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FINITE ELEMENT MODEL FOR IMPACT ON COMPOSITE STRUCTURES

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Outlines

- Context
- Experiments
- Modeling
- Conclusion
Context of the work

Manufacturing

Design of Experiments

Modeling

Impact tests

Characterization

Fatigue

bi-axial Impact

NDT

Tomography RX

Study of impacted composites
Aim of the work

Manufacturing

Characterization

Impact

Modeling

Design of Experiments

Fatigue
Impact tests

Aims

- Use of optical NDT measurements
- Measurements of the residual penetration and the damaged area
- Develop reliable methods for measurements
- Confirm that 25J is the BVID impact energy

<table>
<thead>
<tr>
<th>Test device</th>
<th>MTT drop weight device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impactor</td>
<td></td>
</tr>
<tr>
<td>Diametre</td>
<td>16 mm</td>
</tr>
<tr>
<td>Shape</td>
<td>hemispherical</td>
</tr>
<tr>
<td>Material</td>
<td>Steel Rm = 2000 Mpa</td>
</tr>
<tr>
<td>Ra</td>
<td>&lt; 0.8</td>
</tr>
<tr>
<td>Mass</td>
<td>3 kg</td>
</tr>
<tr>
<td>Impact Energy</td>
<td>25 J</td>
</tr>
<tr>
<td>Drop height</td>
<td>0.849m</td>
</tr>
<tr>
<td>Samples CF/Epoxyde [(45/0)_3]</td>
<td>Thickness : 4.52mm</td>
</tr>
<tr>
<td></td>
<td>Dimension : 150 * 100 mm²</td>
</tr>
</tbody>
</table>

Clamp
Residual penetration measurement by fringes pattern

Stages of residual penetration measurement

- Fringes pattern
- Creation of the plane z=0
- Cartography of the differences/plane z=0
- meshing

<table>
<thead>
<tr>
<th>Penetration (mm)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C1-1</td>
<td>0.275</td>
</tr>
<tr>
<td>C1-2</td>
<td>0.275</td>
</tr>
<tr>
<td>C1-3</td>
<td>0.274</td>
</tr>
<tr>
<td>mean</td>
<td>0.275</td>
</tr>
<tr>
<td>C2-1</td>
<td>0.219</td>
</tr>
<tr>
<td>C2-2</td>
<td>0.24</td>
</tr>
<tr>
<td>C2-3</td>
<td>0.251</td>
</tr>
<tr>
<td>mean</td>
<td>0.237</td>
</tr>
<tr>
<td>C3-1</td>
<td>0.309</td>
</tr>
<tr>
<td>C3-2</td>
<td>0.314</td>
</tr>
<tr>
<td>C3-3</td>
<td>0.349</td>
</tr>
<tr>
<td>mean</td>
<td>0.324</td>
</tr>
</tbody>
</table>
Damaged area (DA) measurement by IR thermography

- **NDT by IR thermo**
- **IR film treatment**
- **Damage area processing**
- **Choice of the max damage**

<table>
<thead>
<tr>
<th>Sample</th>
<th>DA mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1-1</td>
<td>394.7</td>
</tr>
<tr>
<td>C1-2</td>
<td>397</td>
</tr>
<tr>
<td>C1-3</td>
<td>393.8</td>
</tr>
<tr>
<td>mean</td>
<td>395.2</td>
</tr>
<tr>
<td>C2-1</td>
<td>349.4</td>
</tr>
<tr>
<td>C2-2</td>
<td>349.4</td>
</tr>
<tr>
<td>C2-3</td>
<td>349.2</td>
</tr>
<tr>
<td>mean</td>
<td>349.3</td>
</tr>
<tr>
<td>C3-1</td>
<td>321.1</td>
</tr>
<tr>
<td>C3-2</td>
<td>319.9</td>
</tr>
<tr>
<td>C3-3</td>
<td>309.2</td>
</tr>
<tr>
<td>mean</td>
<td>316.7</td>
</tr>
</tbody>
</table>
Impact tests results

