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Sensitivity Analysis of Fatigue Crack Growth Life Prediction Model for Discontinuous Reinforced Metal Matrix Composites

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Abstract

In the present work, a sensitivity analyses are performed to provide in-depth knowledge on the mechanistic aspects of the model.Tevatia and Srivastava has developed fatigue crack growth life prediction model for discontinuous reinforced metal matrix composite and considered in the present work to carried out the sensitivity analysis of microstructural parameters. Sensitivity analysis reflects that a little variation in modeling parameters C_ε, n', and K' can drastically change the fatigue crack life, whereas V_f, a_i and a_f have the least effect on the prediction.The results are presented for AA6061-Al_2O_3-T6DRMMC. The sensitivity analysis of the model provides the insight over the effects of micro-structural parameters over the fatigue crack growth life of DRMMCs.

Keywords: Fatigue crack growth life, DRMMCs, Sensitivity analysis

INTRODUCTION

The mechanical components subjected to cyclic loading leads to fatigue crack growth[1-2]. This inevitable flaw gradually increases and leads to failure with the tragic outcomes; therefore,the accurate prediction of fatigue life becomes critical. This perspective often leads to several deterministic fatigue growth models [3-5] and researchers validate them with the experimental assessments [6-7]. The variability in fatigue model may be caused by the boundary conditions, the loading conditions, and the material properties. The sensitivity analysis is carried out to investigate the potential changes and the errors in the measurement of individual parameters and study the overall impact on the conclusions of present model [8]. The sensitivity analysis is important in the crack identification problems [9]. Castillo et al. [10] proposed a method for the sensitivity analysis for fatigue life prediction model using the probabilistic approach.

Recently, Tevatia and Srivastava [4] developed a fatigue crack growth life prediction model for DRMMCs as

$$\left(\frac{\Delta\varepsilon_p}{2}\right) = \left\{\frac{6\ C_\varepsilon^{\,2}}{\lambda_l Y^2 \pi^2}\left[1 + \frac{8V_f^{\,2}s^2(E_f-E_m)}{3(E_f+4V_f s^2 E_m)}\right]^{-2}\left(\frac{n'}{n'+1}\right)\left(\frac{\sigma_c}{K'}\right)^3 ln\left(\frac{a_f}{a_i}\right)\right\}^{\frac{1}{(3n'+1)}}(2N_f)^{-\frac{1}{(3n'+1)}} \qquad (1)$$

where, $\frac{\Delta\varepsilon_p}{2}$the cyclic plastic strain amplitude, $C_\varepsilon$constraint, $\lambda_l$the correction factor, $Y$the crack geometry correction factor, $n'$the cyclic strain hardening exponent, E_m and $E_f$the Young's moduli of matrix and fiber, respectively; s the aspect ratio, σ_c the cyclic yielding strength of composite, $K'$the cyclic strain hardeningN_f the fatigue crack growth life of DRMMCs, a_i and $a_f$are the initial and final crack lengths, respectively. The various assumptions and micro-structural parameters of fatigue crack growth models are subject to change and result in unknown confidence bounds of the model. Hence, it is of prime importance to delineate the random nature of fatigue growth micro-structural parameters. To overcome this limitation, the present study emphasizes a systematic framework to define the sensitivity in a discontinuous reinforced metal matrix composite (DRMMCs) fatigue crack growth life prediction model[4].

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SENSITIVITY ANALYSIS

The present study establishes a relationship between the various input micro-structural modeling parameters such as (i) constraint (C_ε), (ii) volume fraction of the reinforcement (V_f), (iii) cyclic strain hardening exponent (n'), (iv) cyclic strength coefficient (K'), (v) initial crack length (a_i) and (vi) final crack length (a_f)and output fatigue crack growth life of Al-DRMMC. The deviation is calculated for each input parameter within the variability of $\pm$10% ofthe mean value (Table 1). The effects of each micro-structural parameter on the fatigue crack growth life are analyzed by fixing the other parameter at their mean values.

RESULT AND DISCUSSION

The validation of fatigue crack growth life prediction model is carried out by simulating Eq. (1) for the micro-structural parameters (Table 1) fitted with the experimental results of AA6061-Al_2O_3-T6 DRMMCs (Fig 1).The deviation in fatigue life isalso plotted between the maximum and minimum ($\pm$10%) values. These curves depict the scatter in the fatigue lives of composite. For example, the fatigue life $2N_f$ of 100 cycles implies the mean plastic strain amplitude $2.22\times10^{-3}$with minima and maxima at 2.47×10^{-3}and2.72×10^{-3}, respectively. The experimental data are bounded between the maximum and minimum values.

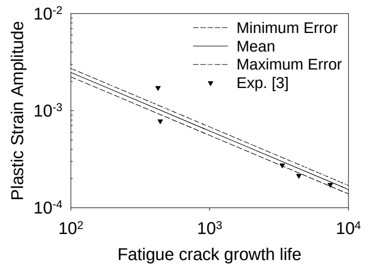

Fig 1: The experimental data fitting using the analytical solution Eq. (1) with defined variation in the range of fatigue crack growth life of AA6061-Al_2O_3-T6 DRMMC.

