FINITE ELEMENT MODELING OF DELAMINATION IN THICK-SECTION COMPOSITES USING LS-DYNA

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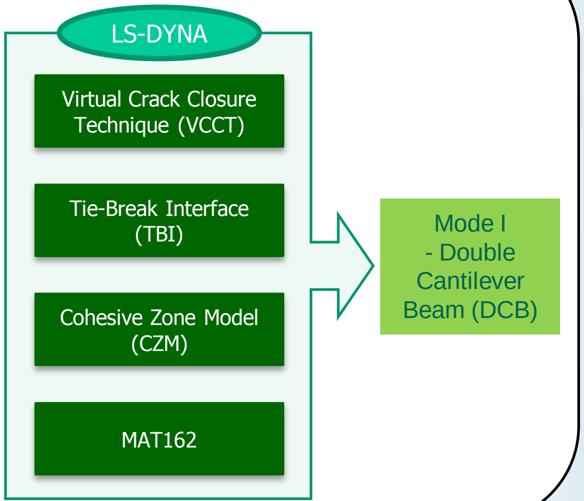
INTRODUCTION

- Delamination brings significant material degradations in both stiffness and strength under compression, tension, and flexural loading
- Delamination can occur under any combination mixed Mode I, Mode II, and Mode III
- Different methods have been used to simulate and predict the Mode I opening delamination
  - Linear Elastic Fracture Mechanics Based Methods
  - Stress Based Methods
- It is necessary to set up parameters necessary for suitable prediction of delamination initiation and propagation

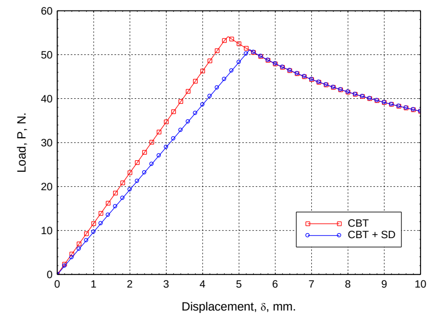
RESEARCH SCOPE



THEORETICAL SOLUTION FOR DCB

- Theoretical solution with shear deformation (Kageyama et al., 1987)

$$C=\frac{\delta}{P}=\frac{8(a+2H)^3}{E_x BH^3}+\frac{3a}{G_{zx}BH} \qquad G_{IC}=\frac{P^2}{2B}\left(\frac{24(a+2H)^2}{E_x BH^3}+\frac{3}{G_{zx}BH}\right)$$



VCCT (1)

- Proposed by Rybicki (1977)
- Assumption: Energy released due to the crack extension is identical to the energy required to close the crack
- Energy release rate (G) is calculated by nodal force at the tip and nodal displacement before the tip

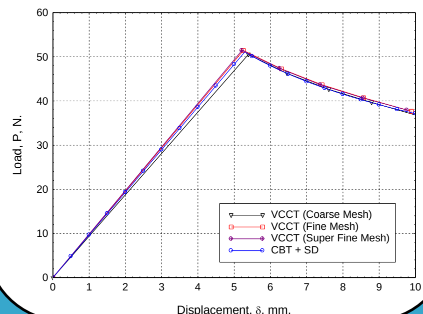
$$G_I=-\frac{1}{2\Delta A}Z_{Li}(w_{Li}-w_{Li^*}),$$

$$G_{II}=-\frac{1}{2\Delta A}X_{Li}(u_{Li}-u_{Li^*}),$$

$$G_{III}=-\frac{1}{2\Delta A}Y_{Li}(v_{Li}-v_{Li^*}),$$

VCCT (2)

- Results matches well with the theoretical solution and is mesh insensitive



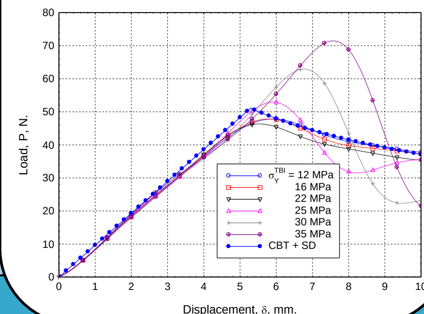
TBI & CZM (1)

- TBI: Contact option 6 in LS-DYNA
- CZM: MAT 138 in LS-DYNA
- For both delamination models, linear elastic fracture mechanics is included for crack propagation

$$G_{IC}=\frac{1}{2}\times\sigma_Y\times d_N$$

TBI & CZM (2)

- There is a threshold for nodal strength for suitable prediction



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(Continued)

