A GENERALIZED TWO-PARAMETER DRIVING FORCE MODEL FOR SHORT AND LONG FATIGUE CRACK PROPAGATION

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Abstract
Numerous different crack growth modeling approaches have been developed to consider the short crack and long crack behaviors by accounting for the stress intensity range-based crack driving forces or the crack closure concept. However, those methods lacked a proper systematic approach to accurately account for the behavior of short cracks. Based on the recent systematic study performed in the authors' group, a new generalized two-parameter driving force model is proposed to account for crack growth driving forces and corresponding crack growth thresholds to predict both short crack and long crack propagation behaviors. The model predicted crack growth rates are compared with crack growth data set of Ti-6Al-4V titanium and 2024-T3 aluminum alloys. Predicted results show good agreement with experimental crack growth data for these materials.

1. Introduction

High cycle fatigue (HCF) failures can be considered as the propagation of short cracks at various length scales, consisting of early stages of crack formation (nucleation), short crack (SC) growth and then propagation of long crack (LC). A sequential progression of cracks at various length scales eventually leads to fatigue failure. Since cracks remain short for most of the HCF regime of structural components, long crack behavior poses a less important aspect in the HCF regime. Some methods have been proposed to bridge short and long crack propagation mechanics by considering the concept of crack closure [1] and two-parameter mechanical driving force [2-3] and effects of crack tip plasticity (e.g., UniGrow model [3]) on the basis of fracture mechanics. Despite some successes, all of those fatigue crack growth models lacked mechanically comprehensive approach to fully address the complex behavior of short cracks, thus it led to very limited applications. Based on recent study on crack propagation modelling conducted by the author's group [4-6], a new generalized crack growth model is proposed to predict propagation behavior of short and long cracks by accounting for two driving force parameters, $\mathrm{K_{max}}$ and $\Delta\mathrm{K}$ influenced by the cyclic plastic deformation (i.e. residual stress field, $\mathrm{K_r}$) and corresponding crack growth thresholds, $\Delta\mathrm{K_{th}}$ and $\mathrm{K_{max,th}}$. Thus, the behavior of fatigue cracks in short and long crack regimes can be modeled in a uniform approach. Fatigue crack growth (FCG) data sets of Ti-6Al-4V titanium and 2024-T3 aluminum alloys are then used to verify the accuracy of the proposed model.

2. Results

The proposed two-parameter driving force model assumes the applied maximum stress intensity factor, $\mathrm{K_{max,apply}}$ and applied stress intensity range, $\Delta\mathrm{K_{apply}}$ are modified by the residual stress intensity, $\mathrm{K_r}$ to account for the effects of reversed cyclic plastic deformation on FCG. The driving force parameters of $\mathrm{K_{max,tot}} = (\mathrm{K_{max,appl}} + \mathrm{K_r})$ and $\Delta\mathrm{K_{tot}} = (\Delta\mathrm{K_{appl}} + \mathrm{K_r})$ can be expressed as $\mathrm{K_{max,tot}}$ and $\Delta\mathrm{K_{tot}}$ respectively. These two driving force parameters, $\mathrm{K_{max,tot}}$ and $\Delta\mathrm{K_{tot}}$ have corresponding thresholds of $\mathrm{K_{max,th}}$ and $\Delta\mathrm{K_{th}}$ respectively. These $\mathrm{K_{max,th}}$ and $\Delta\mathrm{K_{th}}$ thresholds can be defined as material crack growth resistance as a function of the size-dependent SC thresholds and the crack size independent LC thresholds. A new two-parameter driving force model for describing SC and LC propagation behavior can be expressed by the difference between total driving force, $\Delta\kappa$ and the threshold driving force parameter, $\Delta\kappa_{\mathrm{th}}$ as $da/dN = C_1(\Delta\kappa - \Delta\kappa_{th})^{\gamma_1}$ where $\Delta\kappa = \left[K_{\max,tot}\right]^p [\Delta K_{tot}]^{1-p}$ and $\Delta\kappa_{th} = [K_{max,th\_}]^p [\Delta K_{th}]^{1-p}$.

