Image based modelling of composites and lightweight materials

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Overview

• What is image-based modelling?
  – Tomographic imaging

• Why the need?
  – Microstructurally-faithful models

• Where is it used?
  – Metallic/carbon foams
  – Long-fibre composites

• How is it done?
  – Size of models

• Summary
• Acknowledgements
What is image based modelling?

Source: Vendel Szeremi
What is X-ray tomography?

- Transmitted intensity from a series of line projections of a cross section of the object at different angular orientations reconstructed to give **3-D map of x-ray absorption**
- Advantages
  - Non-intrusive
  - Good spatial resolution (currently $\approx 1\mu m$ in lab; $\approx 0.1\mu m$ at synchrotron sources)
  - Very sensitive to composition and density
  - Independent of specimen geometry
Tomography setup

Sample in Perspex Tube

X-Ray Source

Detector Camera
Tomography setup

- X-Ray Source
- Sample
- Detector Camera
Why the need?

- Complex architectures
  - Reinforcement distributions
  - Cell walls
- Fabrication defects
  - Flaws, cracks, porosity
- No need for idealisation of structure or defect
- Model actual test specimen
- Model “intractable” problems

Carbon-carbon composite.
2.5 x 2.5 x 2.5 mm FE model
Mises stress plot
Where has it been used?

• Energy materials
  – Graphite mechanical and physical behaviour (VHTR)
  – C/C and SiC/SiC

• Light materials
  – Metallic and polymeric composites
  – Cellular solids
  – Damage tolerance

• Biomaterials
  – Mechanical behaviour of bone
  – Characterisation of porous scaffolds
Metallic foams
Compression test

Graph showing compression test results with percentage values along the x-axis and corresponding images representing different stages of compression. The graph includes marks indicating 1%, 2.5%, 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 50%, 60%, 70%, 78.3%, and 78.3% on the x-axis.
What information can it provide?

- Characterise microstructure (without sectioning)
  - Distribution of phases
    - Mineral content
    - Size, shape and volume fraction of solid
    - Size, shape and volume fraction of voids
- Deformation mechanisms *in situ*
- Density measurement (without weighing)
  - Quantitative
  - Local: pixel-by-pixel or density map
- Mesh for FE analysis
  - “true” representation of structure
How is it done? - Workflow

Scan data

FE model

Image processing

Meshing
How is it done? – Scanning

• Medical scanners
  – CT – Computerised tomography
  – MRI – Magnetic resonance imaging
  – US – Ultra-sound

• Industrial scanners
  – Industrial CT scanners
  – MicroCT
  – NanoCT

• Any other modality that generates values arranged on a regular 3D grid
How is it done? – Image processing

- Import industrial CT, MicroCT, X-ray tomography (XMT) files
- Visualisation of complex data set
- Segmentation
- Low distortion, multipart surface mesh
How is it done? – Meshing

• Multi-part meshing
  – Robust automated mesh generation for topologies of arbitrary complexity (such as foams) and with any number of constituent materials/phases

• Image-based accuracy
  – Geometric accuracy of mesh domains is only dependent on image accuracy

• Material properties
  – Assigned within a given structure based on signal strength
How is it done? – FE analysis

- Direct export to ABAQUS
  - Nodes, Elements, Contact surfaces
  - Material properties
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- Direct export to ABAQUS
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Is size important?

• How large a volume do you need to model?
• What resolution mesh do you need?
• As resolution of XMT systems improves, data sets and mesh sizes expand
• Development of visualisation methodologies
• Development of serial mesh generation
  – Any size mesh (so far up to 320 GB data set)
• Development of parallelised FE code
  – ParaFEM
  – Ultrascalable
Example – Eagle owl claw
Large meshes

- Abaqus, on a typical PC (2GB memory), can handle up to ~300K degrees of freedom.
- 3D microstructurally faithful models can have up to ~300M degrees of freedom. Can need parallel processing!
Mare Nostrum, Barcelona Supercomputer Center
Large Meshes

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Example: Velociraptor claw
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Multicore processing on workstations

- Dell workstation, 2 x quad core, 64GB RAM < 5,000€
Summary and conclusions

- Non-destructive, 3-D means of characterising structure
  - Development of analytical models
- Generate FE predictions based on structure and local mechanical/thermal properties
  - Good agreement with experiment
  - Not possible to go via the “CAD” path
- Develop code to consider large models
- Key role of architecture
Collaboration opportunities

• “Collaborating for Success”
  – Funding for exchange/placement on tomography
• HECToR Capability Challenge
  – £1.7M cpu time on HECToR
  – Address problems using image-based approach
• Tomographic suite
  – £2.3M to buy 4 new scanners
  – From high resolution (~100nm) to large object (~1m)
  – *In situ* thermomechanical testing
  – Supporting work on reconstruction, visualisation, region-of-interest tomography
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