QUB - Mechanical and Aerospace Engineering PhD Project 2019-2020

Title: Multi-scale and multi-physics modelling of 3D-textile composites

Project description:

3D-textile composites have reinforcement oriented in all three directions (Figure 1) and therefore possess improved out-of-plane mechanical properties as compared to the unidirectional and 2D textile composites. Moreover, these composites have high delamination resistance and improved impact and damage tolerances. Due to their complicated and heterogeneous microstructure, understanding of the macro- or structure-level failure of these composites requires an understanding of a number of failure mechanisms on the micro level. Matrix damage and fibre-matrix decohesion are the two dominant damage mechanisms on the micro level. Therefore, multi-scale modelling provides an accurate computational framework to simulate the behaviour of these composites. During their service lives, these composites can be exposed to harsh environmental conditions including high temperature and moisture ingress leading to matrix swelling, plasticisation, hydrolysis and degradation of fibre-matrix interfaces. In the long-term, these processes significantly reduce the mechanical performance of these structures. Therefore, a fully coupled multi-scale and multi-physics model provides an accurate computational framework for the simulation of the long-term performance of these composites.

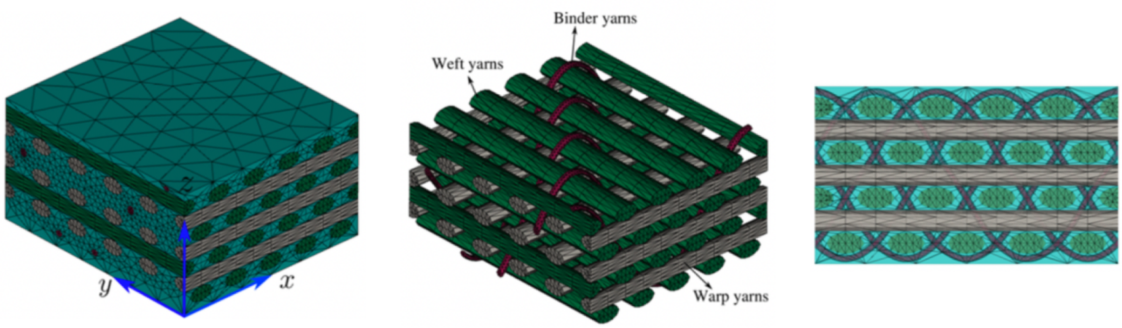

Figure 1: Idealised representative volume element of 3D-textile composites

Aims and Objectives:

This project will investigate the long-term structural performance of 3D-textile composites subjected to adverse hygro-thermal environmental conditions in addition to mechanical loading. For the accurate hygro-thermo-mechanical simulation of these composites, a realistic and detailed geometric modelling of the microstructure is very important. The impregnation and curing processes deform the yarns and alter their trajectories, which subsequently affect their performances. Therefore, a fully automated and robust finite element-based computational framework coupled with an advanced contact algorithm will be developed for the micro level geometry modelling. A variety of failures models will be used on the micro level for modelling the elasto-plastic response of the matrix, and fibre-matrix decohesion. The response of the macro level structure will be determined directly from the computational homogenisation of the micro level structure. Understanding of water ingress through composite materials at different scales is the first step towards accurate modelling of the hygro-thermal ageing process. The heterogeneous microstructure of these composites leads to a highly complex and anisotropic diffusion process. Moreover, variation in water diffusion through fibres, matrix and interfaces adds to the complexity of the diffusion process. A computational framework will be developed for the accurate modelling of moisture diffusion through the microstructure. The diffusion behaviour of the macro level structure will be determined from the computational homogenisation of the microstructure. A hygro-thermal ageing model, representing the degradation of mechanical properties over time, for a given exposure of temperature and moisture concentration, will be subsequently developed. The final stage of the project will be to combine all of the above-mentioned models into a single fully coupled multi-scale and multi-physics computational framework.

The multi-scale and multi-physics nature of the computational framework requires the solution of the micro level finite element problem for each macro level integration point and is computationally demanding. Therefore, state-of-the-art computational procedures including high-performance computing, model order reduction and adaptive analysis will be used to enhance the computational efficiency of the developed computational framework. The developed framework will be implemented in MOFEM (Mesh Oriented Finite Element Method), an open-source C++ based finite element software. The generalised implementation will allow for its exploitation on other composite systems consisting of unidirectional and 2D-textile reinforcement. Finally, the developed code will be used to solve problems from a variety of fields including aerospace, marine, automotive, construction and wind energy.

This PhD project will be carried out within the Advanced Composites Research Group at Queen's University Belfast consisting of academics, PhDs and post-doctoral researchers.

Key skills required for the post:

- Knowledge of structural polymer-based fibre composites
- Knowledge of structural mechanics
- Basic experience of using finite element analysis and knowledge of its theoretical foundations
- Basic C++ programming or other high-level computer language

Key transferable skills that will be developed during the PhD:

- Numerical modelling (finite element analysis)
- Composite materials and structures
- Project management, problem solving and communication skills

Lead supervisor:	Dr Zahur Ullah (z.ullah@qub.ac.uk)
Other supervisor(s):	Prof Brian G. Falzon (b.falzon@qub.ac.uk)
Guaranteed stipend:	Approx. £14,925 per annum.

PhD students in the School have the opportunity to apply to be demonstrators on undergraduate modules. Compensation for this can amount to in excess of £2,400 per year.

Queens University Belfast is a diverse and international institution which is strongly committed to equality and diversity, and to selection on merit. Currently women are under-represented in research positions in the School and accordingly applications from women are particularly welcome.