Multiscale modeling strategy for predicting fatigue life of steels

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Abstract

This study presents a multiscale modelling strategy for accurately predicting the high-cycle fatigue strengths of steels. In the proposed strategy, total fatigue life is estimated from crack growth life alone based on the experimental facts.
The entire model comprises three sub-models, for: (i) a macroscopic finite element analysis, (ii) microstructure, and (iii) crack growth. The required input data are only microstructural information, tensile properties, and loading conditions, without any adjustable material constants. The aim of the model for (i) a macroscopic finite element analysis is to define an active zone where sufficiently contains the whole of possible crack initiation area and to obtain the strain amplitude field in the active zone. In the model for (ii) microstructure, we employed a modeling strategy with two steps of 2D problems, which is modeling for surface and inside of material considering the features of actual fatigue crack initiation and growth behaviors. The Monte Carlo method is applied to simulate distribution of the microstructure, which is a nature of the scatter of fatigue life. In the model for (iii) crack growth, we employed the interaction theory between crack and grain-boundaries. The driving force of the crack growth is quantified using crack tip sliding displacement (CTSD) formulated based on the continuously distributed dislocation theory considering slip transmission between adjacent grains. The material resistance of each phase is determined as the friction strength to move dislocations. All the grains assigned in the surface of the active zone are assumed as possible crack initiation sites and the number of cycles to failure is determined based on the weakest link assumption.

The model was strictly validated against the results of experiments performed on three different steels under various loading conditions using four types of specimens. Although the experimental fatigue life results exhibited wide variation, the predicted and experimental data were accurately matched over the entire range. The notch sensitivity of the fatigue limits depending on the material strength were successfully reproduced by the proposed model. The transition of the crack growth rate was also accurately predicted compared with the experimental results.
The results demonstrate that the fatigue life of steels under high-cycle fatigue can be accurately predicted from crack growth life alone. Furthermore, the proposed strategy is capable of effectively explaining the dependence of fatigue strength on microstructure and loading conditions based on the advanced fracture mechanics.

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