The FCG rates predicted from the proposed model are compared with FCG data set of SC and LC at R-ratios of 0.1 and 0.5 for the titanium alloy, Ti-6Al-4V in Fig. 1 a). The predicted results are also compared to SC and LC propagation data set of the aluminum alloy, 2024-T3 at R-ratios of 0.0 and 0.5 in Fig. 1 b). Solid-line curves in these figures represents the model crack growth predictions as a function of the driving force, $\Delta\kappa$. Predicted FCG rates for different stress levels are depicted as different solid color curves. The model predicts different FCG rates for different stress levels as shown as separate color curves in the SC regime and then predicted results merge with the steady state behavior of the LC for two materials. Fig. 1a) shows that the predicted FCG rates correlate well with the FCG data set for stress ranges of 613-690 MPa and two different R-ratios for Ti-6Al-4V titanium alloy. Fig. 1b) indicates that the predicted results at R=0.0 and R=0.5 agree well with the propagation data set of 2024-T3 aluminum alloy for a range of the stress levels, 110-225 MPa. Based on compared results in Fig. 1 a)-b), predicted FCG results by the proposed model under various stress levels at two different R-ratios agree well with FCG data sets of these two alloys.

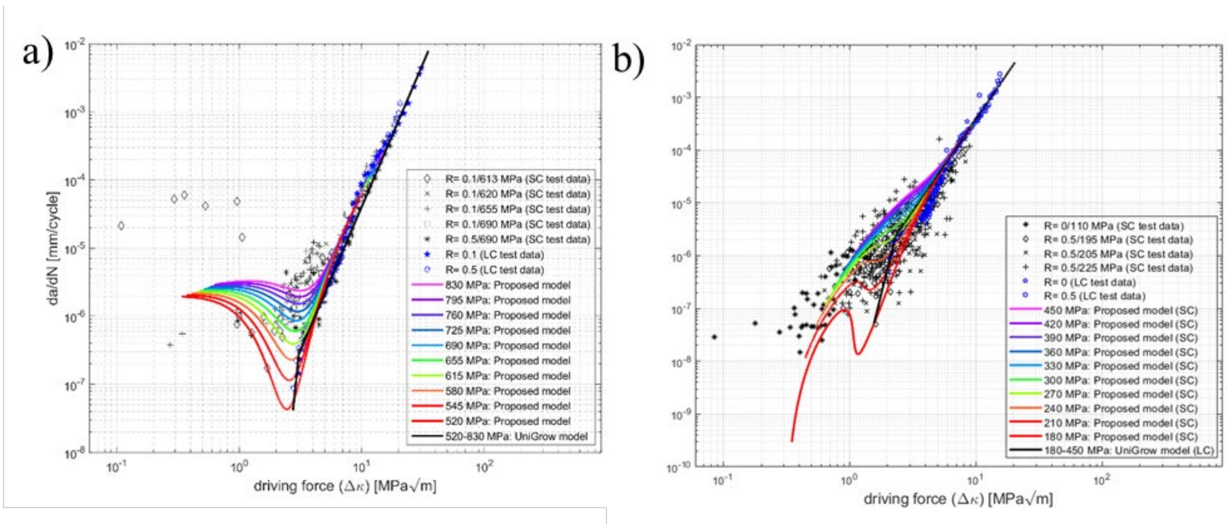

Fig. 1 – SC and LC propagation results a) titanium alloy, Ti-6Al-4V; b) aluminum alloy, 2024-T3.

3. Conclusions

A new generalized two-parameter crack growth driving force model is proposed to predict SC an LC propagation behaviors in a unified manner. The model predictions agree well with FCG data sets for Ti-6Al-4V titanium and 2024-T3 aluminum alloys in both SC and LC regimes under various stress levels at two different R-ratios. Compared results also shows that the proposed model predicts higher FCG rates for greater stress levels for short cracks, in good agreement with FCG data sets of two different alloys.

References

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