Optimization of the process of X-ray tomography applied to the detection of defects in composites materials

C. UHRY¹, F. GUILLET¹, V. KAFTANDJIAN², P. DUVAUCHELLE²

¹ CEA/DAM, Le Ripault, 37260 Monts, France
² INSA Lyon, 69621 Villeurbanne, France
Carbon fiber-reinforced polymers (CFRP): high mechanic resistance compared to their weight

Example: hydrogen reservoir

- Composed of filament of carbon fibers impregnated with epoxy resin
- Architecture is obtained by filament winding around a cylindrical polyamide liner

Defects can decrease the thermo-mechanical properties of the material

- Non destructive inspection is mandatory
- CT provides 3D images of internal structures allowing detection of defects

- CT is a relevant tool for inspection of CFRP materials
INTRODUCTION

CT scan of a hydrogen reservoir

- Good detection of porosities
- Architecture defects more complicated to detect
PROBLEM

- Simulation: VXI (Virtual X-ray Imaging) a deterministic software (INSA Lyon)
- Weak contrast => optimization of the tomographic process should be considered
- Experimental validation of the computation with a simple phantom object

<table>
<thead>
<tr>
<th>Materials</th>
<th>Chemical composition (wt%)</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbone</td>
<td>C: 100%</td>
<td>1,8</td>
</tr>
<tr>
<td>Epoxy</td>
<td>C: 76%  O: 17%  H: 7%</td>
<td>1,2</td>
</tr>
</tbody>
</table>

- Study of the experimental parameters and phenomena that decrease contrast in CT scan
- Simulation: VXI (Virtual X-ray Imaging) a deterministic software (INSA Lyon)
- Experimental validation of the computation with a simple phantom object
1. **Material and method**
   - The phantom
   - The experimental measurement
   - The simulation

2. **Results**
   - Projection comparison

3. **Discussion**

4. **Conclusion**
1. Material and methods: the phantom

- Characteristics of phantom object are close to the hydrogen reservoirs.
- Importance of the chemistry composition
- Comparison of simulated and experimental projection using homogeneous samples of graphite and resin: 2% difference

### Materials and Chemical Composition

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<tr>
<th>Materials</th>
<th>Chemical composition analysis (wt%)</th>
<th>Density</th>
</tr>
</thead>
</table>
| Graphite          | C : 93%  
                    O : 4%   
                    Si : 1.1%  
                    S : 1.1%  | 1.7     |
| Resin (RSF)       | C : 71%  
                    O : 17%  
                    H : 8%   
                    Cl: 0.6% | 1.15    |

**Graphite K10**

**RSF 816**
1. Material and methods: experimental measurement

Voltage: 90kV
Exposure: 8.9s
Intensity current: 550µA

Square pixel size: 100µm
Image size: 4000x4000 pixels

Reconstruction: DigiCt (DigiSens)
Reconstructed volume: 106.6 mm x 106.6 mm x 30 mm

Coupling lens

3600 projections along 360°
1. Material and methods: the simulation

Virtual X-ray Imaging (VXI), a deterministic simulation code

- Ray-tracing technique
- Computation of the first order of phantom scattering

One projection is computed with VXI

Duplication of the projection

Reconstruction
2. Results: projection comparison

Experimental projection

Computed projection

Normalized greyscale level

Pixel number
3. Hypothesis: backscattering phenomenon inside the detector

Hypothesis:
- The mirror backscatters X-ray photons towards the scintillator
- X-ray photons backscattered are absorbed by the scintillator and contribute to the signal
- Backscattered phenomenon is more important in the right side of the detector
3. Measurement of the backscattering in the detector

Measurement of the backscattered radiation

- A lead panel covers the entire surface of the scintillator, except for a vertical slit
- Measurement of the backscattered radiation on each side of the slit

As expected, scattered intensity is higher at the right of the detector.
3. Measurement of the backscattering in the detector

- Measurement of the backscattering along the entire width of the detector
- Backscattered radiation were considered in the central line
- Rough computation of the backscattered radiation $I_{\text{backscattered}}$ from a projection $I_{\text{measured}}$

$$I_{\text{backscattered}} = \alpha \cdot I_{\text{transmitted}} \approx \alpha \cdot I_{\text{measured}}$$

- Backscattered radiation is higher on the right side of the projection
- Contribution of the backscattering is higher without object
3. Discussion: projection comparison

![Graph showing comparison of experimental and computational data with and without backscattering.](image)
3. CT scan comparison

- Linear attenuation coefficient is overestimate in simulation
- Cupping effect is underestimate in simulation
- The computation of the backscattering allows to reduce more than the half of the gap between experimental and simulation
4. Conclusion

Simulation can be used in order to optimize the tomographic process

- Study of materials displaying weak contrast difference requires to have an accurate computation
- An experimental validation of the computation is mandatory
- Importance of the chemistry of materials
- Simulation can reveal experimental artefact

Study of optimization of contrast between carbon and resin is under process
Thank you for your attention
Experimental CT scan

- Heterogeneities can be observed in the graphite layers
- Linear attenuation coefficient is higher in the border than in the center, corresponding to higher graphite density in the border
- Graphite were cut from blocks of graphite, a process which could account for higher densities close to the cutting zone