Inner Defect Detection in Ceramic Matrix Composite Parts using 3D X-ray Image Registration

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What is CMC?

- High-performance material called Ceramic Matrix Composite (CMC) is used for trial manufacturing of new jet engine.

- CMC, applied to engine parts, has 3D woven structure comprising silicon carbide (SiC) yarns.

- It is known that CMC part’s strength is critically affected by inner defects such as meandering of the yarns.

- Detection of these defects is necessary to guarantee CMC part’s quality.

CMC tail cone of HYPR core engine [Ishizaki 07]

Exhaust guide vanes for ESPR engine [Ishizaki 07]

3D woven CMC model [Yamauchi12]

CT volume (Imitation of CMC)

Meandering defect

X-yarn (green)

Y-yarn (blue)

Z-yarn (red)
Detecting Meandering Defects of yarns

**INPUT**: CT volumes

Reference CT volume (designed model)

Test CT volume (test object)

Compare using registration

**OUTPUT**: CT volume (meandering defects part)

Difference volume
Registration based Approach

Reference CT volume (Fixed image)

Test CT volume (Moving image)

Rigid registration
- Align position roughly
- Obtain displacement vector field

Non-rigid registration
- Use displacement vector field to evaluate meandering defects (explain in latter slide)

Magnitude image of displacement vector
Rigid Registration for Flat Plate

Data is generated by simulation

INPUT

Reference CT volume

Overlapping before registration

Blue: Reference
Red: Test

Rigid registration

Overlapping after registration

Test CT volume

Meandering
Detecting Meandering Defects

Create a squared difference from overlapping region

Overlapping after registration

Squared difference after registration

Detected meandering defects
Rigid Registration for Curved Plate

- Data is generated by simulation

INPUT

Reference CT volume

Overlapping before registration

Blue: Reference
Red: Test

Test CT volume

Meandering

Overlapping after registration

Rigid registration
Detecting Meandering Defects

Create a squared difference volume from overlapping region

Overlapping after registration

Squared difference after registration

Detected meandering defects

Our proposal method detects meandering defects
Non-Rigid Transformation

**INPUT**: CT volume

- Deform
- Magnitude image of displacement vector

- Control point grid
- Distort coordinate system
- Displacement vector field

B-spline transformation (schematic)
Evaluation of Meandering Angle

**INPUT**: Displacement vector field

**OUTPUT**: Meandering angle value

Calculate meandering angle value from displacement vector field
Calculation of Meandering angle (Flat Plate)

- Our definition of meandering angle

\[ \theta = \tan^{-1} \left( \frac{h}{L} \right) \]

- But, this calculation method is not effective!

- In CT image, it is difficult to identify start of meandering

- Ideal case

- Actual case (CT image)

Practical calculation method is needed
Practical calculation method of meandering angle

Assume that small areas not affect to whole area

Approximation

Maximum displacement

\[ S = Lh = \frac{h^2}{\tan \theta} \]

\[ \theta = \tan^{-1} \left( \frac{h^2}{S} \right) \]

\( S \) is summation of displacement vector at each voxel
Examples

Computed near angle to expected angle

Angle $\theta = 6.737$ (°) $\theta = 3.961$ $\theta = 1.947$
(calculated)

Angle $\theta = 8.0$ (°) $\theta = 4.0$ $\theta = 1.0$
(designed)
Conclusion

• We proposed a detection method of meandering defects in CMC parts by registration of a reference CT volume with a test CT volume to obtain their difference in shapes.

• Proposed detection method demonstrated effectiveness to a flat plate and a curve plate of CMC (imitation)

• We also proposed an evaluation method of meandering angle in a flat plate

• Calculated angle error is less than 2 degrees
Future work

• Develop an detection method of kinking, breaking defects

• Develop an evaluation method of meandering angle in a curve plate

• Improve the evaluation method more accurately

• Apply this method to actual CMC data