Cyclic Deformation and Low-Cycle Fatigue for 316LN Stainless Steel under Non-proportional Loading

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Abstract. The effects of loading path and strain amplitude ratio on the cyclic behavior and fatigue life were investigated on a 316LN nuclear grade stainless steel employing a series of symmetrically strain-controlled fatigue tests at room temperature. The loading paths of Uniaxial, Torsional, Proportional, Rhombic, Rectangular, and Circular were employed with the constant equivalent strain amplitude of 0.5%. The strain amplitude ratio of 2.35, 1.73 and 1.27, defined by the ratio of shear strain amplitude to the axial strain amplitude, was realized by changing the shear strain amplitude under Proportional, Rhombic, Rectangular and Elliptical loading paths. As expected, the significant non-proportional additional hardening was observed. It's interesting to note that the axial cyclic stress response varied with the strain amplitude ratio, and the law was different under different loading paths. The fatigue life of all the tests were evaluated by three critical plane criteria proposed by Smith-Watson-Topper (SWT), Fatemi-Socie (FS) and Chen-Xu-Huang (CXH). Results show that the SWT criterion significantly overestimated the fatigue life of non-proportional loading because the effect of shear damage was not considered. The CXH criterion for tensile-type failure yielded good prediction results except for two torsional data points. The FS criterion provided better predictions than other models.

1 Introduction

316LN austenitic stainless steel (ASS) has become the main pipeline material of primary circuit of China's third-generation AP1000 pressurized water reactor nuclear power plant. As structural components, they are often subjected to complex multiaxial fatigue loading owing to the repeated start and stop-operation during service. Therefore, it's of great engineering significance to study the cyclic deformation and suitable fatigue life prediction methods of 316LN ASS under multiaxial fatigue loading.

Some researchers have studied the cyclic deformation behavior and fatigue behavior of 316 type ASS under cyclic loading. Facheris et al. [1] and Mazánová et al. [2] conducted the strain-controlled fatigue tests of 316L ASS subjected to uniaxial, torsional, multiaxial

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Rectangular loadings, but the results are very non-conservative for the other four loadings. While for CXH(T) criterion, most of the predictions are within the life factor of two except two torsional tests.

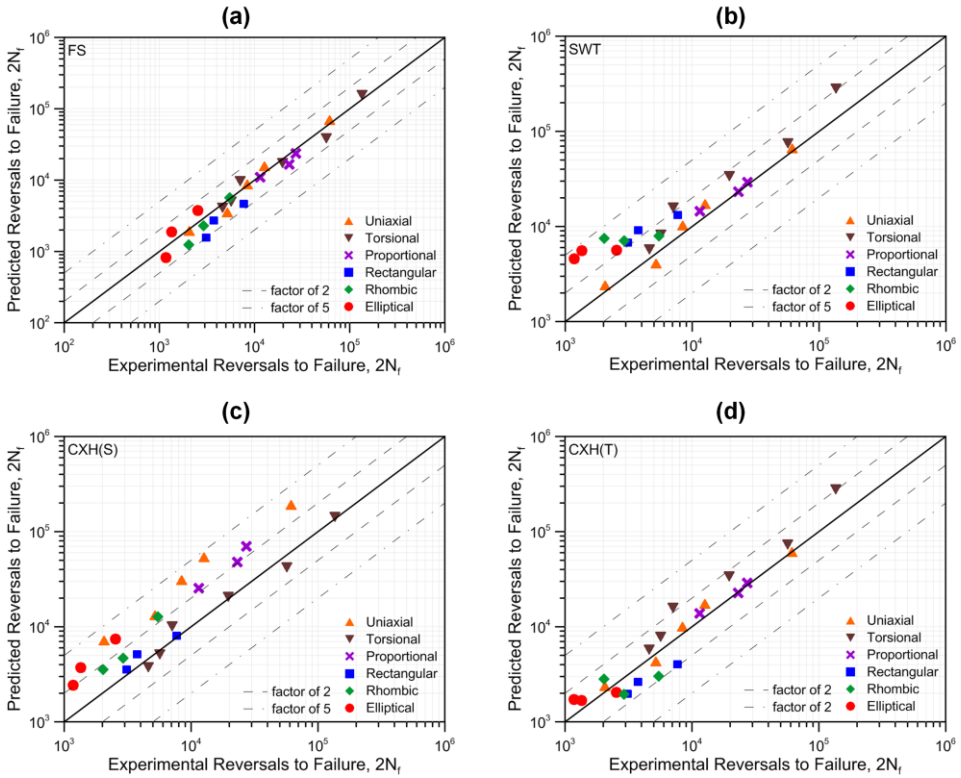

Fig. 4. The fatigue life prediction results by (a) FS (b) SWT (c) CXH(S) (d) CXH(T) criterion.

4 Conclusions

A series of cyclic tests on a 316LN ASS were carried out to investigate the effect of the loading path and strain amplitude ratio on cyclic deformation behavior and fatigue behavior. The non-proportional additional hardening was observed. The strain amplitude ratio can make a different influence on the axial cyclic stress response for various loading paths. Three fatigue life prediction criteria, SWT, FS and CXH were employed for fatigue life prediction. It is shown that the SWT criterion and CXH criterion for shear-type failure perform poorly for non-proportional loadings. While the FS criterion and CXH criterion for tensile-type failure can provide acceptable prediction results for most of experiments.

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References

1. G. Facheris, K.G.F. Janssens, S. Foletti. Int. J. Fatigue **68**, 195-208 (2014)
2. V. Mazánová, V. Škorík, T. Kruml, J. Polák. Int. J. Fatigue **100**, 466-476 (2017)
3. K.C. Liu, J.A. Wang. Int. J. Fatigue **23**, 129-134 (2001)
4. E.S. Feng, X.G. Wang, C. Jiang. Int. J. Fatigue **122**, 1-8 (2019)

5. H. Zhu, H. Wu, Y. Lu, Z. Zhong. Int. J. Fatigue **121**, 1-8 (2019)
6. M.S. Pham, C. Solenthaler, K.G.F. Janssens, S.R. Holdsworth. Mater. Sci. Eng., A **528**, 3261-3269 (2011)
7. A. Benallal, P. Le Gallo, D. Marquis. Nucl. Eng. Des. **114**, 345-353 (1989)
8. E. Tanaka, S. Murakami, M. Ōoka. J. Mech. Phys. Solids **33**, 559-575 (1985)
9. A. Fatemi, D. Socie. Fatigue Fract Eng M **11**, 149-165 (1988)
10. K.N. Smith, P.Waston, T.H. Topper. J. Mater **5**, 767-78 (1970)
11. X. Chen, S. Xu, D. Huang. Fatigue Fract Eng M **22**, 679-686 (1999)