MACHINE LEARNING AND FINITE ELEMENT METHOD TO PREDICT TRANSVERSE MODULUS OF UNIDIRECTION COMPOSITES WITH VARIED FIBRE SHAPES

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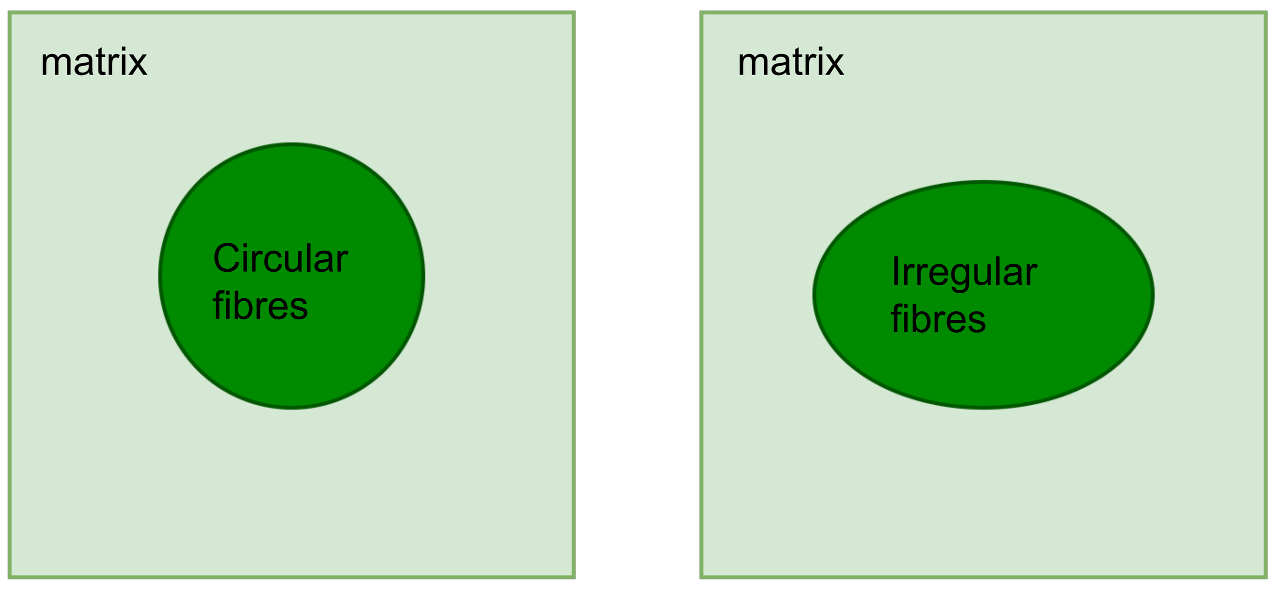
Research background