METHODOLOGY FOR TBI AND CZM

- Taking advantage of the merit of VCCT
- Beam on an elastic foundation model is used in estimating the end rotation correction for DCB specimen (Williams, 1989)
- Nodal strength (maximum traction) and corresponding displacement:

$$\sigma_Y = \frac{G_{IC}}{w(l_e)} = \frac{G_{IC}}{\frac{2P_{cr}}{BE_X H^3}(a-l_e)^3 + \left(C_1 - \frac{P_{cr}}{KG_{ZX}BH}\right)(a-l_e) + C_2}$$

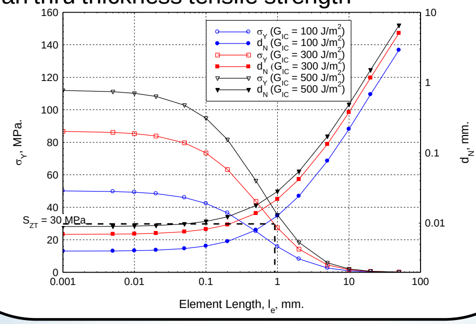
$$d_N^{VCCT} = \frac{2G_{IC}}{\sigma_Y}$$

- Minimum element length for DCB with $\sigma_Y^{TBI} = S_{ZT}$
  ➔ Solution of the following polynomial

$$\frac{2P_{cr}}{BE_X H^3}(a-l_e)^3 + \left(C_1 - \frac{P_{cr}}{KG_{ZX}BH}\right)(a-l_e) + C_2 = \frac{G_{IC}}{S_{ZT}}$$

METHODOLOGY FOR TBI AND CZM

- If element length is smaller than the minimum element length, through thickness tensile strength can be used as a nodal strength
- If element length is larger than the minimum, one needs to obtain a nodal strength, which is less than thru thickness tensile strength



MAT 162 FOR MODE I APPLICATION

- 3D composite damage mechanics constitutive model developed by MSC and UD-CCM
- Delamination onset

$$S^2\left\{\left(\frac{E_Z\langle\varepsilon_Z\rangle}{S_{ZT}}\right)^2 + \left(\frac{G_{YZ}.\varepsilon_{YZ}}{S_{YZ}+E_Z\tan(\varphi)\langle-\varepsilon_Z\rangle}\right)^2 + \left(\frac{G_{ZX}.\varepsilon_{ZX}}{S_{ZX}+E_Z\tan(\varphi)\langle-\varepsilon_Z\rangle}\right)^2\right\} - r^2 = 0$$

- Softening: Matzenmiller's damage model (1995)

$$\omega = 1 - e^{\frac{1}{m}(1-r^m)} \qquad \text{(m: softening parameter)}$$

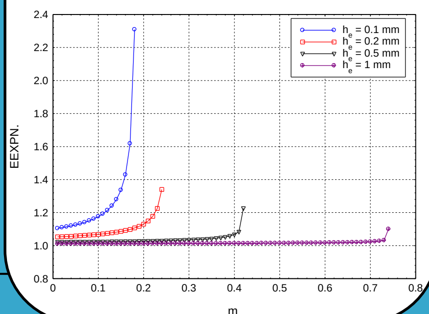
- Connection of stress-based failure criteria with fracture mechanics

$$\bar{G}_{IC} = U_e h_e$$

- Eroding the MAT162 elements at the delamination front using the element eroding volumetric expansion parameter, i.e., EEXPN

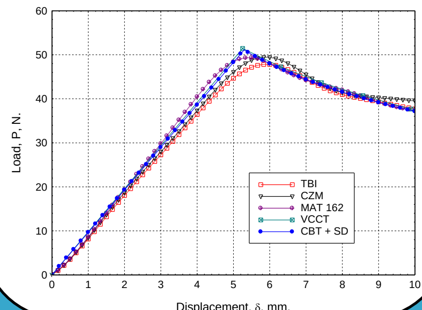
MAT 162 FOR MODE I

- For small element thickness, EEXPN is sensitive to m value



RESULT

- Comparison of all the methods used with theoretical solution



CONCLUSION (1)

- Different modeling methodologies in simulating Mode I delamination in explicit finite element analysis code LS-Dyna 971 are presented with comparison to VCCT and theoretical solution.

  (i) Tie-Break-Interface (TBI)

  (ii) Cohesive Zone Model (CZM)

  (iii) MAT162

CONCLUSION (2)

- For TBI and CZM, a new methodology is developed to theoretically determined the mesh dependent stress-displacement pair by combining the VCCT and William's beam on elastic foundation solutions.
- The pseudo-physical delamination model MAT162 is shown to predict the initiation of delamination accurately using the stress based criteria.