The change in fatigue growth life is estimated by varying a single input parameter (keeping the others constant) for investigating the variation in the output due to the individual micro-structural parameter. The C_ε, V_f, n', K', $a_i$and $a_f$modeling parameters are varied within $\pm$10% and spider plot (Fig. 2a) is obtained which depicts that C_ε reduces the fatigue life by 19% or increases by 20.99%, $V_f$reduces by 1.76% or increases by 1.70%, n'reduces by 38.44% or increases by 59.98%, K' reduces by 26.78% or increases by 32.26%, a_f reduces by 1.48% or increases by 1.96% and a_i reduces by 1.96% or increases by 1.48%. It is concluded that C_ε, n', and K' are more sensitive parameter than the V_f, a_i and a_f as regards to the fatigue life. This is also verified from the tornado plot (Fig 2b) in which the baseline represents the predicted fatigue growth life corresponding to the micro-structural parameter values given in Table 1.

Table 1: Mechanical and micro-structural parameters of AA6061-Al_2O_3-T6 DRMMC at 298 ^oK [4]

S. No.	Parameter	Definition	Values
1	E_c(MPa)	Measure the resistance to being deformation elastically in the DRMMC	71000
2	E_m (MPa)	Measure the resistance to being deformation elastically in the matrix material	71000
3	E_f (MPa)	Measure the resistance to being deformation elastically in the short fiber material	312000
4	n'	Cyclic strain hardening exponent is material constant and used in stress strain relation	0.16
5	K' (MPa)	Cyclic strength coefficient of the DRMMCs	1066

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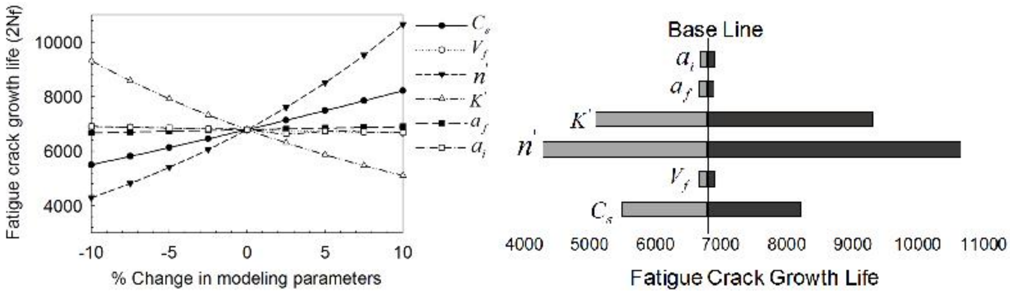
6	σ_c (MPa)	Cyclic yield strength of DRMMCs	387
7	σ_m (MPa)	Cyclic yield strength of matrix material	340
8	V_f	Content of particle/ short fiber in the matrix by weight	0.15
9	λ_l	A material dependent parameter and controls the state of stress near the crack tip under large scale yielding	0.3497
10	C_ε	The level of constraint within the crack tip region and defined as the ratio of mean to effective strain.	0.2
11	Y	Crack geometry correction factor depends on the geometry of the crack	1.12
12	s	Aspect ratio	1.7
13	a_i (mm)	Initiation crack length size	0.005
14	a_f (mm)	Fracture crack length size	2



(a) (b)

Fig 2: The sensitivity analysis using the various modeling parameters (C_ε, V_f, n', $K' a_i$ and a_f) on the fatigue crack growth life ($2N_f$): (a) Spider plot (b) Tornado plot.

Since the fatigue crack growth model depends on several micro-structuralparameters, variations in these parameters affect the fatigue life of composite.The sensitivity and uncertainty analyses helped in determining the bounds on the parameters so that the model predictions are still valid. For example, a small variation in the parameters C_ε, n' and K' results in huge impact on the predicted life. Thesensitivity and uncertainty analysesdefinesthe boundaries on the fatigue crack growth life of DRMMCs. The present analysis used the local sensitivity in order to identify the overall impact of the crucial contributors to the fatigue growth life of DRMMCs.Sensitivity analyses revealthat a small variationin the constraint during the crack growth may significantly scatter the fatigue life.

CONCLUSIONS

The robustness of present model is verified using the sensitivity and uncertainty analyses of Al based DRMMC. The following conclusions are drawn based on the analytical results:

1. The cyclic deformation in FDZ very near to the crack tip is the principal mechanical driving force for the propagation of fatigue crack under the strained controlled conditions.
2. The fatigue crack growth life prediction model is tested from the experimental data of AA6061-Al_2O_3-T6 DRMMCs. A good agreement between the two results proves the reliability of present model.
3. The sensitivity analysis shows that C_ε, n', and K'have high impact whereas V_f, a_i and a_f have very low effect towards the fatigue life.

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