11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20–25, 2014, Barcelona, Spain

PERFORMANCE OF COHESIVE ZONE MODELS FOR FATIGUE DRIVEN DELAMINATIONS

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Key words: *Fatigue, cohesive zone model, delamination, benchmark.*

This work presents a benchmark study of cohesive zone model methods for fatigue driven delamination simulation. The methods considered are the method by Robinson et al. [1], Turon et al. [2] and the very recent method by Bak et al. [3]. These methods are so called envelope load damage models and the overall approach of these is described in the recent review of fatigue driven delamination [5]. The methods are based on a quasi-static bilinear cohesive law, see Fig. 1(a). For pure mode I opening displacement and a loading

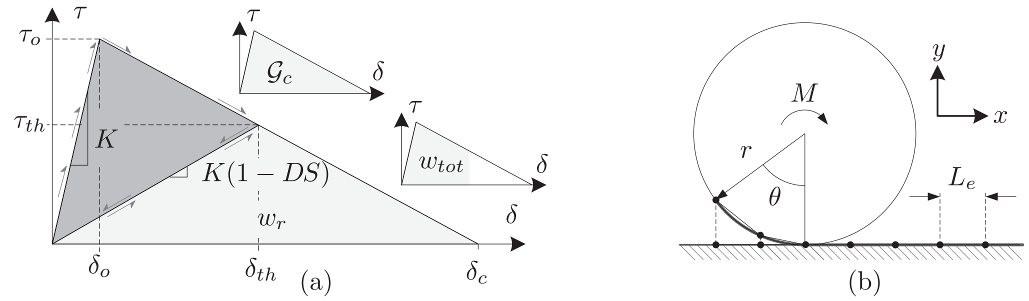

Figure 1: (a) Bilinear quasi-static cohesive law. w_r is the specific remaining ability to do non-conservative work of the interface tractions and w_{tot} is the total specific work of the interface at given point. (b) Cylinder model [4] for testing envelope load damage models in mode I opening. M is the applied moment, r is the cylinder radius, θ is the angle of rotation and L_e is the element length.

ratio equal to zero the definitions of the damage rate models reduce to:

Robinson et al. [1] $$\frac{dDS_f}{dN} = \frac{c_1}{1+c_3} e^{(c_2 DS)} \delta_I^{(1+c_3)} \quad (1)$$

Turon et al. [2] $$\frac{dDS_f}{dN} = \frac{1}{L_{cz}} \frac{(\delta_c(1-DS)+DS\delta_o)^2}{\delta_c \delta_o} \cdot C \left(\frac{w_{tot}}{\mathcal{G}_{Ic}}\right)^m \quad (2)$$

Bak et al. [3] $$\frac{dDE_f}{dN} = \frac{\partial DE}{\partial w_r} \frac{\partial w_r}{\partial \delta_I} \frac{\partial \delta_I}{\partial a} \cdot C \left(\frac{\mathcal{G}_I}{\mathcal{G}_{Ic}}\right)^m \quad (3)$$

where c_1, c_2 and c_3 are fitting parameters, L_{cz} is the distance from a given point in the interface to the damage front, C and m are the Paris law parameters and DE is the energy damage parameter defined as $(\mathcal{G}_c - w_r)/\ \mathcal{G}_c$ and is uniquely related to DS. The models [1, 2, 3] have been studied and benchmarked using the cylinder model by López Armas et al. [4] which the authors have extended to include linear 4-node cohesive elements, see Fig. 1(b). The model consists of a rigid cylinder rolling on a flat rigid surface with cohesive elements connecting the two on the left side of the contact point. The cylinder model provides a simple approach to perform parameter studies as well as isolate and compare certain properties of the fatigue damage rate models. The following properties of the models [1, 2, 3] have been studied using the cylinder model: ability to represent Paris' law in the case of [1] or reproduce it in the case of [2, 3], sensitivity to change in cohesive law parameters K and τ_o, element size sensitivity study, influence of the size of the crack growth increment per solution substep Δa, and influence of the length of the cohesive zone modelled by varying the radius r. Overall the method of [3] provides the highest accuracy and is most robust in terms of change of these parameters. A study of the influence of the radius is r shown in Fig. 2. The remaining results of these studies will be presented at the conference.

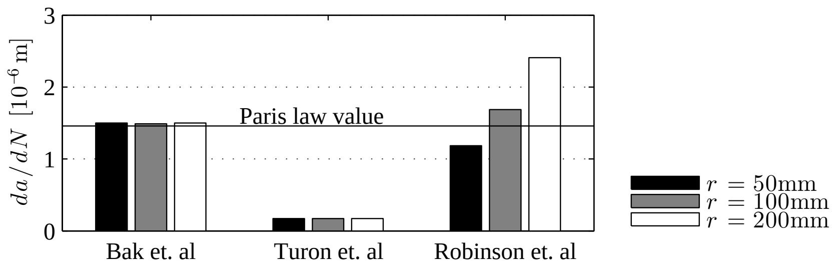

Figure 2: Crack growth rate as a function of the cylinder radius, r for $\mathcal{G}/\mathcal{G}_c = 0.5$. Results are converged in terms of the size of L_e and Δa. The used material properties are obtained from [2]. The parameters c_1, c_2 and c_3 are obtained by a best fit in the range $\mathcal{G}/\mathcal{G}_c \in [0.2, 0.9]$ for $r = 100$mm

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