Modelling in-plane electrical behaviour of unidirectional and cross-ply carbon fibre laminates

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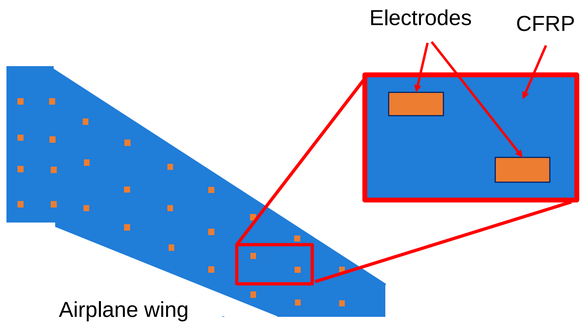
Background

One of the most promising methods to monitor the integrity of composite structures is the electrical resistance change method [1]. It is a developing method which directly associates damage with an increase in electrical resistance [2]. However, the 2D in-plane electrical resistance behaviour have been poorly studied in the literature, limiting the design of the electrode array to detect damage in carbon composites.

Objective

To study the electrical resistance between two electrodes located anywhere in a unidirectional (UD) and cross-ply (CP) carbon fibre composite laminate to help design an electrode array to detect damage.

Motivation



Schematic of the electrode array in an aeroplane wing to detect damage.

In an aeroplane wing, it could be possible to **detect damage** using the electrical resistance change method. But first, the **in-plane electrical behaviour** of CFRPs needs to be studied and understood..

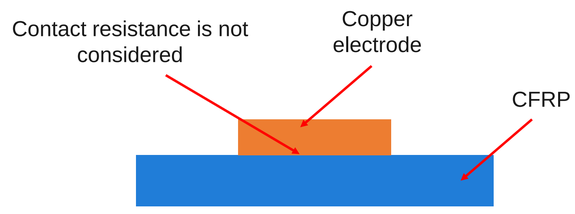
Method

The electrical resistance in unidirectional (UD) laminates is predicted using Ohm's law.

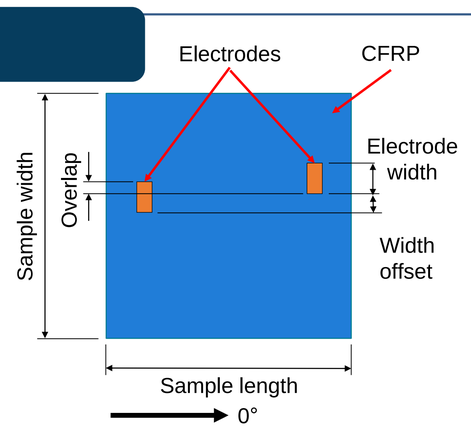
$$R = \lambda \frac{D}{A}$$

Where λ, refers to the material's resistivity, D, the distance between interest points and A, the cross-section area.

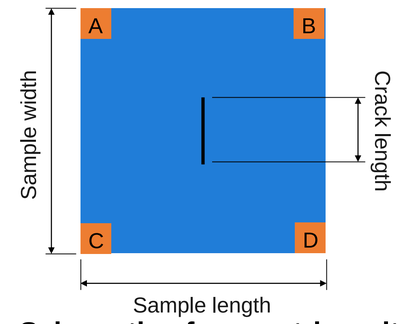
Electric numerical simulations for different width offset and crack lengths were developed (see figures on the right). Electrical contact resistance was not considered**.**



Schematic of contact between electrode and CFRP.



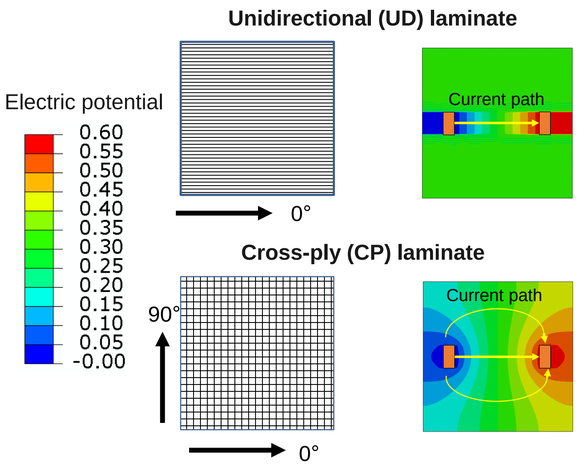
Schematic of width offset geometry.



