Development of Automated J-R Curve Analysis Software to Simplify Fracture Toughness Testing and Analysis

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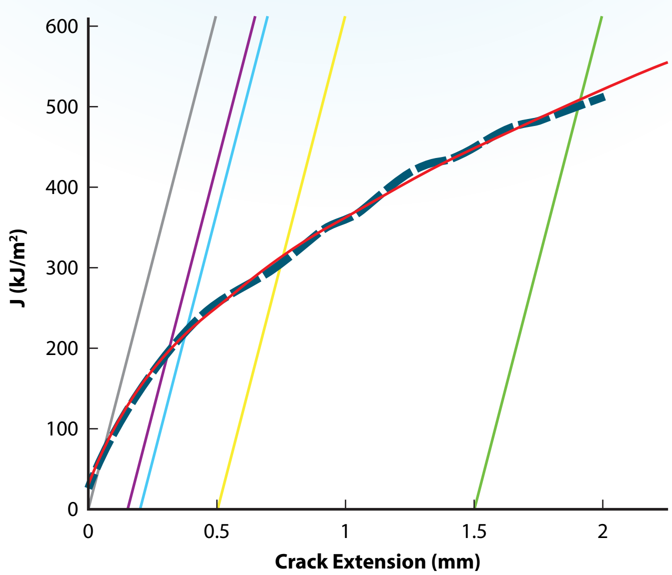
The Materials Research Pathway developed open-source software to perform the automated J-integral versus crack growth resistance curve (J-R curve) analysis. The J-R curve is a useful tool for evaluating materials fracture toughness and has been widely used in both academia and industry [1], such as assessing the fracture resistance behavior of reactor vessels and the irradiation embrittlement of reactor internal materials. A widely accepted practice for conducting J-R curve testing is American Society for Testing and Materials (ASTM) Standard E1820 [2], which includes the normalization method and the conventional elastic unloading compliance (EUC) method. The normalization method significantly simplifies the testing procedure because it does not require compliance measurements during testing, unlike the EUC method, but it does require very complicated analysis procedures. Because of this, the Materials Research Pathway researchers recently developed an open-source J-R curve analysis software to automate the analysis procedures. The source codes were written in MATLAB® and the compiled executable software has a user-friendly graphical interface that is readily compatible with Windows® operating systems. The software provides a convenient tool for evaluating the long-term aging effect on materials fracture toughness properties to support the safe operation of existing nuclear power plants. Figure 7 shows the startup window for the software.

Figure 7. Startup window of the normalization analysis software (automated J-R curve analysis based on the ASTM E1820-18 normalization method).