Conclusions

- Boths methods are repetitive and no judgement of the person is necessary
- Penetration confirms that 25J is the BVID impact energy
- CAI stress is governed by the damaged area so by the cure cycle

Need a medium to predict this results if change of materials
Modeling

Aims

- Create an advanced model representing low-velocity impact on composite plate
- Model should be used by Daher-Socata Industry
- Correlate it with simple finite element model and experiments in terms of damaged area

Choices

- FEM software : Abaqus
- Advanced model
  - Need to separate phenomenon
  - Need to use known theory
  
  Modeling each ply by a laminate and each interply by a cohesive surface
Creation of the model

1. Create an orphan mesh
2. Offset the orphan mesh to create shell part
3. Offset the orphan mesh to create shell interface
4. Continue offsetting to realise the whole lay-up

- Assign orientation for each ply that have a $\theta$ direction
- Assign continuum shell for plies and cohesive behaviour for interplies
Theories used for the model

Progressive damage in fiber reinforced composite (ply)

- Hashin’s damage initiation criteria

\[ f_I = \left( \frac{\sigma_{11}}{X_T} \right)^2 + \alpha \left( \frac{\sigma_{12}}{S_L} \right)^2, \text{ where } 0 \leq \alpha \leq 1 \]

\[ f_{II} = \left( \frac{\sigma_{11}}{X_C} \right)^2 \]

\[ f_{III} = \left( \frac{\sigma_{22}}{Y_T} \right)^2 + \left( \frac{\sigma_{12}}{S_L} \right)^2 \]

\[ f_{IV} = \left( \frac{\sigma_{22}}{2S_T} \right)^2 + \left[ \left( \frac{Y_C}{2S_T} \right)^2 - 1 \right] \frac{\sigma_{22}}{Y_C} + \left( \frac{\sigma_{12}}{S_L} \right)^2 \]

- Evolution law based on energy dissipated (Davila & Camanho)

\[ d = \frac{\delta_{eq}' \left( \delta_{eq} - \delta_{eq}^0 \right)}{\delta_{eq}' \left( \delta_{eq}' - \delta_{eq}^0 \right)} \]
Theories used for the model

Progressive damage in cohesive elements (interply)

- initiation : Maximun stress criteria

$$MAX \left\{ \frac{\langle \sigma_n \rangle}{N_{max}}, \frac{\sigma_t}{T_{max}}, \frac{\sigma_s}{S_{max}} \right\} = 1$$

- Evolution : linear traction separation law
  - taking into account effective displacement

$$\delta = \sqrt{\langle \delta_n \rangle^2 + \delta_s^2 + \delta_t^2}$$
**Model**

**Used elements**
- Continuum shells : SC8R
- Cohesive elements : COH3D8

**Type of analysis**
Explicit

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size of elements</strong></td>
<td>5 x 5 mm²</td>
</tr>
<tr>
<td><strong>Number of elements</strong></td>
<td>18601</td>
</tr>
<tr>
<td><strong>Number of DoF</strong></td>
<td>62502</td>
</tr>
<tr>
<td><strong>Number of CPUs</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>Type of parallelization</strong></td>
<td>Domain</td>
</tr>
<tr>
<td><strong>Total time</strong></td>
<td>4h20min</td>
</tr>
</tbody>
</table>
Results/Correlation

Modeling
- Enveloppe results
- 13 eroded elements (coh3d8+sc8r)
- Damaged area: 325 mm²
- Differentiation between crack ply and delaminated interface

IR Thermography
- Damaged area: 349.3 mm²
- Difference modelling / IR thermo: 7.5%
Perspectives

**Impact model**
- Make the mesh coarser to perform the correlation of the DA
- Use another type of evolution criteria for cohesive elements
  - Benzeggagh-Kenane for example

**Impact test**
- Finish to adapt sensor in the drop weight device
- Correlate other datas
Thanks for your attention