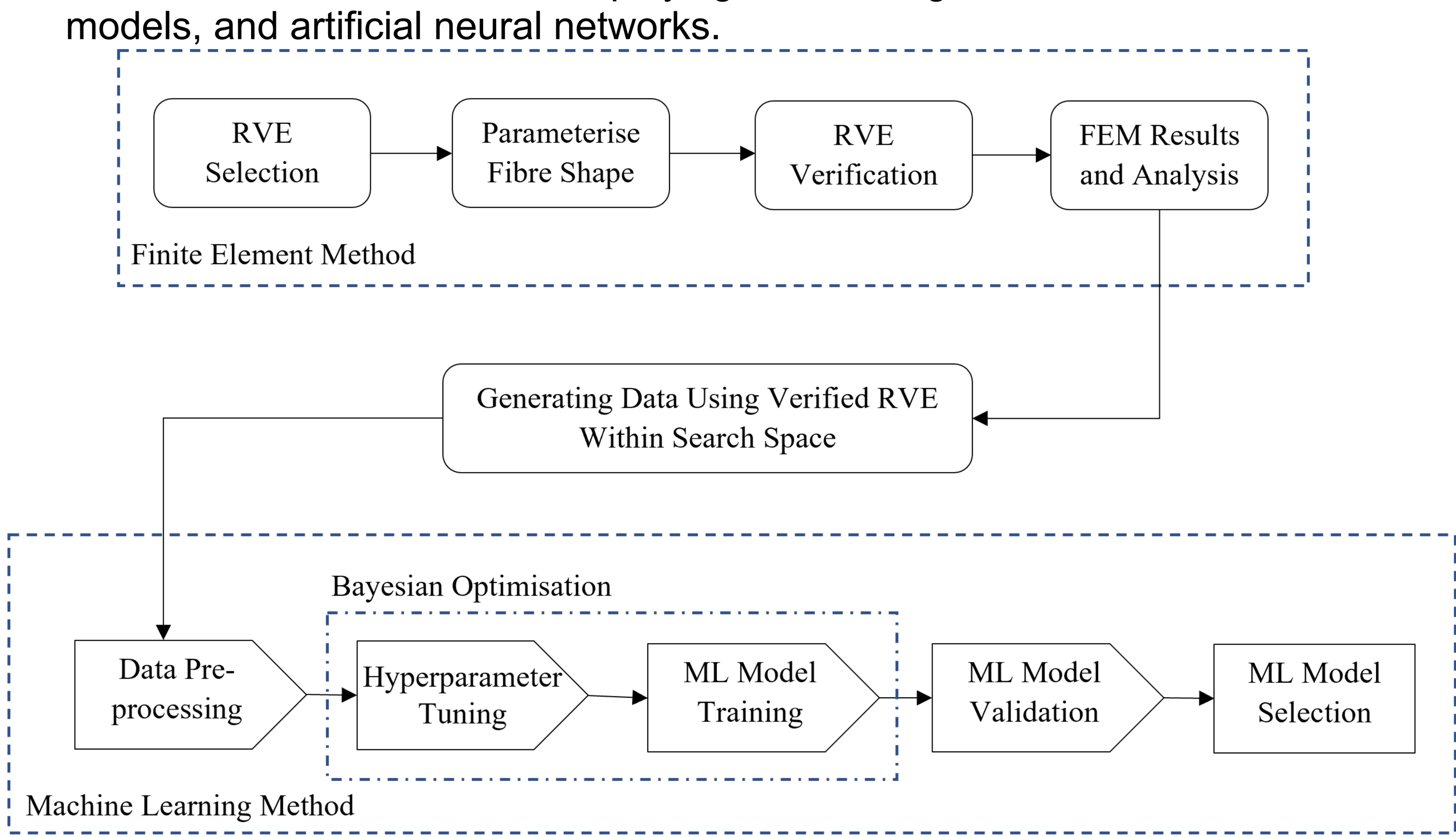
The use of unidirectional fibre reinforced polymer (FRP) composites is growing in industries such as aerospace and automotive. While traditional methods accurately predict the modulus in the longitudinal direction, the prediction of the transverse modulus using current methods yields scattered results. The lack of precise information on the transverse modulus poses significant challenges to the modelling and simulation of unidirectional FRP composites [1]. Additionally, as manufacturing technologies continue to progress, irregularly shaped fibres are becoming more achievable in the market, However, current analytical methods often disregard the significance of fibre shapes.

Current methods for predicting the transverse modulus of unidirectional FRP composites often rely on the assumptions that the fibres are circular or rectangular. Consequently, there is a need for the development of more sophisticated approaches capable of predicting the transverse modulus of unidirectional fibres, encompassing the inherent diversity in fibre shapes



