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一种基于约束因子的超载迟滞模型

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An Overload Retardation Model Based on Constraint Factors

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摘要 在常幅载荷中加入一个超载会明显影响后续一段时间裂纹扩展的速率。要准确预测结构在变幅载荷谱下的疲劳裂纹扩展寿命,必须研究超载对裂纹扩展的影响。现有的变幅疲劳裂纹扩展模型大致可分为屈服区模型、经验的裂纹闭合模型和条带屈服模型。条带屈服模型预测较准确但需要数值迭代求解,计算量大,且程序复杂,不利于工程应用;屈服区模型比较简单,但当前大部分屈服区模型中的相应参数需要通过多组试验确定,缺乏明确的物理意义。本文把裂纹闭合和屈服区的概念相结合,并考虑三维约束影响,提出了一种基于约束因子的超载迟滞模型。在此模型中,裂尖的三维约束状态显著影响超载塑性区,从而显著影响裂纹的闭合和扩展速率。在常幅疲劳裂纹扩展速率已知的前提下,本文模型只需根据某一超载比下的迟滞试验来确定材料的超载迟滞参数,其他超载比的迟滞效应即可基于该参数进行预测。把该模型用于2024-T3、2024-T351和6061-T6等铝合金试件在单超载和多超载作用下疲劳裂纹扩展寿命的预测,预测结果和试验值的相对误差小于20%;在高超载比时,由于裂尖大范围屈服,预测误差相对较大,但仍小于34%。对2024-T351的验证结果还表明,本文模型能够有效预测超载迟滞的厚度效应。

关键词: 疲劳裂纹扩展 约束因子 超载 迟滞模型 裂纹闭合

Abstract: Application of a single overload to a constant amplitude loading will significantly affect subsequent crack propagation rate. Therefore, it is necessary to evaluate the influence of overloads on crack growth rates for the fatigue life prediction of structures subject to variable amplitude loadings. The existing fatigue crack growth models for structures subject to variable amplitude loadings can be classified into three categories: the plastic zone based models, the empirical crack closure models and the strip yield models. Of these, the strip yield models can make precise predictions for the overloading effect, but they are too complicated for engineering applications. The plastic zone based models are simple, but they generally include empirical parameters which often lack clear physical significance and have to be determined by a lot of experiments. By combining the advantages of the plastic zone based models and the strip yield models, the three-dimensional constraints near the crack tip are introduced and a new overload retardation model is developed. In this model, the plastic zone induced by the overload is affected by the three-dimensional constraints, and it leads to significant influence on the crack closure and growth rate. On condition that the crack growth rate at constant amplitude loading is obtained, the overload retardation factor of this model can be determined by a retardation test under any overload ratio. The retardation effects of other overload ratios can be predicted by the obtained factor. With the aid of the factor and the sound basis of exact prediction of the crack propagation under constant amplitude loading by the constraint theory, the developed model is proved to be efficient on aluminium alloys such as 2024-T3, 2024-T351, and 6061-T6. In most cases, its life prediction errors are within 20% compared with the results of the crack propagation tests with overloads. The errors are still less than 34% even in large-scale yielding situations. Moreover, from the verification of 2024-T351, the new model is shown to be effective for predicting the thickness effect on overloading retardation.

Keywords: fatigue crack propagation constraint factor overload retardation model crack closure

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