Development of reconstitution technique and testing of reconstituted bending bars in hot cell

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Abstract

NRG has been performing research in the field of long term operation (LTO) of current light water reactor pressure vessels (RPV). The shift in transition temperature of RPV steel, determined by fracture mechanics master curve testing on surveillance specimens, is important to make predictions about the RPV lifetime. The available surveillance specimens are often very limited and re-use of the broken specimens is warranted to generate the required data for LTO. Therefore, an in-cell reconstitution test setup according to ASTM E1253 has been developed at NRG, which enables fabrication of multiple new test specimens from the broken pieces of a tested surveillance specimen. In parallel, an in-cell three point bending test setup has been developed to be able to perform K_{IC}, J_{IC} and master curve testing according to ASTM standards. This paper describes the development of both reconstitution setup and a three point bending setup and illustrates various tools required for realization of these test setups for hot cell use.

1. Introduction

The integrity of the reactor pressure vessel (RPV) is of extreme importance for the safe operation of the nuclear power plants (NPPs). For the current operating NPPs, surveillance programs are used to monitor and predict the material degradation behaviour of RPVs under irradiation. For life time extension of some current nuclear power plants, practically no original surveillance samples remain unused, while there are usually large quantities of broken specimens kept in archive. Reconstitution of full-size Charpy specimens is a widely used technique to execute the reactor pressure vessel surveillance testing programs, in particular for long term operation of LWRs. Reconstitution is a technique which constructs full size testing sample by attaching additional material (studs) to the material of interest (insert material, normally broken specimens from surveillance program) using welding techniques (Figure 2). It is important that the material properties of the insert material is not altered by the welding process.

The ASTM standard Guide E1253-13 [1] provides guidelines to reconstitute an irradiated broken Charpy impact specimen. The underlying principles of ASTM E1253 are:

- No deformation from prior testing in the central test section
- To preclude annealing of irradiation damage, the temperature of the central 10 mm portion of the reconstituted specimen shall not exceed the irradiation temperature
- The reconstitution procedure must be qualified by comparing results from reconstituted specimens with virgin specimens
- The plastic deformation of a reconstituted specimen must be contained within the unaffected region of the test material between two Heat Affected Zones (HAZs) of the reconstitution welds.

2. Reconstitution

Figure 1 is a schematic view of the reconstitution process. To prepare inserts for the stud welding process, the rough, fractured surface of the broken halves from the tested surveillance samples need to be machined first by an in-cell milling machine. After machining, the inserts are joined to dummy cylindrical studs on both sides by arc stud welding process. After welding, full size Charpy specimens (including notch) can be fabricated from the joints using the same milling machine. In this way, extra new data points could be generated in addition to the existing surveillance data.

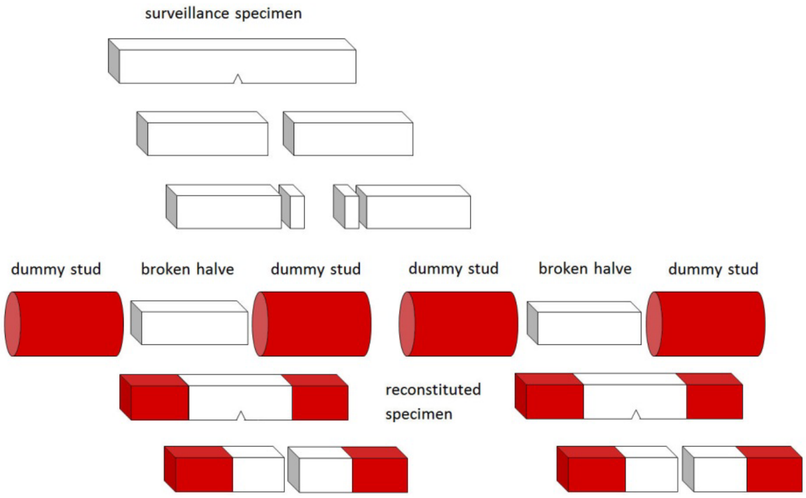

Figure 1. Reconstitution steps

2.1 Arc stud welding

For reconstitution program at NRG, arc stud welding technique was chosen to reconstitute the insert material to full size specimens because this technique was previously qualified [2] and standardized [1], Moreover, stud welding setup is relatively simple for installation in hot cells. During the welding process, an arc is initiated between the stud and the insert, melting the surfaces of both pieces. The stud is then projected into the insert and both pieces fuse. To ensure proper alignment and square sectional welds, slightly oversized stud is used. Figure 2 shows stud, insert, welded studs and fabricated specimen.