Research methodology

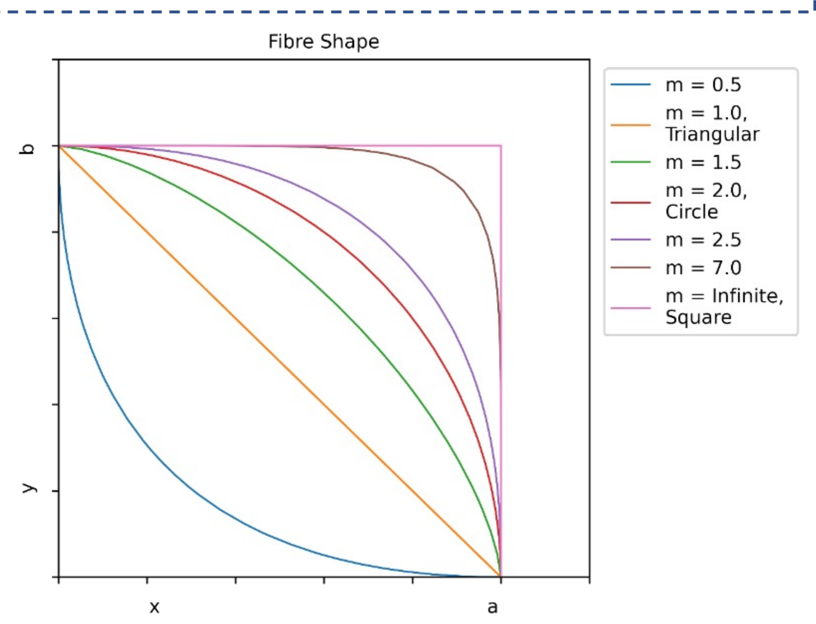
We propose a machine learning approach to predict the transverse modulus of unidirectional composites while considering the effect of fibre shapes. Firstly, finite element method models are constructed to computationally determine the transverse modulus for a range of irregular fibre shapes, as defined in eq 1. Parameters including volume fractions, mechanical properties of fibres and matrix, and defined shape parameters (λ_{pa}, a, b) are used as input to train the machine learning models. The desired output of the models is the predicted transverse modulus. To facilitate a comprehensive analysis, a comparative evaluation is conducted, employing linear regression models, ensemble models, and artificial neural networks.



Defined fibre shapes:

$$\left(\frac{x}{a}\right)^m + \left(\frac{y}{b}\right)^m = 1 \quad eq1$$

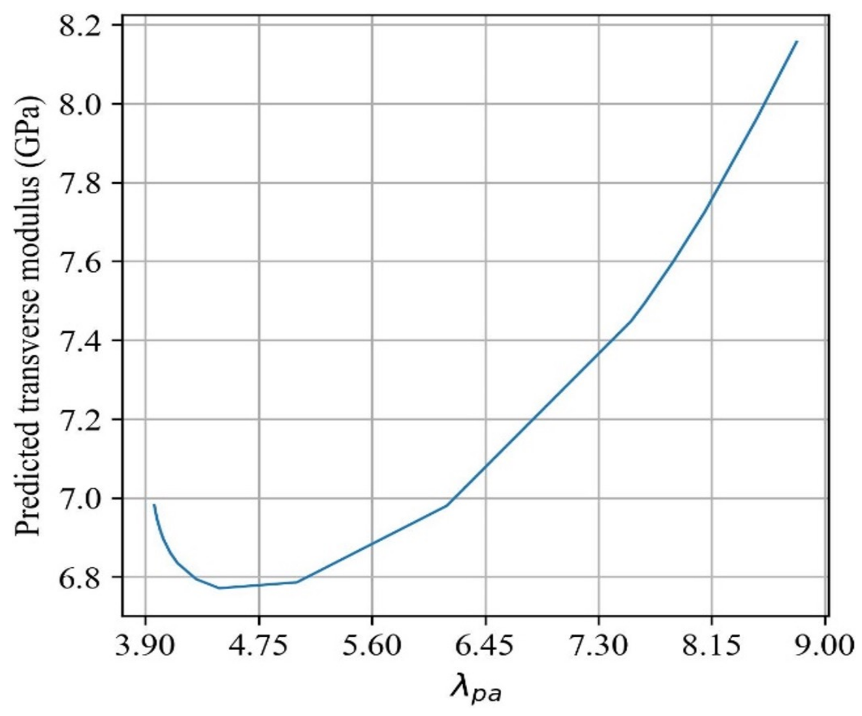
Where "a" and "b" represent the width of the fibres along the x and y axes, respectively; "m" denotes the curvature of the fibre shape.

