UTILITY ASPECT OF APPLICABILITY OF DIFFERENT FLAW TYPES FOR QUALIFICATION TEST PIECES

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ABSTRACT

The objective is to give the utility perspective for the basis of selection and fabrication of realistic flaws for different qualification cases. Good knowledge about the applicability of flaw types for different purposes is important. National project has been carried out for getting information of essential crack features considering ultrasonic response and finally defining the metallographic features of fabricated cracks.

Fortum Nuclear Services is an expert organization supporting Loviisa NPP. Trueflaw is an advanced crack manufacturer. Wide experience of VVER components and the knowledge of component failures, failure mechanisms, defect morphology, manufacturing technology and welding give good background also for design and fabrication of test pieces with representative flaw population of realistic flaws. The basic ideas for flaw design and selection of crack and flaw fabrication methods are described in the paper.

The key issue of reliable ISI inspections at Loviisa NPP is to select the potential failure areas for inspection program and to detect cracks in early stage, before they grow to critical size during an inspection interval. Compilation of comprehensive and technically sound input data for the qualification cases is one of the key issues of the utility organizations, and the best way to guarantee conditions for successful qualification, and fabrication of test pieces with proper flaws. The main objective of test piece design is to use test pieces with several cracks, weighing benefits and disadvantages of different crack types for each qualification case.

Utility experience and views are discussed and conclusions are drawn based on results of qualification cases and current national project about the applicability of different crack production techniques, realistic simulation of studied crack types and NDE results.

INTRODUCTION

Council of State of Finland has recently granted for both VVER-440 units of Loviisa Power Plant an operating license for additional 20 years, totally for 50 years operation. Extension of operation life is essentially based on assessments of plant life management (PLIM) program, and analysis and development of identified degradation phenomenon of components and structures.

The material research program of Fortum is tightly connected and targeted to support licensing and plant life management process of Loviisa NPP. The purpose of material R&D program, managed by Fortum Nuclear Services (FNS) is to produce the material knowledge for recognition of degradation issues in time, and create technical preparedness for application of methods and knowledge needed for safety assessments and trouble-free operation of Loviisa NPP.

Reliable ISI has an important role in confirmation of structural integrity of components and piping. Compilation of the RI-ISI programs for Loviisa NPP is the new requirement of Finnish Authority. The selection of risky areas into the ISI program would reduce the total risk. The qualification of inspection systems and inspection personnel is needed for reliable performance of ISI program.

One subtask of the material R&D program is to create preparedness for manufacturing test pieces with relevant cracks and reflectors needed for different qualification cases of Loviisa NPP. The co-operation with Trueflaw Ltd. strengthens and completes the capabilities of FNS for test piece and flaw manufacturing, and vice versa.

Test piece fabrication and trials for qualification of UT inspection systems started in 1996 at Loviisa NPP. The qualification rules were established in 2000 and the roles of participants were defined to follow the qualification requirements of guide 3.8 of the Finnish Authority /1/ and the ENIQ Methodology /2/.

Inspecta Certification is independent and permanent member of qualification body in Finland using case by case nominated, outside expert members /3/. The Authority approves the input data for qualification and all the qualification activities are delegated to the qualification body (QB). The Authority supervises the activity of QB.

Training of UT personnel for detection of stress corrosion cracking started in the middle of 80's, when this cracking phenomenon was identified. Additional training of UT personnel for crack detection was the requirement of the Finnish Authority. In the beginning of 90's, test pieces with service induced cracks were rented from Sweden for practical training, and unofficial qualification tests started. Most of the blind and open test pieces with crack simulations, used for personnel training and qualification in Finland today, are produced by FNS together with Trueflaw.

Training today includes theoretical training for using proper inspection techniques and practical training for flaw detection of typical crack types using test pieces with crack simulations. The official personnel qualification started in 1997 using blind test pieces with crack simulations. Pilot qualification for flaw sizing was organized in 2000. Inspecta Certification as an independent organization is responsible for the qualification of NDE personnel in Finland.

DESIGN BASIS FOR SELECTION OF FLAW POPULATION AND FLAW TYPES

National qualification rules in Finland define guidelines for test piece fabrication for open and blind trials describing the amount and sizes of defects needed /3/. The input data for qualification case with detection target and defect types to be detected shall be considered when selecting defect types and sizes for test pieces. Exact rules are not given so far for the defect types to be applied simulating different degradation mechanisms defined in input data for qualification. Common documentation requirements for test pieces and flaws are now given in revised national qualification rules.