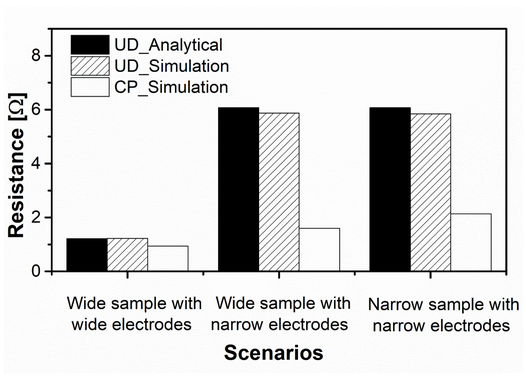
Schematic of geometries with a centre crack.

Results and discussion

Ohm's law resistance prediction



Electric potential distribution [V] for UD and CP laminates.

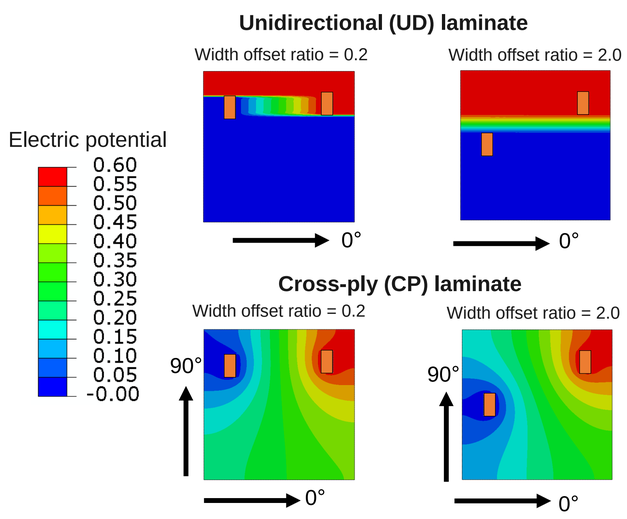


Electrical resistance [Ω] for different electrodes and sample widths in UD and CP laminates.

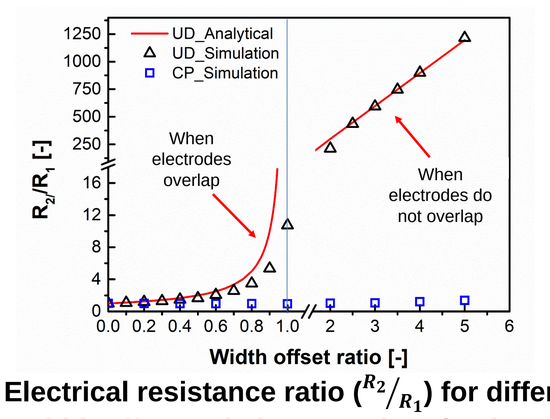
- Ohm's law can predict the 2D electrical resistance for UD, contrary to CP laminates.
- The main current path in UD is in the longitudinal direction and the resistance behaves as a 1D case.
- The current path in CP is in the longitudinal and transverse direction, 2D, which is not considered in Ohm's law

Resistance between two electrodes

Width offset ratio= $\frac{Electrode\ width}{Electrode\ width\ offset}$ (<1 when electrodes overlap)



Electric potential distribution [V] for UD and CP laminates.



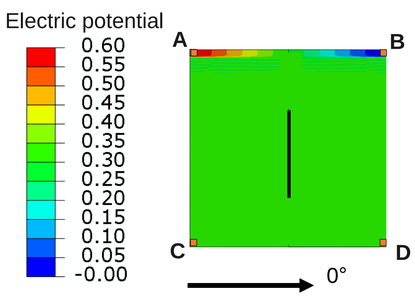
Electrical resistance ratio ($^{R_2}/_{R_1}$) for different width offset ratio in UD and CP laminates.