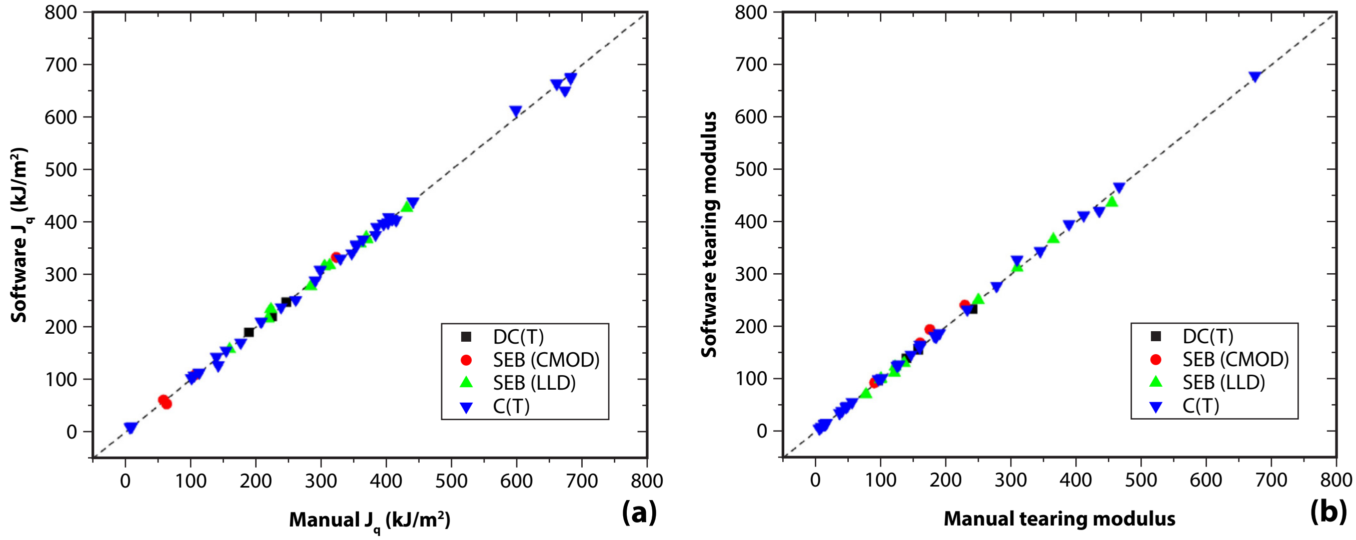
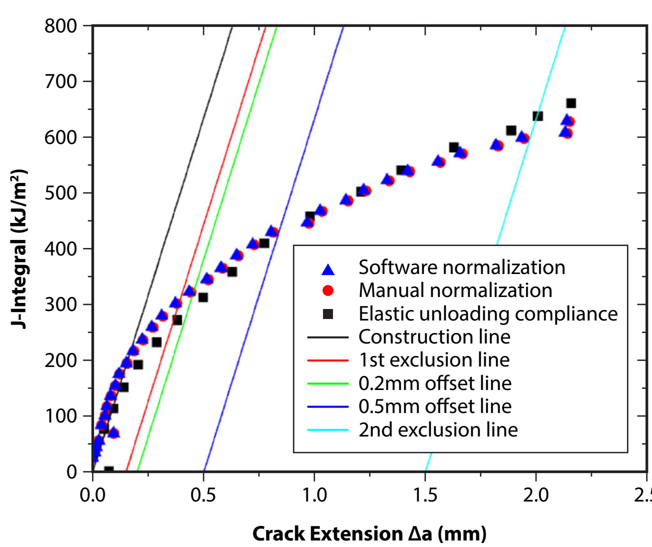


Figure 8. The close match of the J-R curve derived Jq results in (a) and the tearing modulus results in (b) between the software and the manual analysis.

The software is capable of analyzing the four most commonly used fracture toughness specimen geometries (i.e., compact tension [C(T)], disk compact tension [DC(T)], single edge bend with load line displacement measurement [SEB(LLD)], and single edge bend with crack mouth opening displacement measurement [SEB (CMOD)]). To verify that the J-R curve analysis software yields valid J-R curves, the software results were compared with the results from the manual analysis based on the normalized method. The sampling dataset for the comparison included 50 tests covering all four different specimen geometries; a wide testing temperature range from 23°C to 700°C; and materials including stainless steels, nickel-based alloys, ferritic-martensitic steels. The comparisons for fracture toughness Jq and tearing modulus results derived from the J-R curves are shown in Figure 8 [3]. The software yields essentially identical results as the manual analysis method. The small differences observed between two analysis routes are due to the different criteria used in terminating the iterative calculation process. Further, Figure 9 shows the same specimen J-R curve results derived from three different analysis routes [3], namely the software normalization analysis, the manual normalization analysis, and the EUC method. The J-R curve results from the software and manual normalization analyses overlap with each other while small differences are observed between the normalization method and the EUC method due to the differences in the calculation of crack sizes between the two methods.

Figure 9. Comparison of J-R curves from three different analysis routes for the same specimen.



The reference for the analysis software has been balloted and added to the ASTM E1820 standard. Both source codes and the compiled executable file are available to download at code.ornl.gov/xc8/ANJR.

References

1. X. Chen, et al., 2014, AM&P, 172, pp. 19–23.
2. ASTM, Standard Test Method for Measurement of Fracture Toughness, 2018, E1820–18.
3. A.E. Linares, et al., 2019, AM&P, 177, pp. 27–30.