The Supplements of mandatory Appendix VIII of ASME Code Section XI are relevant regulation for design of flaw size and type population for the test pieces for different qualification cases and applications. Clear rules are given in those Supplements for the amount of different types of cracks and size distribution in flaw population that should be present in test pieces, and how other type of reflectors can be used.

Fabrication of test pieces and flaws is executed in Finland with financing of the utility. New open test pieces for qualification cases of Loviisa NPP are designed together with QB and FNS, taking into account the needs of Inspection Company and the Utility. With respect to blind test pieces, the Utility doesn’t know the details of flaw sizes, types and amount to be fabricated. This will guarantee the confidentiality and independency of QB for executing qualification without influence of the Utility.

For blind test pieces, QB and FNS will design the flaw size population together. In many cases FNS will propose the flaw simulations to be applied, and the design is reviewed together before its approval by QB. Flaw manufacturing can be audited by QB.

EXPERIENCE OF DESIGN AND MANUFACTURING OF TEST PIECES AND FLAWS

From flaw manufacturing perspective, the most crucial aspect is the condition of test piece. Producing flaws in the finished test piece is the most limiting case concerning the possibilities to apply different crack simulation methods. The easiest case is to fabricate a new test piece and to utilize all relevant crack and reflector simulations.

Features and applications of crack simulations of some degradation mechanisms and reflectors simulating welding defects and planar defects are described below based on experience gained from trials and qualifications of inspection systems.

Thermally produced cracks

Thermally produced cracks are initiated and grown with heating and cooling cycling without any initiator on surface. Thermal fatigue crack production will not change the structure of material, and cracking will follow the weakest path in material.

The advanced crack producing technique of Trueflaw is beneficial to certain qualification cases. The best advantage is the possibility to produce cracks into finished test piece without any disturbing effects on NDE response. One additional benefit is the capability to manipulate crack opening along the crack face on purpose, if needed.

Typical application cases are the cracks of base material and corners (simulating fatigue cracks) and cracks further from weld toe (simulating crack location of stress corrosion cracking), cracks transverse to weld and cracks for ET and VT applications. Thermal fatigue crack is applied to qualification cases in ferritic steel, austenitic stainless steel and Inconel base materials and welds, buttering and cladding. Thermal fatigue cracks are postulated crack type in many qualification cases of piping at Loviisa NPP. Experience gained from qualification cases shows that these cracks are suitable.

Mechanically produced crack simulation

Mechanically produced crack simulations are produced using welded aid piece and manually cycled with bending the aid piece up to fracture, to create crack surface on weld groove. The shape of crack front is finished on aid piece before welding the fracture surfaces together. Crack simulation can be tilted, skewed and fabricated to defined size.

Crack simulation can be produced in different materials and boundaries as surface and subsurface cracks. Typically crack surfaces are rather rough and crack tips can be fitted tight, but crack opening on surface is often more open. Mechanically produced crack simulations are most convenient to a new test piece to be welded, or to finished test pieces with small crack sizes. Fatigue cracks are the postulated crack type in the most qualification cases of Loviisa NPP. Experience of qualification cases shows that these simulated cracks are working.

Welded solidification cracks

Solidification cracks are produced into narrow opening by welding with proper filler material to produce mixing of melt, sensitive for cracking. Solidification crack has blunt tip and it’s typically located in the middle of welded pass. Crack opening is wide in austenitic, narrower in Inconel and quite narrow in ferritic weld. Crack can be straight, winding or tortuous and have interruptions in longitudinal and depth direction.

The first trials and applications were executed at the end of 90’s into root surface of thick walled butt weld of piping by opening the finished root and by welding the solidification crack. In those applications, the dendrite structure of welded opening with crack is opposite compared to weld structure around the opening. This metallographic difference may be detectable in test piece with UT examination.

UT examination of RPV cladding of Loviisa NPP in 2002 was one qualification case when solidification cracks have been applied in test pieces. Solidification cracks were welded into strip welded cladding as surface cracks with crack front shape and as subsurface cracks with elliptical shape. Before the commissioning of Loviisa unit 2, real solidification cracks were found in cladding as connected to slag lines, located in corner between weld beads, in the overlay layer welded on slag line (due to delayed solidification caused by slag line). Thin ligaments above cracks were broken when cladding was stressed (during pressure tests).

