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EFFECT OF PROCESS-INDUCED DEFECTS ON MODE I BEHAVIOR OF PMCS: RANDOM DEFECTS VS. CONTROLLED DEFECTS

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Abstract

With advances in composite manufacturing, the need to establish process-microstructure-property relations remains an ongoing challenge. Effective property predictions, including damage tolerance behavior of advanced composites, often requires explicit modeling of defects and investigating the onset and propagation of damage. The high porosity level is a more commonly encountered defect in heterogeneous composite materials. The current work uses the cohesive zone modeling (CZM) approach adapted for explicit defects in the crack path within a finite element (FE) numerical framework. Random and controlled pore distributions have been modeled and numerically compared. Experimental efforts toward creating controlled pores in the crack path are ongoing. The execution of the current approach will enable better material behavior predictions for advanced composite materials.

1. Introduction

Composites are a key instrument in the future of high-performance aerospace materials due to their advantageous material properties, such as low density, high strength, and low thermal expansion coefficient. However, current manufacturing processes for composites produce pores. As a result, it is essential to understand the role porosity plays in the effective material properties, including damage tolerance. This paper seeks to develop the process for modeling and computationally testing a composite material with random pore distributions and a purposefully designed 'engineered' pore distribution under Mode I delamination using a double cantilevered beam (DCB) test per ASTM Standard D-5528 [1].

2. Results

The CZM approach has been implemented using a bilinear traction separation law wherein the cohesive surface exhibits linear elastic behavior until damage onset (δo), beyond which a linear softening law governs damage evolution (see figure 1). The constitutive behavior follows equation (1) with damage (*D)* defined in equation (2). For $\delta \leq \delta_o$ (prior to softening onset), $\sigma_n \leq t_n$and *D=0.* As $\sigma_n > t_n$, D gradually increases with *D=1* representing the opening up of the crack or crack progression. A mixed-mode power law has been used for the damage propagation criterion based on equation (3). The cohesive and other mechanical properties, numerical implementation, and validation were conducted based on Turon et al. [2].

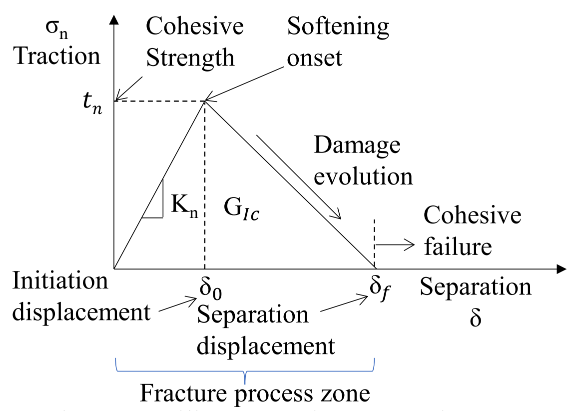
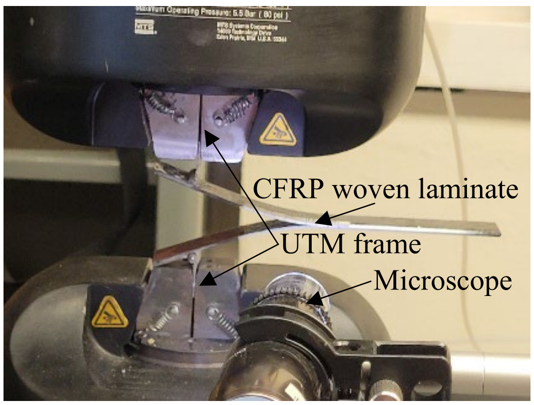