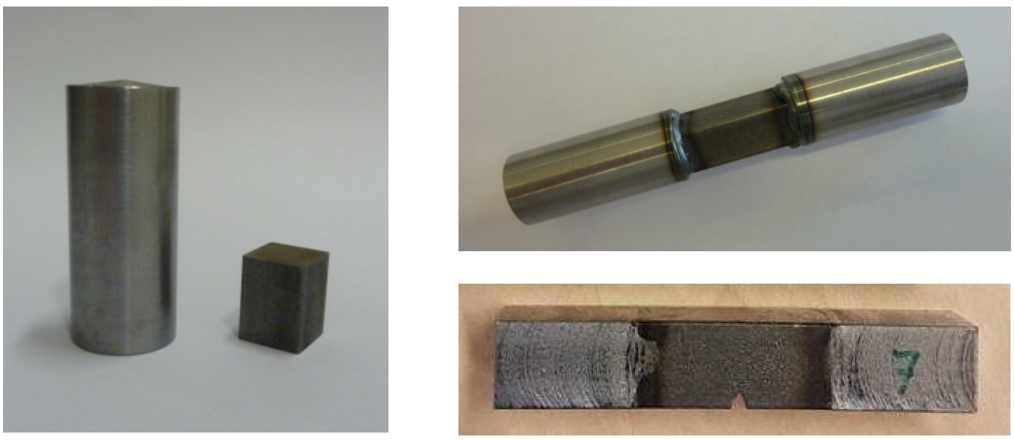

Figure 2. Stud, insert, welded studs and fabricated specimen

The reconstituted specimens normally need mechanical finishing. As the broken surveillance specimens (inserts) are available only in limited amounts, high quality welding and reproducibility of the welding process is of extreme importance. To achieve consistent welding

process and ease for hot cell operation of the welding process, a dedicated semi-automatic arc stud welding setup was designed at NRG for this purpose, as shown in Figure 3.
Within this setup, the welding gun is fixed at the top with a stud holder, in alignment with cooling jigs in the bottom for holding inserts. The cooling jigs are made of brass with water channels inside for active cooling of the inserts during the welding process. PLC systems incorporated within the setup for automatic moving, aligning and welding. Several parameters could be adjusted within this welding setup, such as welding current, welding time, welding gases, gas flow etc. to ensure the desired welding quality.

The challenge in this step was to get good welds with a small heat affected zone (HAZ). Several trial reconstitution welds were produced outside hot cell to optimize the weld parameters. Hardness and microstructural investigations are performed to characterize the weld quality and size of HAZ. Thermocouples are used to measure the temperature profile on the inserts. Finally, the specimen reconstitution technique is assessed by verification tests on a selection of reconstituted specimens.

