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

Virtual Crack Closure Technique (VCCT)

Tie-Break Interface (TBI)

Cohesive Zone Model (CZM)

MAT162

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

\[
C = \frac{\delta}{P} \left[ \frac{3\sigma}{G_{IC}} \right] + \frac{G_{IC}}{2B} \left( \frac{2\sigma + 2H}{H} \right) + \frac{3}{G_{IC}} \right]
\]

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.

\[
G_1 = -\frac{1}{2\Delta A} Z_{i}(w_{i} - w_{i+1}),
\]

\[
G_2 = -\frac{1}{2\Delta A} X_{i}(u_{i} - u_{i+1}),
\]

\[
G_3 = -\frac{1}{2\Delta A} Y_{i}(v_{i} - v_{i+1}).
\]

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.

\[
G_{IC} = \frac{1}{2} \sigma_{y} \times d_{y}
\]

TBI & CZM (2)

There is a threshold for nodal strength for suitable prediction.

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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:
  \[ \sigma_m = \frac{G_0}{w(t)} \left[ \frac{2P}{BE_i} \right] (a^{-1})^2 + \left[ \frac{P}{K_G BH} \right] (a^{-1}) + C_i \]
- Minimum element length for DCB with \( \sigma_m^m = S_{th} \)
  Solution of the following polynomial
  \[ \frac{2P}{BE_i} (a^{-1})^2 + \left[ \frac{P}{K_G BH} \right] (a^{-1}) + C_i = \frac{G_0}{S_{th}} \]

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.
  1. Tie-Break-Interface (TBI)
  2. Cohesive Zone Model (CZM)
  3. 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.