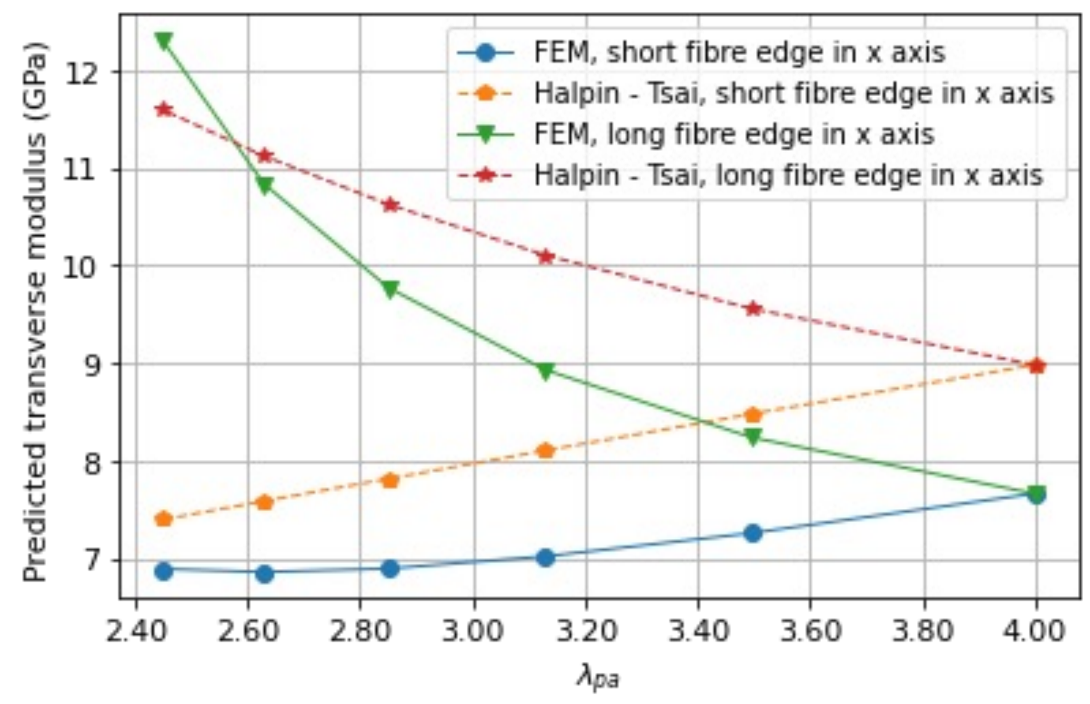


$a = b = 5\mu m$

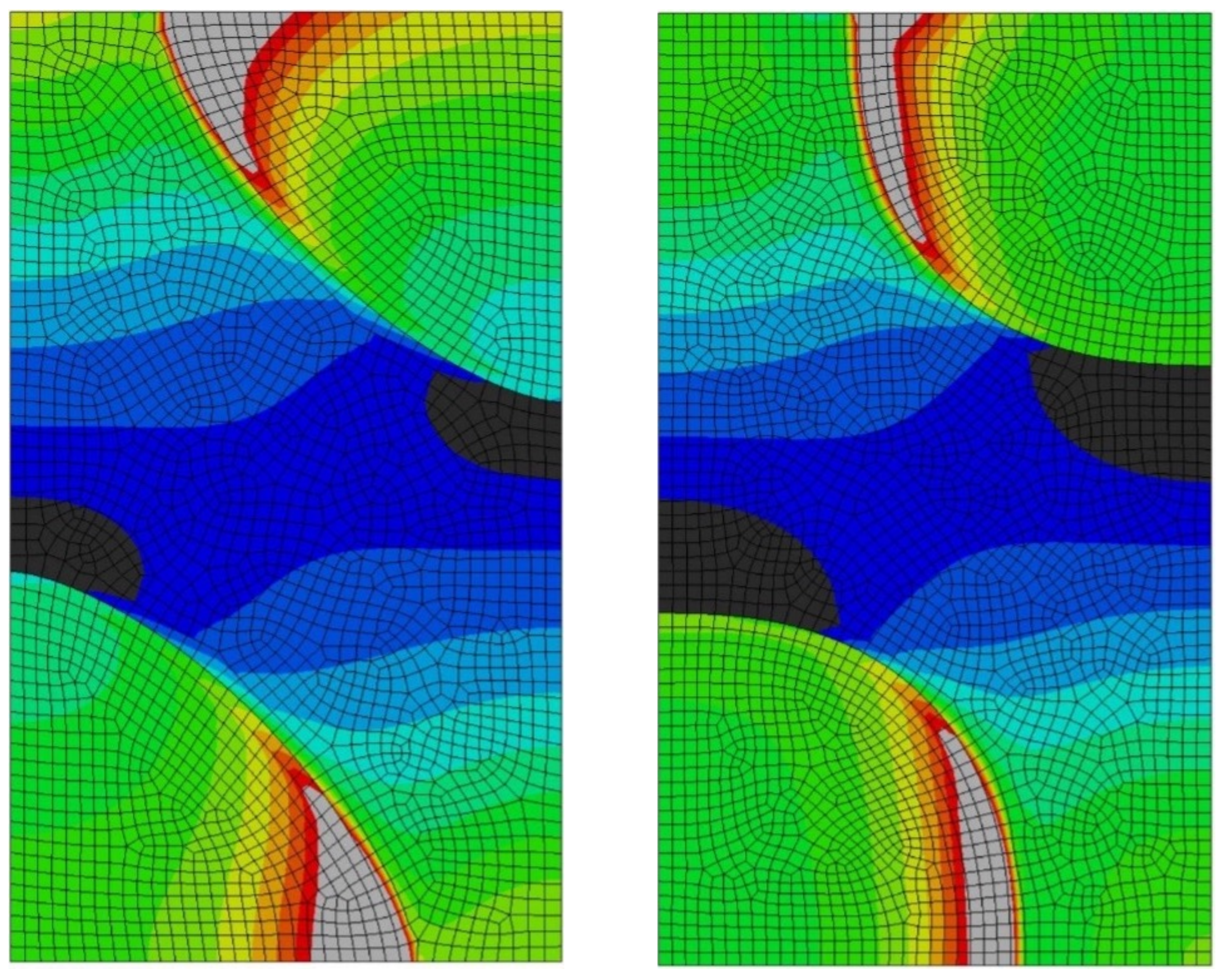
Results and discussion

- Transverse modulus found to be sensitive to fibre shapes, In general, higher fibre perimeter to areas ratio (λ_{pa}) returns higher transverse modulus values.
- A longer fibre edge aligned with the loading direction correlates with a higher transverse modulus.