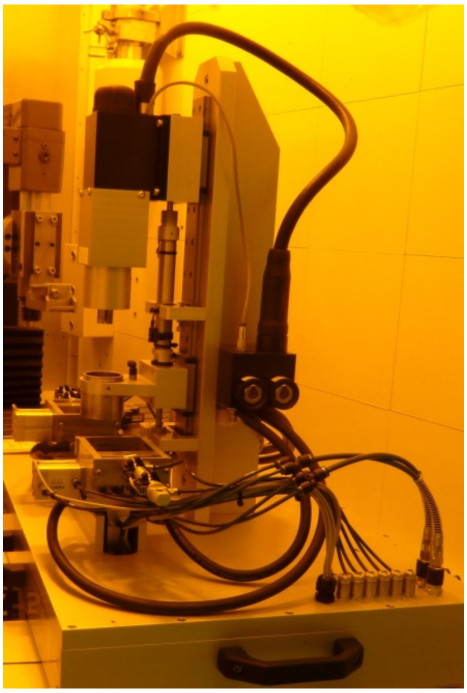

Figure 3. Stud weld machine

2.2 Mechanical finishing of stud welded specimen

Once the welding of studs on both sides of the insert is finished, the specimen has to undergo various mechanical finishing steps to produce a standard full size Charpy specimen. The machining is done in two steps; the first step involves machining of the welded cylindrical studs on both sides of the insert into square cross section in line with the cross section of the insert. The second step is to produce a notch by milling (see Figure 4). Special clamping- and measuring tools have been developed to ease the clamping, alignment, milling and measuring steps in the hot cell. These tools, as shown in Figure 4, have been developed in such a way that the required tolerances of the full size Charpy specimen can be achieved after these machining steps.

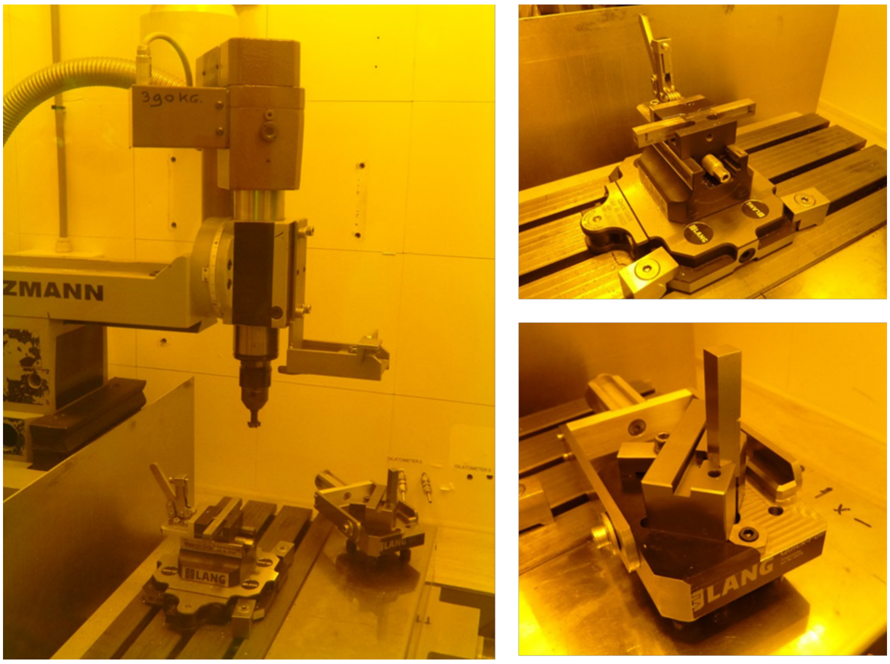

Figure 4. Milling machine and tools

3. Fracture mechanics test by a three point bending setup

A three point bending test setup shown in Figure 5 was developed for use on an Instron test machine, to perform K_{IC} and J_{IC} tests according to ASTM standards.

