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Editorial

Fatigue Damage Mechanism and Fatigue Life Prediction of Metallic Materials

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1. Introduction and Scope

Metallic materials are crucial in engineering applications and often subjected to complex loads and extreme environments, with fatigue being one of the key problems. At present, the fatigue of metallic materials remains a challenging problem that still needs to be addressed in engineering applications. The behavior of metallic materials under fatigue loading is a micro–macro multi-scale issue encompassing microscopic defect and damage evolution, the formation of small cracks and their coalescence, propagation, and microstructural interaction, ultimately leading to macroscopic component fracture. Therefore, the study of fatigue of metallic materials typically requires interdisciplinary knowledge of advanced mechanics, materials science, mechanical engineering, numerical computing, etc.

In addition, fatigue is affected by many internal and external factors, including material processing and microstructures, geometric size and configuration, load, environment, etc. It is important to study the fatigue mechanism and fatigue behavior considering these factors. Moreover, the research into fatigue life prediction and fatigue performance optimization methods can provide technical understanding of and solutions for engineering applications. This Special Issue aims to report experimental, theoretical, and numerical studies related to the fatigue damage mechanism and fatigue life prediction of metallic materials.

2. Contributions

Eleven articles are included in this Special Issue, including one review article and ten research articles. The research subjects encompass industrial materials, such as superalloys, steels, and aluminum alloys, and span multi-scales, ranging from materials to large-scale components.

Among these articles, four focused on steel, which is one of the most significant metallic materials with extensive industrial applications. Christodoulou et al. [1] studied crack initiation behavior and life using combined experimental and numerical methods. Life prediction was implemented based on the local strain and fracture mechanics parameter. Su et al. [2] developed a digital image correlation (DIC)-based method to measure the relative displacement between contact surfaces in fretting fatigue, and the transition from gross slip to partial slip was identified via the measured relative displacement distribution. Yelemessov et al. [3] assessed the effectiveness of reusing previously used railway rails by applying the fatigue analysis method to the rail steels. Coupled study methods using various microstructural characterization and mechanical tests were adopted to reveal the microstructural and mechanical property changes during operation. Rui et al. [4] studied the evolution of intragranular misorientation parameters KAM and GROD, obtained via 2D-EBSD, and their relationships with 3D plastic deformation were clarified at a crystal level.

Two articles focused on the fatigue behavior and modelling of superalloys under extreme conditions. Wu et al. [5] studied the crack behavior and mechanism of superalloy under the biaxial fatigue loading condition. Biaxial fatigue tests were conducted and fatigue crack formation and propagation processes were captured via a replica method. Hu et al. [6]

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developed constitutive models for superalloy under creep-fatigue loading at different elevated temperatures. The cyclic softening effect was considered in the constitutive models, and the results showed the models' capabilities to describe responses under creep-fatigue conditions.

Two articles focused on the fatigue behavior of aluminum alloys used in various industrial environments. Shi et al. [7] conducted pre-corrosion fatigue tests of an aluminum alloy in a marine atmosphere, and various electron microscopy methods were used to characterize fatigue damage mechanisms and their relationships with the fatigue life. Urrego et al. [8] studied the fatigue behavior of an aluminum alloy used in industrial joining structures. The effects of geometric factors on fatigue behavior were considered, and the relationship between the stress intensity factor and crack length was obtained.

Several articles investigated other important aspects of fatigue, such as fatigue performance optimization design, system fatigue reliability evaluation, and fatigue fracture simulation methods. Cui et al. [9] reviewed the state of the art of phase field methods, including fundamentals, recent progress, and their applications in various conditions across multiple scales. Performance-enhancing strategies for phase field methods were summarized, and the outlook was presented in the aspect of complex loading conditions, fatigue degradation criterion, coupled crystal plasticity, etc. Li et al. [10] conducted gear low-cycle fatigue tests under different stress levels and studied the system reliability estimation method using finite element modelling. The effect of component geometric size was considered, and its effect on the fatigue life of the large aviation planetary system was determined. Wen et al. [11] determined the shape optimization design of the vent hole structure to achieve enhancing fatigue life. Non-parametric- and geometric parameter-based optimization methods were implemented, and the reduction in the stress concentration was analyzed.

3. Conclusions and Outlook

Some of the most recent progress in damage mechanisms, fatigue life prediction, and performance optimization was reported in this Special Issue. The development of experimental, theoretical, and numerical methods and their application in the field of fatigue can serve as good foundations for future research. Finally, as Guest Editors, we would like to express our gratitude to all authors for their contributions, as well as to the reviewers and the *Metals* Editorial Office for their time and efforts.

Conflicts of Interest: The authors declare no conflict of interest.

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