



CIMComp **EPSRC Future Composites** lanufacturing Research Hub



# **Considerations and Potential for** Inductive Sensing Evaluation of **Carbon Fibre Composites**

#### **Robert Hughes**

Lecturer in Non-Destructive Testing Robert.hughes@bristol.ac.uk Ultrasonics & NDT Group (UNDT) Mechanical Engineering University of Bristol



## Non-Destructive Testing of CFRP







### bristol.ac.uk

# Fibre Reinforced Polymers (FRPs)

**Structure (Alignment)** 





bristol.ac.uk



**Common manufacturing defects\*** 

Side-profile micrograph of wrinkling



Credit: Ege Arabul, PhD Candidate, University of Bristol

\*S. Meister, composite manufacturing, 2021



# Inductive Sensing (Eddy-Current Testing)

- Non-contact
- High sensitivity
- High-speed
- Safe
- Simple data-analysis\*
- Sub-surface penetration\*\*
- \* Anomaly detection

\*\* Within a few mm



Hughes, R.R, EngD Thesis. University of Warwick, 2015.



### ECT of CFRP







bristol.ac.uk

7

D. Wu, F. Cheng, F. Yang, and C. Huang, "Non-destructive testing for carbon-fibre-reinforced plastic (CFRP) using a novel eddy current probe," Compos. Part B Eng., vol. 177, no. September, p. 107460, 2019.



# Considerations for Sensing of AFP

- C1: Ply stacking sequence
- C2: Inter-ply contact
- C3: Fibre density variations



# C2: Inter-ply Contact







#### Natural variability in local fibre volume fraction

### Contributes to coherent noise

## C3: Fibre Density

X-ray CT Data:

ECT Data:



Courtesy: Fernando Alvarez Borges, Mark Mavrogordato & Ian Sinclair,  $\mu$ Vis, University of Southampton, UK

### ECT of CFRP

### ECT of Cured C-Spar







Credit: William Rees, NCC



bristol.ac.uk

## Sensor Design – Vast Parameter Space



H. Kosukegawa, et.al, Philos. Trans. R. Soc. 2020

# Challenges & Opportunities

- 1. Application specific sensor design
  - a) Wide variety of materials, stacking sequences, defects
  - b) Multitude of design variables (one sensor does not fit all applications)
  - c) Requires effective modelling for virtual design optimisation
- 2. Industrial acceptance of ECT technology for CFRP inspection
  - a) Requires repeatable & reliable process for (1)
- 3. Advanced measurement inversion (electrical  $\rightarrow$  structural properties)
  - a) Requires accurate models of EC interactions with CFRP



# Potential

Modelling for sensor design

## bristol.ac.uk

# Simulating Ply Structure

- Simulating coherent structural noise
- Enables evaluation of defect selectivity







Yi, et.al., Comp. B., 2023





# Simulating Wrinkling







Mussatayev, M., et.al, Comp. B., 2023

### bristol.ac.uk

......

# Measuring Wrinkling







#### Mussatayev, M., et.al, Comp. B., 2023



# Virtual Sensor Comparison



bristol.ac.uk

Mussatayev, M., et.al, Comp. B., 2023





# **Conclusions & Future work**

- Developing a model-assisted sensor design process
- Demonstrated design comparison for wrinkling and waviness sensors

### Next steps:

- Sensor design optimisation for target defects
- Greater understanding required of relationship between fibre structure and electrical properties



# Acknowledgements

- Ege Arabul
- Atul Sharma
- Meirbek Mussatayev
- Qiuji Yi

- Vincent Maes
- Mark Fitzgerald
- James Kratz
  - Paul Wilcox



- 1. D. Maass, Progress in automated ply inspection of AFP layups, Reinf. Plast., vol. 59, no. 5, pp. 242–245, Sep. 2015
- 2. Hughes, R.R, Drinkwater, Smith, Characterisation of carbon fibre-reinforced polymer composites through radon-transform analysis of complex eddy-current data, Comp. B, 2018
- 3. S. Meister, composite manufacturing, 2021
- 4. Yin, W., Withers, P.J., Sharma, U., & Peyton, A.J. (2009). IEEE Transactions on Instrumentation and Measurement,
- 5. Bardl, G. et.al. Comp. B., 2016, doi: 10.1016/j.compositesb.2016.04.040

•

- 6. K. Mizukami et al., Compos. Struct., 2019, doi: 10.1016/j.compstruct.2019.111227
- 7. Marsh, G., Automating aerospace composites production with fibre placement, Reinforced Plastics, 2011
- 8. C. Schmidt et al., Composites: Part B, 56 (2014) 109–116
- 9. H. Kosukegawa, et.al, Evaluation of detectability of differential type probe using directional eddy current for fibre waviness in CFRP, Philos. Trans. R. Soc. 2020
- 10. Yi, et.al., Modelling and evaluation of carbon fibre composite structures using high-frequency eddy current imaging, Comp. B., 2023
- 11. Mussatayev, M., et.al., Directional eddy current probe configuration for in-line detection of out-of-plane wrinkles, Comp. B., 2023
- 12. Mizukami, K. et al., Compos. Struct., 2021
- 13. Pasadas et al., Measurement. 2020



# Thank you for listening



#### robert.hughes@bristol.ac.uk

Department of Mechanical Engineering, University of Bristol