- For UD laminates when electrodes have carbon fibres connecting them, the longitudinal resistance non-linearly increases with the electrode width offset. While the transverse resistance linearly increases with the distance between electrodes, when electrodes do not overlap.
- The resistance measurements are similar between electrodes with different width offset ratios in CP laminates.

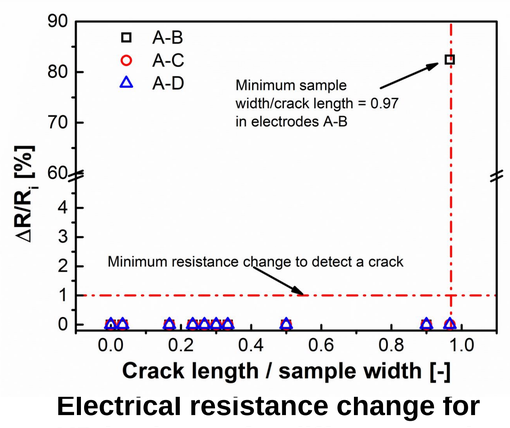
Minimum crack detection using the electrical resistance change method

Criterion for detection: $^{\Delta R}/_{R_i} > 1\ \%$ (based on a typical multimeter)

Unidirectional (UD) laminate

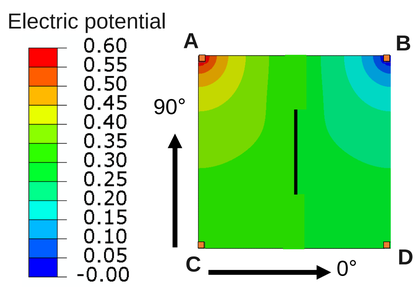


Electric potential distribution [V] for UD laminates for a 0.5 crack length/sample width.

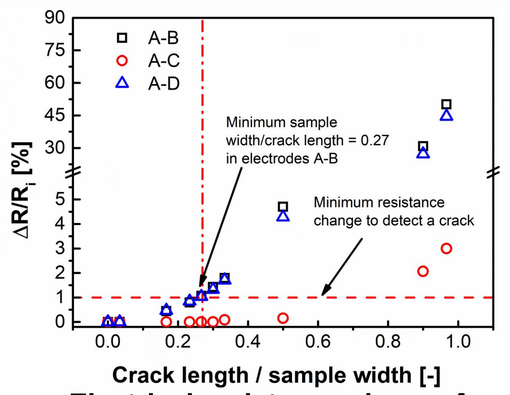


Electrical resistance change for UD laminates for different crack length/sample width.

Cross-ply (CP) laminate



Electric potential distribution [V] for CP laminates for a 0.5 crack length/sample width.



Electrical resistance change for CP laminates for different crack length/sample width.

- A central crack in UD laminates can be detected only when the crack length is similar to the width of the sample (>=97% of width).
- However, a central crack can be detected for cross-ply laminates when its length is around 27% of the sample width.

Conclusions

- The results showed that the 2D electrical resistance could be assumed as a 1D resistance in CFRP UD because the primary conductivity mechanism is through the fibres.
- Ohm's law can predict the 2D in-plane electrical resistance behaviour between two electrodes located anywhere in a UD composite fibre plate. However. Ohm's law was unable to predict electric resistance behaviour of CP laminates.
- In practice, central cracks can be detected in cross-ply laminates but not in unidirectional laminates.

Future work

To investigate the relation between electrical resistance and different location and size of the damage.

Acknowledgments

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References

[1] X. Qing, W. Li, Y. Wang, and H. Sun, "Piezoelectric transducer-based structural health monitoring for aircraft applications," Sensors (Switzerland), vol. 19, no. 3, pp. 1–27, 2019.
[2] J. Wen, Z. Xia, and F. Choy, "Damage detection of carbon fiber reinforced polymer composites via electrical resistance measurement," *Compos. Part B Eng.*, vol. 42, no. 1, pp. 77–86, 2011.

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