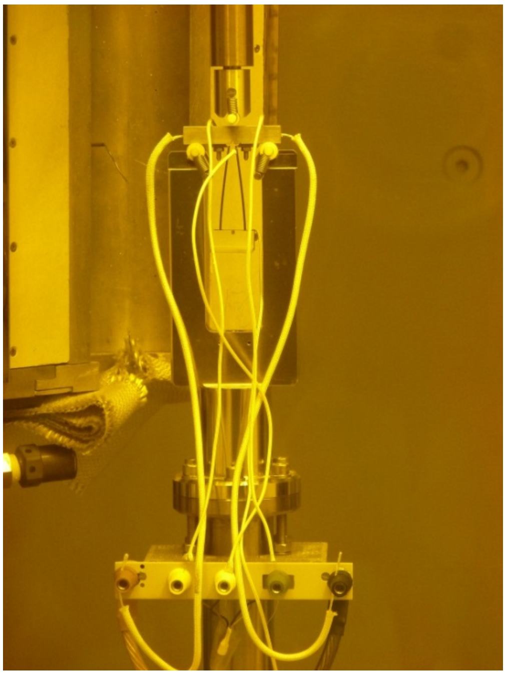
Figure 5. Three point bending setup

Testing can be performed in a temperature range from -170°C to 300°C. A clip gauge is used to measure the crack mouth opening displacement (CMOD) and a Direct Current Potential Drop (DCPD) system is used to measure the crack extension (in case of J_{IC} testing). Testing can be performed on surveillance specimens for reactor pressure vessel (RPV) lifetime assessment based on T_0 shift measurements. Special tools, as shown in Figure 6, were made to improve the ease of mounting knife edges and wires in hot cell for the DCPD measurement.

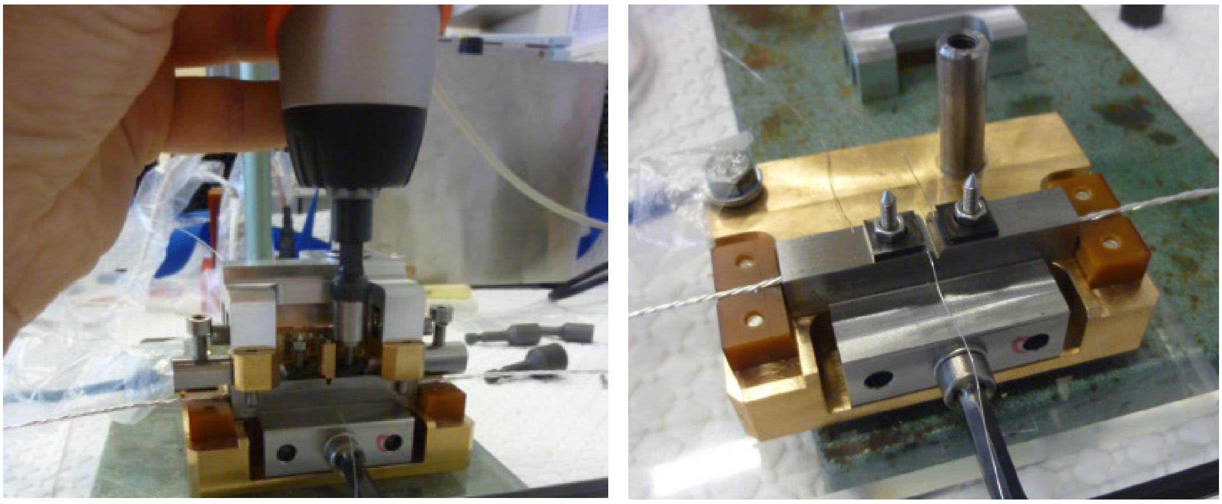

Figure 6. Special tools to prepare specimen for testing

With regard to the status of fracture mechanics setup, several tests on unirradiated material have been performed in the lower shelf and transition regime to validate the functionality of the setup. Reference J_{IC} tests using DCPD for crack growth measurement are in the planning for the upcoming period. The results of those tests are out of the scope of the current paper.

4. Conclusions

In this research, two experimental test setups, namely a reconstitution setup and a three point bending setup, were developed. Reconstitution setup enables re-use of broken pieces of surveillance RPV specimens to fabricate new test specimens in hot cell. Fracture mechanics setup fixed with a controlled temperature chamber, COD and DCPD meters enable master curve testing of the full size Charpy specimens. These setups together is a powerful tool to execute the surveillance test campaigns of LWR RPVs and to perform required testing for ageing management programs of RPVs for the life time extension of NPPs.

Export control note

The content within this document is classified with the code EU DuC = 0E001. EU DuC means European dual use code.

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References

[1] E1253-13, “Standard guide for reconstitution of irradiated charpy-sized specimens”.

[2] E. Van Walle et. al., “Reconstitution techniques qualification and evaluation to study ageing phenomena of nuclear pressure vessel materials (RESQUE)”, IAEA Specialists Meeting on Irradiation Embrittlement and Mitigation, 26-29 April 1999 Madrid.