertical sparkling movement is produced by EDM machine by using stable arms on the specimen, see Figure 4. Vibration of sparkling arm shall be obstructed. Deep notches are difficult, when electrode corners will wear round or oblique shape. Electrode can be finished to straight shape and with that finish the bottom of EDM machining, but positioning of electrode into earlier position is difficult. In many cases, the mouth of notch will slightly widen.

Machining other type of defects than EDM-defects is used for basic reference defects (SDH, FBH). The copper tube contains totally 61 defects. Machining of soft copper material is rather easy. The large diameter creates some limitations for facilities and machining device, see Figure 5. Finished reference specimen has been tested in tube inspection manipulator called Rotator at SKB in Oskarshamn Sweden, see Figure 6. This tube specimen is used for ET and UT inspection studies, for calibration of sensitivity level and optimisation of both techniques.

One example of the inspection results of specific type is ET studies with low frequency ET probe shown in Figure 7. The sizing capability of low frequency coils will be studied with help of this specimen among other parametric studies.
Figure 7 - ET results of LF probe

Figure 8 - Defect sets of copper lid

Figure 9 - EDM machining of notches into counter bore of copper lid
Fabrication of EDM defects into copper lid

Full size copper lid was selected for reference specimen. Population of defects includes 79 narrow notches, 22 wide V-shape notches, 45 FBH and 6 SDH, totally 152 defects for ET and UT applications and trials. Positions of defects are presented in Figure 8. The fabrication of defect set was difficult because of the size of the specimen and the defects were machined to all surfaces of the lid specimen. But the shape of geometry of lid offered also some help for manufacturing of EDM defects as shown in Figure 9. Still special arrangements were needed for machining and EDM defects in counter bore area, and especially in upper corner as inclined, see Figure 9. This copper lid reference specimen was designed for upper outer surface eddy current inspection and similarly for ultrasonic testing, because at the encapsulation plant there are no possibility to inspect from inside. All possible methods have to be developed for this type of inspection.

NDT inspections of manufacturing trials and pre-manufactured copper lids are carried out on turn table of Posiva with ET and UT techniques, see Figure 10.

Figure 10 - Turn table of Posiva and UT scanning of copper lid

Figure 11 - Reference specimens for ET and UT methods

Figure 12 - Results of UT measurements of reference specimens shown in Figure 11
Fabrication of reference specimens for EBW weld of copper canister

Segments of EBW test welds are used as reference specimens for UT, ET inspections for trials and calibration of inspections, see Figure 11. An example of UT trial from outer circumference of reference specimens set together is presented in Figure 12. The main reference defect for UT has been used FBH φ3 mm. Reference defects has been manufactured in front, in the middle and in the back of the weld. This is because the attenuation effect in the weld is very large, but in any case it is possible even to see defects through the weld, if the signal to noise ratio is good enough. The attenuation has been measured to be about 10 dB compared to reference defect in the front of weld and in the back of weld, which means attenuation of about 1 dB/mm. This rate of attenuation is very high. For ET inspection calibration will be used the surface notches along and perpendicular to the weld. For RT inspection, reference specimen has been reported in presentation /6/.

Fabrication of reference specimens for parametric studies of ET inspections of EB/FS- weld and other copper components

One defect type detected in inspection of EB-weld trials was lack of fusion defect, formed in horse shoe shape, caused by welding process due to impurities in joint surfaces as shown in Figure 13. At the beginning of trial, this type of defect was not foreseen. Because of that defect type, the low frequency ET technique and same type of sizing technique for that defect type as well as other types of surface and subsurface defects was developed. Also typical defect types for eddy current inspection calibration and sensitivity setting was manufactured, like notches and holes. Notches simulate planar defect types and holes more volumetric defect types. One difficulty in designing of those plate reference specimens was the distance of defects from each other. This is because ET low frequency technique is detecting defects already at about 30-35 mm distance. This was one cause for new design of the probe for inspection.

Figure 13 - Plate specimen with horse shoe defects and ET results with LF probe
Visual inspection plays an important role when checking the final state of EBW weld and canisters before moving them into repository tunnels and into gave hole. Visual testing trials were carried out to discover the difficulties and capabilities of remote testing with cameras. Radiation tolerant color camera (Ahlberg) and black and white tube camera (Diakont) were selected for trials.

View angles, distances and light conditions are important due to reflections. Reference defects of specimens and test welds were used for trials. Horse shoe shaped defects are difficult to detect because the machining will close the opening of those defects. The inspection arrangements of test weld using color camera are shown in Figure 14.

Reference specimen for visual testing is designed and it will be manufactured during 2009. This reference specimen will be used mainly for POD-purposes.

CONCLUSIONS AND FUTURE ACTIONS

The final aim is to qualify the inspection systems for manufacturing inspections for copper components and EBW weld following the ENIQ Methodology, Recommendations and Finnish qualification rules. The input information for qualification of manufacturing inspections will be collected and the inspection procedures will be written based on the inspection trials of pre-fabricated components. An expert team supports Posiva to proceed toward the qualification.

Combination of inspection methods is necessary for industrial inspection of copper components and EBW weld because of material effect on inspections. Reference specimens are important for NDE investigations, testing trials, capability studies and for qualification activities. EDM machining of defects in copper material is challenging and it has been used successfully in this study.

Future action are manufacturing of calibration charts and full size weld specimen for resolution piece for remote VT inspections with camera. Additional small size defects will be manufactured into reference specimens for capability studies and defining POD curves for ET, UT and RT inspection methods.
REFERENCES


4) Inspecta Certification, 2006, Practical trials SP - 7, revision 0, 17.01.2006, The Finnish Qualification Practice for nuclear power plant inspections, 7p + 4 appendices.