Subsurface solidification cracks were applied in 2006 in test pieces of thick walled primary collector weld of a steam generator to simulate hot cracks in the weld volume. Deep openings into collector weld were machined and grinded from outside surface. Welded solidification cracks were produced into weld volume with same dendrite direction structure as in SAW weld of primary collector. Real subsurface hot cracks were detected in the volume of primary collector welds of steam generators during outage in 1980. Hot cracks were repaired in the upper weld and left in the lower weld of primary collector to be re-inspected with UT examination.

Welding trials and real applications in Inconel buttering and weld started in 2006. Cracking of buttering and weld was simulated with solidification cracks. Short, deep transverse cracks in wide buttering were difficult to control on the bottom of opening, but both surface and subsurface cracks were produced. Feedback is not given whether the crack behavior resembles the service induced crack, whether the opening edge will be revealed or disturb detection and sizing of the crack.

Circular, subsurface solidification cracks were produced into weld volume of Inconel test pieces in 2006 and 2007. The test piece with circular cracks will be inspected later this year. The influence of the direction of dendrite structure in Inconel weld will be found out. Development work will be continued in this field.

Welding trials and real applications in ferritic base material and welds started in 2006. Two cracks in ferritic base material were also included into the national "Crack opening project" for getting feedback from UT response. Many applications can be seen for this kind of crack production in ferritic materials and welds. Underclad cracks, cracks near the buttering boundary and cracks in ferritic welds will be the application areas. Development work will be continued in this field.

Simulation of planar defects

Lack of fusion defects (LOF) are defined as specific defect type in many qualification cases of Loviisa NPP. LOF defect can be simulated by welding aid piece on weld groove with tilted orientation or between weld beads when a new test piece has to be manufactured (see NESC III /4/), or in the finished test pieces by opening weld area, fitting and welding aid piece and filling the opening carefully. LOF defect can be actually very tight and not detectable with x-ray. Aid piece can be welded partly transparent to ultrasound, if needed.

Other an aid piece application is to simulate cracks by finishing aid pieces to shape of crack front, simulating surface crack or to elliptical shape of subsurface cracks, and by welding surfaces tightly together.

Deep planar crack simulation with tilt and skew can be produced, especially in cases when accurate location on boundaries of buttering and cladding is needed. Large planar reflectors are suitable application case. Surface roughness and the opening between surfaces can be varied, if needed. Typical applications are ferritic and austenitic welds, dissimilar welds, buttering and cladding boundaries and positions between buttering and cladding layers simulating LOF defects and cracks in qualification cases. Reflectors are simulating quite effectively the real defects, partly being the worst cases for qualification.

EDM reflectors

EDM reflectors can be adapted in cases of finished test pieces as additional surface and subsurface reflectors, when exact positions, orientations and depth sizes are needed.

Narrow notches can simulate LOF defects and also cracks with electrodes having crack front shape. Notches of PISC type A are no longer used due to wide opening and round reflecting surfaces (the last application was in the late 90's).

Notches can be easily tilted and skewed, accurately positioned and produced to defined sizes. Shape and size of notch can be documented with replicas and by preserving the electrode used for finishing the notch. Even heavy and large size test pieces are possible for EDM production with special arrangements using proper equipment and skilled partner.

Notches are used in base material, transverse to weld defects and dissimilar welds in some qualification cases of Loviisa NPP to complete the flaw population in addition to cracks.

RECENT DEVELOPMENT WORK FOR QUALIFICATION

Needs for qualification test pieces with relevant cracks and new application areas are considered annually. R&D project plan for crack development work includes crack trials needed for producing the pieces for actual and future qualification cases. Flexible planning enables crack trials, checking of NDE response and control of crack sizes with destructive test by using simplified test pieces.

National crack opening project 2006-2007

This project started from feedback of difficulties with sizing. The idea was to manufacture cracks with different crack openings using thermally and mechanically produced cracks and welded solidification cracks. The aim was to adapt the qualified ultrasonic inspection procedures (manual and phased array) for sizing of cracks. Also other sizing techniques were used.

The targets of national "Crack opening project" realized during 2006-2007 were to get

- real data about UT response versus crack opening
- information about crack opening values critical for sizing
- evidence of sizing accuracy of crack simulations
- information about features of crack simulations
- experience from destructive examination of cracks using comprehensive reporting of cracks according to SKI recommendations /5/
- feedback for fabrication of crack simulations
- certification for flaw manufacturing

Project is a good example of flexible co-operation in Finland, when each participant is ready to use their resources into the same useful target. The summary report of the project will be finalized together with FNS, Trueflaw and Inspecta Certification (QB).