Figure 1. Bilinear traction separation law used for CZM

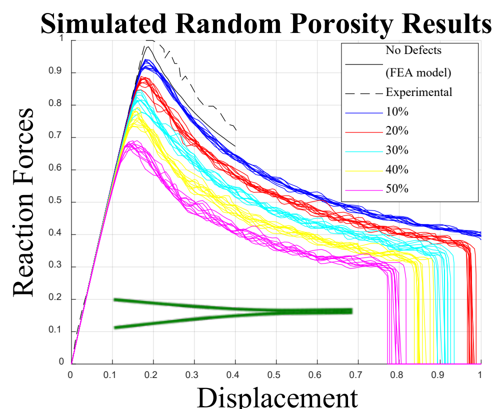
$$\sigma_n = (1-D)K_n\delta \qquad (1), \qquad D = \max\begin{cases} 0 & \delta \leq \delta_o \\ \frac{(\delta-\delta_o)\delta_f}{(\delta_f-\delta_o)\delta} & \delta \leq \delta_o \\ 1 & \delta \leq \delta_o \end{cases} \qquad (2)$$

$$\left\{\frac{G_I}{G_{Ic}}\right\}^{\alpha} + \left\{\frac{G_{II}}{G_{IIc}}\right\}^{\alpha} + \left\{\frac{G_{III}}{G_{IIIc}}\right\}^{\alpha} = 1 \qquad (3)$$

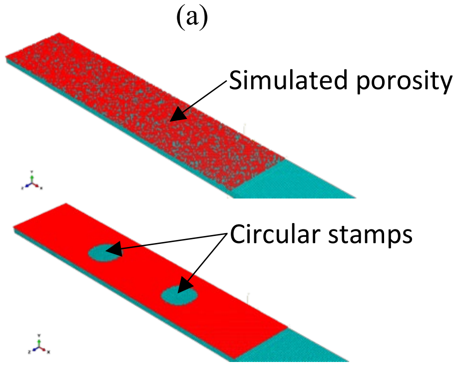
Laboratory testing has been completed with the setup shown in figure 2(a) based on ASTM standard D-5528 [1]. Figure 2(b) displays the preliminary numerical results validated with experimental data from [2] designated as ‘no defects’. Additionally, figure 2(b) depicts the load-displacement plots for randomized porosities 10% - 50% of bonded region as shown in Figure 2(c). This numerical procedure and results align with the work of Kumar [3]. Random pore distribution represents a realistic specimen given its inherent porosity. This model is created within Abaqus FE framework via python scripting interface by defining a random function generator on the nodes along the interaction layer to remove a specified number of nodes simulating porosity in the crack path. A engineered pore distribution, the circular stamps in figure 2(c), represents a lab specimen with designed porosity, figure 2(d). The displayed circular stamp figure 2(c) is not currently to scale with figure 2(d), as the testing outline and the material parameters are being finalized. With the results of lab testing and the results of the porous computational models a relationship between porosity and effective material behavior will be firmly established. Alternative patterns such as strips across or through the specimen, size effects of the pores and other traction separation critieria will be considered.



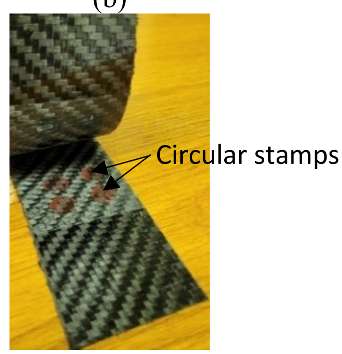
(a)



(b)



(c)



(d)

Figure 2. (a) The DCB testing setup (b) plotted nodal bands at various porosity levels and experimental results with nested computational testing setup, (c) 20% simulated porosity virtual DCB testing specimen and a vitual model with porous circular stamps and (d) a lab specimen with designed porous stamps

3. Conclusions

The objective is to prove a methodology for capturing the effects of porosity with the engineered porosity and then extrapolate the results to the realistic, random pore distribution. This method will then be generalized to find effective material properties and predict behavior for all porous composite materials.

4. References

[1] ASTM Standard D5528.
[2] A. Turon et al. Engineering Fracture Mechanics, Volume 74, 2007.
[3] R. Kumar. Engineering Fracture Mechanics, Volume 248, 2021.