Validation of Mini Compact Tension Specimens for Fracture Toughness Characterization of Reactor Pressure Vessel Steels

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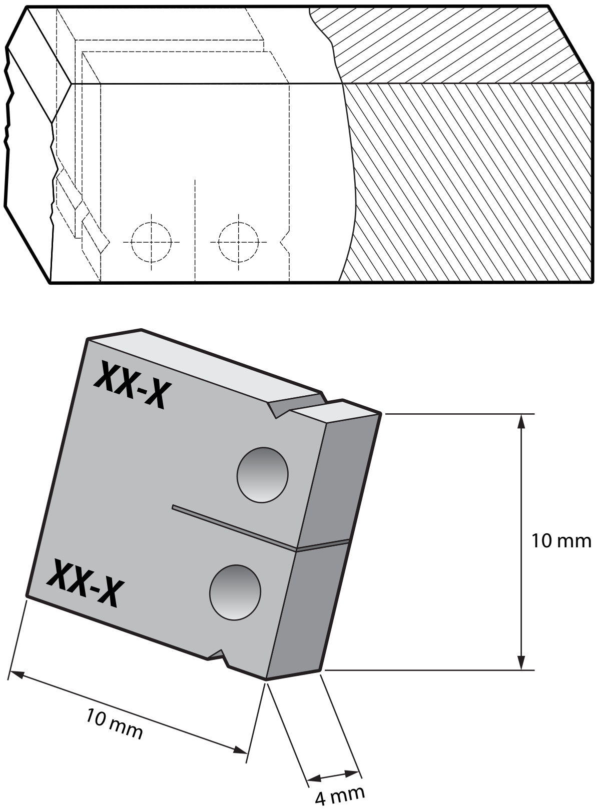
Surveillance capsules located inside the reactor pressure vessels (RPV) of commercial reactors can achieve faster radiation damage exposures than the wall of the RPV, providing insight into the future performance of the vessel ahead of the actual vessel. The Charpy V-notch specimen is the most commonly used specimen geometry in surveillance programs and most likely to be used in advanced reactors as per American Society of Mechanical Engineers (ASME) code. However, fracture toughness assessment of these materials requires indirect correlations to the Charpy impact specimens that may result in potential bias of the test data, especially at very high fluences that are of interest for extended operating life conditions.

Any fracture toughness specimen that can be made from the broken halves of standard Charpy specimens may have exceptional utility for evaluation of RPVs since it would allow one to determine and monitor directly actual fracture toughness. Mini-CT specimens are becoming an accepted geometry for use in the RPV community for direct measurement of fracture toughness in the transition region using the Master Curve methodology, as per American Society for Testing and Materials (ASTM) Standard E1921, for evaluating RPV integrity. The advantage of the Mini-CT specimen technique is coming from a similar net shape as the standard Charpy specimen and can be made from a broken half of a previously tested Charpy specimen, from a standard RPV surveillance capsule. Although it is a very small specimen, the thickness of this Mini-CT specimen is sufficient to fit in a very narrow validity limit window allowed by ASTM E1921. Figure 5 illustrates the layout of Mini-CT specimens within a broken Charpy half, as well as the overall dimensions of the Mini-CT specimen. In this example, it is shown that, typically, two Mini-CT specimens can be machined from one broken half of a surveillance weld metal Charpy specimen and four Mini-CT specimens of a surveillance base metal Charpy specimen.

Up until now, the validation of Mini-CT specimens has been performed on non-irradiated base metals, and only recently has limited work been performed on weld metals, which can produce more sample variability and can be more sensitive to aging effects. Expanding on this early work, the LWRS Program set out to validate Mini-CT specimens uses on a weld material with reduced impact properties (low upper-shelf) in both unirradiated and irradiated conditions. This type of RPV beltline weld can be a limiting material for controlling the extended life of the current fleet of U.S. reactors. The low upper-shelf Linde 80 weld, designated WF-70, has been selected for this study. This weld was utilized in the Midland Reactor Unit 1 beltline weld and has been previously well characterized at the Oak Ridge National Laboratory (ORNL) with various conventional fracture toughness specimens in both unirradiated and irradiated conditions. The latter fact is critical because it made this study efficient by reducing the

Figure 5. Layout of Mini-CT within a broken Charpy half of surveillance weld metal and overall dimensions of Mini-CT specimen.



need to perform a large testing program with conventional specimens and without the need to perform an expensive irradiation campaign. To complete this task, an informal international partnership was formed, with acknowledged contribution from Drs. Masato Yamamoto from Central Research Institute of Electric Power Industry (CRIEPI), Robert Carter from the Electric Power Research Institute (EPRI), William Server from ATI Consulting, and Brian Hall from Westinghouse. Without their invaluable contributions, this project would have been hard to accomplish.

Figure 6 illustrates 1-T adjusted fracture toughness data of a Midland beltline weld WF-70 from the present studies with larger specimens in the unirradiated and irradiated conditions and compared with data as derived using Mini-CT specimens. These results (see the red color) are superimposed on the fracture toughness database for the Midland WF-70 weld previously produced by LWRS Program researchers at ORNL using conventional specimens in both the unirradiated and irradiated conditions. Overall, the transition temperature (To) values derived from a relatively small number of Mini-CT specimens in this study are in remarkable agreement with values from previously reported fracture toughness data. The Master Curve and 5% and 95% tolerance bounds are based on current study Mini-CT data and envelop the scatter exhibited on a large set of variously sized conventional specimens over a wide temperature range. At the same time, this study indicated areas that need to be addressed in the current ASTM E1921 Standard, which require future development and/or clarification for adopting this small specimen for wide use in surveillance specimen testing such that the Mini-CT specimen would provide a powerful tool for direct fracture toughness characterization of RPV material using already available Charpy surveillance specimens, thus enabling industry to better assess RPV integrity through reducing potential bias and uncertainties. The lessons learned from the Materials Research Pathway study also have application to other industries where important decisions are needed, but only limited material is available for testing.

Reference

1. D. E. McCabe, R. K. Nanstad, S. K. Iskander, R. L. Swain, "Unirradiated Material Properties of Midland Weld WF-70," NUREG/CR-6249 (ORNL/TM-12777), 1994.

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Figure 6. Fracture toughness data of unirradiated and irradiated Midland beltline weld from the present study using Mini-CT specimens and conventional specimens in [1]. Master Curves and Tolerance bounds are derived from Mini-CT data only.