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Cohesive zone and interfacial thick level set modeling of the dynamic double cantilever beam test of composite laminate

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Abstract

The mode-I interlaminar fracture toughness of composite laminates under different loading rates can be measured by the double cantilever beam (DCB) test. It is observed from the DCB test of a unidirectional PEEK/carbon composite laminate that as the loading rate increases from quasi-static to dynamic range: (1) delamination crack growth exhibits a transition from stable to unstable ("stick/slip") and back to a stable type; (2) the interlaminar fracture toughness is not constant as the loading rate increases. In this paper, two numerical approaches are used to reproduce the experimental observations: a cohesive zone model (CZM) and the interfacial thick level set (ITLS) model. CZM simulations with rate-independent and rate-dependent cohesive laws are carried out. A new version of the ITLS is introduced with a phenomenological relation between crack speed and energy release rate. The simulation results of the CZM and the ITLS model are compared with the real DCB test data to evaluate the capability of these two types of models. It is found that the used CZM can reproduce rate-dependence of the fracture energy, but not the stick/slip behavior. The ITLS can capture the stick/slip behavior, but needs different parameter sets for different loading rates.

Keywords: Double cantilever beam, Rate dependency, Crack arrest, Cohesive zone model, Thick level set

1. Introduction

Delamination is one of the crucial degradation mechanisms of composite laminates [1]. Engineering composite laminates can be subjected to complex working load conditions including quasi-static and dynamic loading (e.g. low velocity impact). In order to predict the extent of delamination under given load conditions, it is important to quantify the interlaminar fracture toughness of composite laminates for both quasi-static and dynamic loading.

The double cantilever beam (DCB) test is one of the most commonly used experimental methods for determining the mode-I interlaminar fracture toughness [2]. Studies on measurement of the mode-II, mode-III interlaminar fracture toughness can be found in [3–8]. Based on published results on the DCB test with a smallest test rate of 1.67×10^{-7} m/s in [9] and a largest test rate of 15 m/s in [10, 11], the following observations can be made. Firstly, depending on the investigated test rate and composite system, the crack propagation in the DCB test could be either stable or unstable ("stick/slip") [3, 9, 10, 12–14]. In [9], where a carbon/epoxy composite material, T300/2500, was tested within the crosshead speed range of 1.67×10^{-7} to 8.33×10^{-3} m/s, the delamination crack growth was unstable for test rates lower than 8.33×10^{-6} m/s and became stable for higher test rates. In [12], a unidirectional and a woven carbon/epoxy composite laminate with 19% inclusion of transversal E-glass fibres was tested with different crosshead velocities ranging from 8.3×10^{-5} m/s to 0.19 m/s. For both materials and all loading rates, the crack propagated in an unstable fashion. Secondly, the loading rate may influence the fracture toughness although there is no universal trend in increased loading rate effects on the toughness. Aliyu and Daniel [15] investigated an AS-4/3501-6 carbon/epoxy system with DCB tests at a crosshead displacement rate up to 8.5×10^{-3} m/s. It was found that the mode-I interlaminar fracture toughness increased 28% over three orders of magnitude of loading rate. Smiley and Pipes [13] found that the mode-I interlaminar fracture toughness for APC-2 carbon/PEEK composite remains constant over four decades of low loading rates while further increase in loading rate caused a decrease up to 70% over the next decade of loading rate. This inconsistency in the trends might be attributed to differences in material constituent, specimen geometry, data-reduction scheme, measurement technique and definition of the rate parameter [16, 17].