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Micro-Mechanical Modeling of Nano-Toughened Adhesives

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Constraint, Finite Volume, Unit Cell, Void Growth

1 Introduction

Significant toughening of structural adhesives is attainable with addition of nano particles. Experimental Tapered Double Cantilever Beam (TDCB) tests conducted at University College Dublin (UCD) have observed a significant dependance of the fracture toughness of these adhesives with bond gap thickness[2]. Classical analysis suggests the change in toughness may be attributed to a physical constraint of the size of which a plastic zone around a crack tip may develop. However, simulation of these TDCB tests using OpenFOAM have found that little plasticity develops in the bulk adhesive layer and is instead concentrated in the fracture process zone. Significant changes in void evolution with bond gap is observed on the fracture surface of these tests using SEM. This research aims to develop a realistic numerical model of the studied adhesive to investigate the parameters affecting damage evolution and fracture in the fracture process zone, which ultimately affect the toughness of these adhesives.

2 Methods & Results

A void growth model derived by Rice & Tracey[1] describes a dependance of void growth, D, on constraint, H, defined as

$$D = 0.283e^{1.5H}, H = \frac{\sigma_{hyd}}{\sigma_{eq}} \tag{1}$$

where σ_{hyd} is the hydrostatic stress and σ_{eq} is the equivalent stress.

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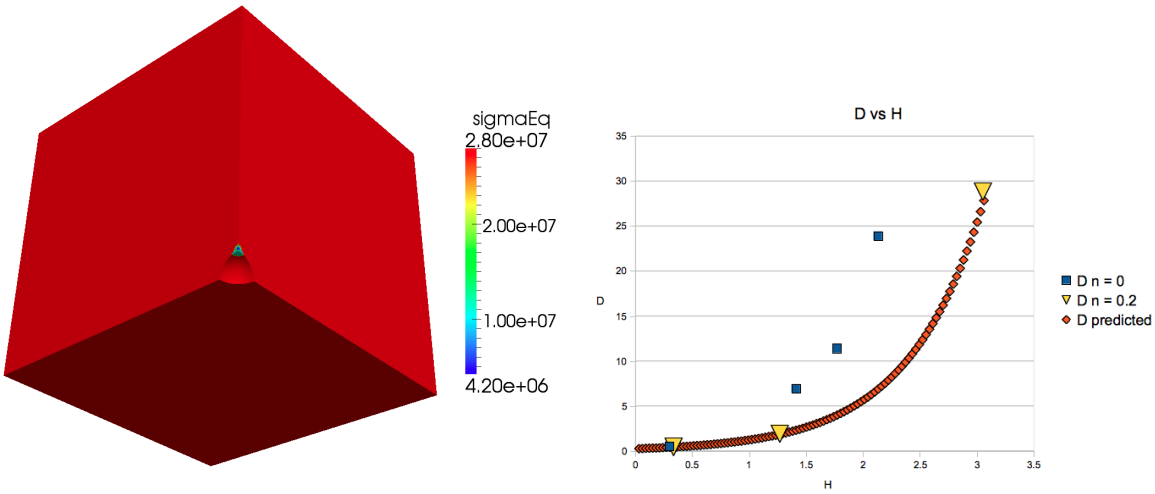

(a) Sigma Equivalent

(b) Void growth vs constraint

Figure 1: Numerical results

A spherical void in center of a unit cell was made in Gambit and meshed using Gambit and the OpenFOAM utility *fluentMeshToFoam*. Due to 3 planes of symmetry, only one eighth of the geometry was modeled. A displacement was prescribed on one face of the unit cell and for a particular constraint, stresses were calculated and imposed on the two remaining faces giving a particular value of constraint, H for every time-step in each case. A stress analysis solver incorporating plasticity implemented in OpenFOAM was employed. A homogenous model was considered; isotropic elastic-plastic material with a Youngs modulus of 8.4 GPa, yield stress of 28 MPa, strain hardening coefficients, n, of 0, 0.1 and 0.2, elastic Poissons coefficient of 0.3 and plastic Poissons coefficient of 0.5. Dramatic increase in void growth with constraint was observed but results do not correspond directly with that of Rice & Tracy[1] for all strain hardening exponents.

3 Conclusions

Numerical analysis of void growth as a function of constraint, H, was performed using finite volume based OpenFOAM and compared with finite element based Abaqus and good agreement was found between them. Initial results show significant dependance of void growth with constraint but do not adhere to the classical void growth model of Rice & Tracey [1]. The authors wish to acknowledge financial support from Henkel and the SFI/HEA Irish Centre for High-End Computing (ICHEC) for the provision of computational facilities.

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