Development work for Loviisa NPP specific applications ongoing

Development work of FNS is concentrated in 2007 to widen the fabrication capacity and on training for producing deep fatigue cracks for qualification of sizing with phased array technique. Welding of solidification cracks into deep and narrow openings has been developed for Inconel weld and also for non-nuclear application.

Producing cracks to buttering interface in ferritic material has been the main development task together with Trueflaw. The purpose is to manufacture test blocks for flange of control rod drive nozzle in reactor pressure vessel head and for dissimilar weld of steam generator.

DISCUSSION

Development work for producing different types of cracks in different types of materials and test pieces has given experience how to apply different flaw manufacturing processes. Natural cracks are rare at Loviisa NPP and test pieces with field cracks are not available, therefore test pieces with crack simulations are needed.

The Utility is responsible to manufacture test pieces with flaws. Design of the test pieces for qualification cases of Loviisa NPP is carried out by QB and FNS together. Opinions and needs of Inspection Company and Utility are considered in case of open test pieces. No information of flaw population of blind test pieces is given to the Utility and Inspection Company. This will guarantee the confidentiality and independency of QB for executing qualification without influence of the Utility.

One important duty of QB is to execute the fingerprint examination of the flaws to confirm the relevance of crack and flaw simulations for qualification case and confirm their sizes. QB will fingerprint the flaws with phased array UT examination and in many cases collect the inspection data for qualification of data analysts.

Feedback from fingerprint examination and qualification trials to flaw manufacturers has been minor so far in Finland. One way to improve crack simulations is to give the chance to see the NDE response of fingerprint examination and assess all the details of scanned data together with QB, and also later to hear all feedback gained from qualification.

In many qualification cases of Loviisa NPP, it was expected that Inspection Company has experience and evidence from cracks - unfortunately minor information has been available. In Finnish approach, the most effort has put to produce relevant blind test pieces. During blind trials, difficulties have been faced in many qualifications - proposed inspection technique has not been able to detect, characterize and size the cracks properly.

National rules and ENIQ Recommendations contain check lists of QB for review of content of procedures and technical justification and for supervision of practical trials. Those check lists are tools for review - just filling the lists is not the main thing. The main task of QB is to get confidence and clear evidence, that the inspection system proposed by the Inspection Company will detect the defined flaws reliably and all the qualification targets are achieved.

The national project "Crack opening project" was realized with thermal fatigue cracks and with crack simulations. Thermal fatigue cracks were produced with the controlled process like in the real test pieces. The crack simulations in the project were produced with variation of details in manufacturing work to get feedback from destructive testing for further improvement work and to see the UT response.

CONCLUSIONS

Theoretical and practical training and qualification of NDE personnel with cracks is the most effective way to improve the reliability of ISI inspections. Personnel qualifications and national trials have shown that the knowledge of NDE personnel about the features of the cracks should still be improved. With better understanding of cracks, the detection and sizing will be improved.

The Qualification Bodies have an important mandate when taking care of qualifications. QB should review the inspection system and assess the capabilities of the proposed technique. When problems are faced during practical trials, QB should react fast and demand the improvement of inspection technique. Otherwise the ISI might be utilized with unsatisfactory performance and purpose of the qualified and reliable ISI would be ruined, and investments on safety would be useless.

More attention is needed for open test pieces. The real improvement can be achieved only when the Inspection Company can test the capability of inspection system and optimize the inspection technique by using relevant cracks and reflectors of open test pieces.

The effective way for the manufacturer to improve crack simulations would be the chance to see the NDE response and results of fingerprint examination of QB and assess all the details of scanned data together with QB. Also the feedback from qualification should be reviewed together with QB to get all the feedback from the cracks used for qualification.

The targets of national crack opening project have been achieved. Real data for evidence and decision making for future has been received. Destructive testing of cracks is reported using recommendations /5/ and preparedness for future investigations of cracks has been achieved. Thermally produced cracking by Trueflaw was certified by QB. Advanced crack opening measurement program was also created by Trueflaw. The same software would be used for crack documentation and to scan crack features from representative old failure analyses.

Crack features of representative service induced cracks should be analyzed and measured from earlier failure reports to increase knowledge and to be able to improve crack production and simulate field cracks better in test pieces. New failure reports should include all the necessary information, needed for qualification activities.

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