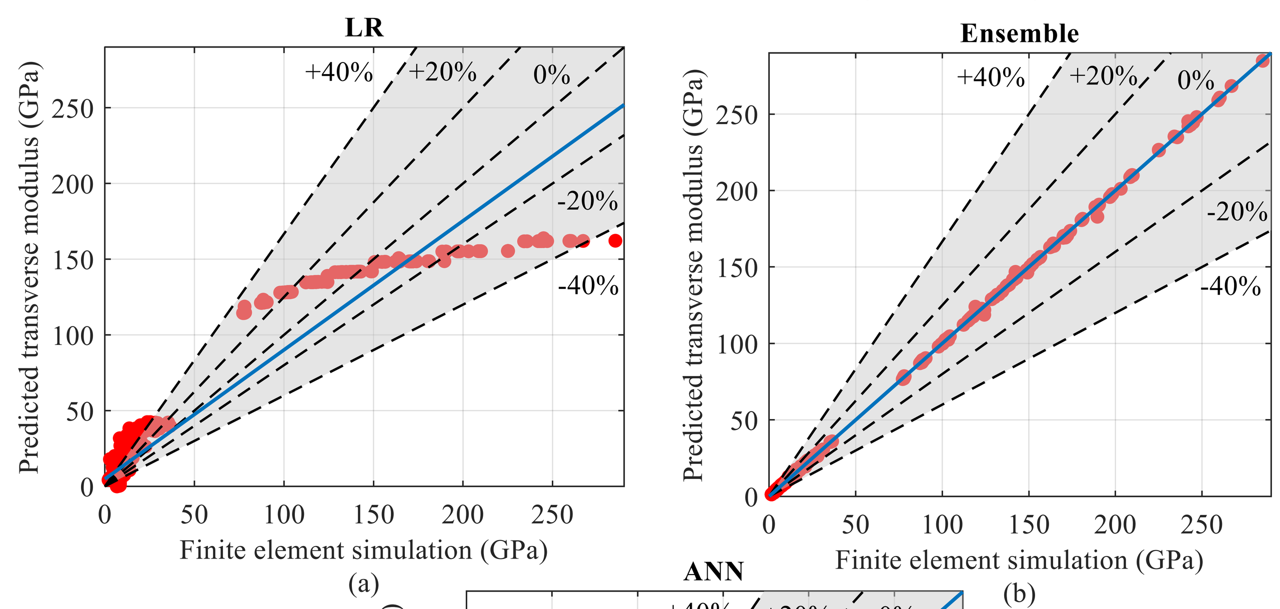




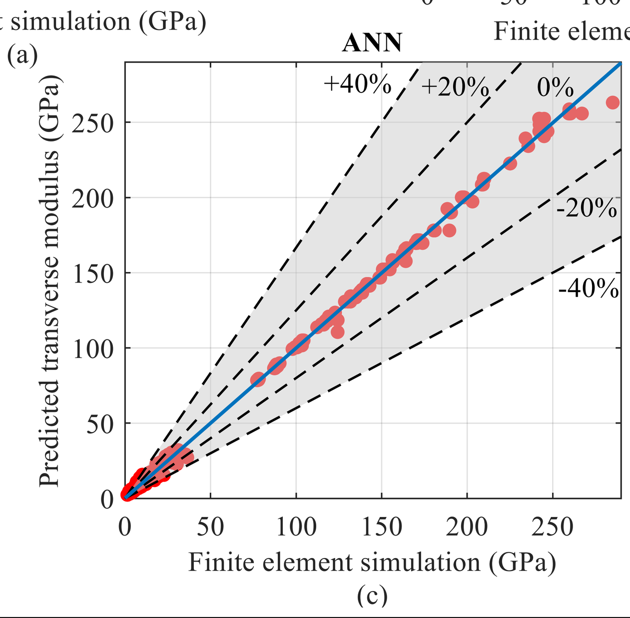
- The morphology of fibres significantly influences the modulus by causing modifications in stress distribution within the materials.



a = 0.5 μm , b = 0.5 μm , m = 1.5   a = 0.5 μm, b = 0.5 μm, m = 2.5



- Machine learning methods have been found to produce accurate predictions of the transverse modulus of fibre-reinforced composites, particularly with more sophisticated models such as Ensemble and Artificial Neural Network (ANN) models.



Conclusions:

- Fibre shape should be considered in the prediction of transverse modulus of unidirectional composites.
- Geometric parameters that characterise fibre geometries can be used for prediction.
- Machine learning algorithms, such as Ensemble and ANN models, can accurately predict transverse modulus and are reliable tools for predicting mechanical properties of complex unit cells.
- Further research is needed to investigate the performance of machine learning models on unsymmetric fibres, and alternative Machine Learning methods such as CNN can be adopted to characterise fibre shape patterns.

Acknowledgments

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Reference:

[1] Pathan, M. V., et al. "Measurements and predictions of the viscoelastic properties of a composite lamina and their sensitivity to temperature and frequency." *Composites Science and Technology* 149 (2017): 207-219.

[2] Huang, Haowei, S. Ali Hadigheh, and Keyvan Aghabalaei Baghaei. "Influences of fibre shape on the transverse modulus of unidirectional fibre reinforced composites using finite element and machine learning methods." Composite Structures 312 (2023): 116872.