Very Low Cycle Fatigue Failure: Life Evaluation and Experimental Validation

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Recently, evaluating structural integrity and determining the safety margin of nuclear power plant piping components under beyond design basis earthquake (BDBE) events has been increasingly important. Existing experimental works for piping components and piping systems have confirmed that the major failure mode of piping system under seismic load is fatigue or fatigue-ratcheting. Thus, a reliable estimation method for very low cycle fatigue is needed for structural integrity assessment for BDBE conditions. Various experimental data confirmed that the stress-based evaluation method in In ASME BPVC Sec. III is generally very conservative. In this respect, strain-based very low cycle fatigue assessment methods need to be developed. Currently several strain-based very low cycle fatigue assessment methods have been suggested. One strain-based acceptance criteria using equivalent plastic strain and stress triaxiality was proposed as the ASME BPVC Code Case (CC) N-900. In ASME BPVC Sec. VIII Div. 2 Part 5, another strain-based acceptance criteria have been presented using equivalent plastic strain and stress triaxiality based on the ductility exhaustion concept. Although existing strain-evaluation methods presented in ASME BPVC Sec. VIII and CC N-900 have been applied in some works, no work has been yet done to systematically investigate the degree of conservatism of the methods by comparing with experimental data, which is a very important issue for application of the strain-based evaluation method.

The conservatism of existing ASME strain-based evaluation methods for seismic loading is quantified by comparing with very low cycle fatigue test data of elbows under various quasi-static cyclic loading conditions. For strain-based evaluation methods, the method presented in ASME BPVC CC N-900 and Sec. VIII are used. Predicted failure cycles are compared with experimental failure cycle. Comparison shows that all methods give very conservative failure cycles. Then, a new strain-based fatigue assessment method considering void growth and shrinkage effect under cyclic loading is proposed. In the model, tensile stress increases plastic damage but compressive one reduces by the void shrinkage ratio. It is proposed that the void shrinkage ratio can be determined in terms of the plastic strain range from the best fit strain-life curve of the material. It is shown that the proposed method significantly reduced the conservatism.