University of BRISTOL
Bristol Composites Institute (ACCIS)
ADVANCED COMPOSITES COLLABORATION FOR INNOVATION & SCIENCE

EPSRC
Engineering and Physical Sciences Research Council

Imperial College London
The Composites Centre
for research, modelling, testing and training in advanced composites

HiPerDuCT Programme Grant

Final report: Triaxial Braided Composites

Loading in transverse direction

Triaxial braided composites can show a highly non-linear stress-strain response. For example, the [0/±30] carbon/epoxy braid shown in Figure 1(a) loaded in the transverse direction features a pseudo-ductile plateau due to the complex damage behaviour. Severe non-linearities are present in the stress-strain response for loading in the transverse direction. The [0/±30] braid features a complex damage behaviour, which is shown in Figure 1(a). Here, the material response can be separated into three distinct domains up to final failure: an elastic domain, a damage progression domain and a saturation domain. When a critical load level is reached in the linear domain, matrix cracks form in the axial yarns and initiate further cracking inside the braid yarns. As the strain further increases, the load level exhibits a stable plateau. In the experiments, this behaviour is associated with the continuing development of inter-yarn and also intra-yarn cracks across the entire specimen length, originating from the initiation location. Final failure of the specimen occurs where multiple cracks coalesce across the specimen width.

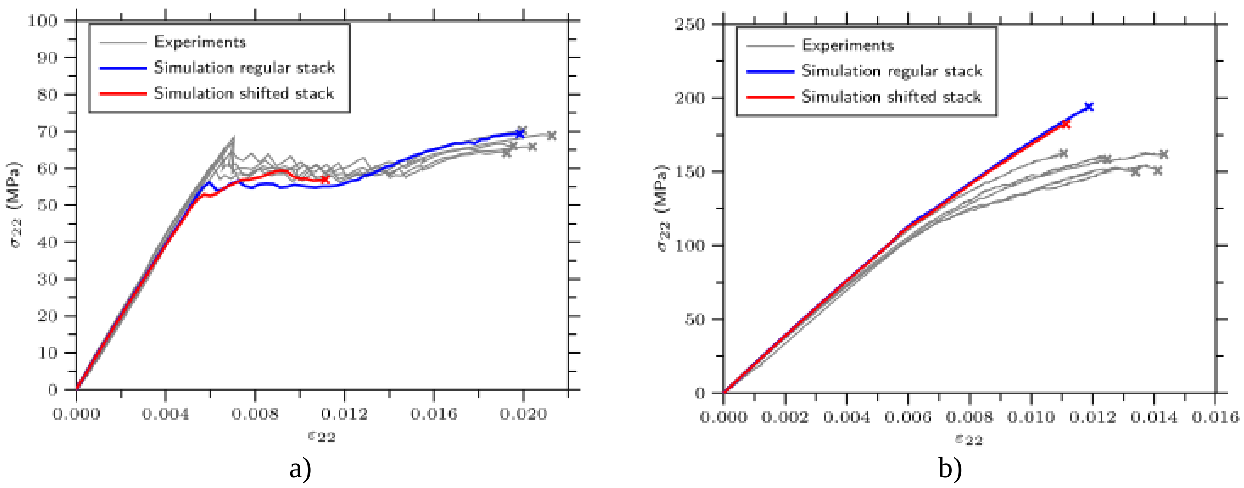

Figure 1: Stress-strain curves for loading in transverse direction (a) [0/±30] (b) [0/±45]

Loading in braid fibre direction

The triaxial braided composite was also loaded in the braid fibre direction, experimental results are shown in Figure 2.

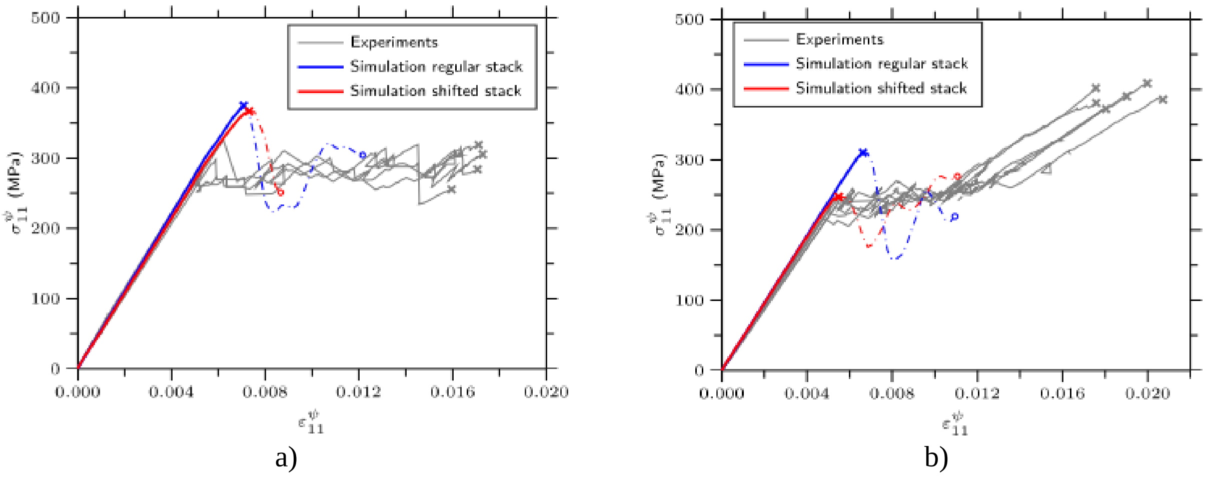

Figure 2: Stress-strain curves for loading in braid fibre direction (a) [0/±30] (b) [0/±45]

Up to a homogenized strain level 0.6 %, all braid architectures exhibit approximately linear stress-strain behaviour. Distinct load drops after this can be attributed to a progressive mixed mode failure mechanism intrinsic to the textile architecture: as the external load is coincident with the braid fibre direction, the aligned yarns straighten along their longitudinal direction. Hence, intersecting axial yarns are subjected to an out-of-plane movement, which is at first inhibited by the overlying non-aligned braid yarns. As the load is increased, transverse cracks and delaminations develop in these areas. This process continues, until multiple inter and intra-yarn cracks appear in the braid yarns along the path of a single underlying axial yarn. Finally, the braid yarns lose their capability to resist the out-of-plane movement, resulting in a sudden delamination of individual axial yarns across the entire specimen width. This mechanism is repeated, until all axial yarns debond over the specimen length, causing global delamination of the coupon.

Meso-scale simulation framework

A meso-scale framework for predicting the non-linear mechanical response of triaxial braided composites was developed, which showed good correlation with the measured stress-strain curves and damage mechanisms (1,2). Based on a reduced unit cell concept which exploits symmetries to minimise computational expense, a compacted and interpenetration-free yarn geometry is created within a three-stage simulation process. In the first step, a nominal geometry is constructed from user-defined input parameters. Local volumetric interpenetrations present in the model are resolved in a subsequent fictitious thermal step. The unit cell is further compacted to the desired fibre volume fraction using flexible membranes Out-of-plane periodic boundary conditions allow an implicit consideration of the compaction of multiple braid plies in different nesting configurations, which further enables us to render high global fibre volume fractions (55-60%) using experimentally determined intra-yarn fibre volume fractions.

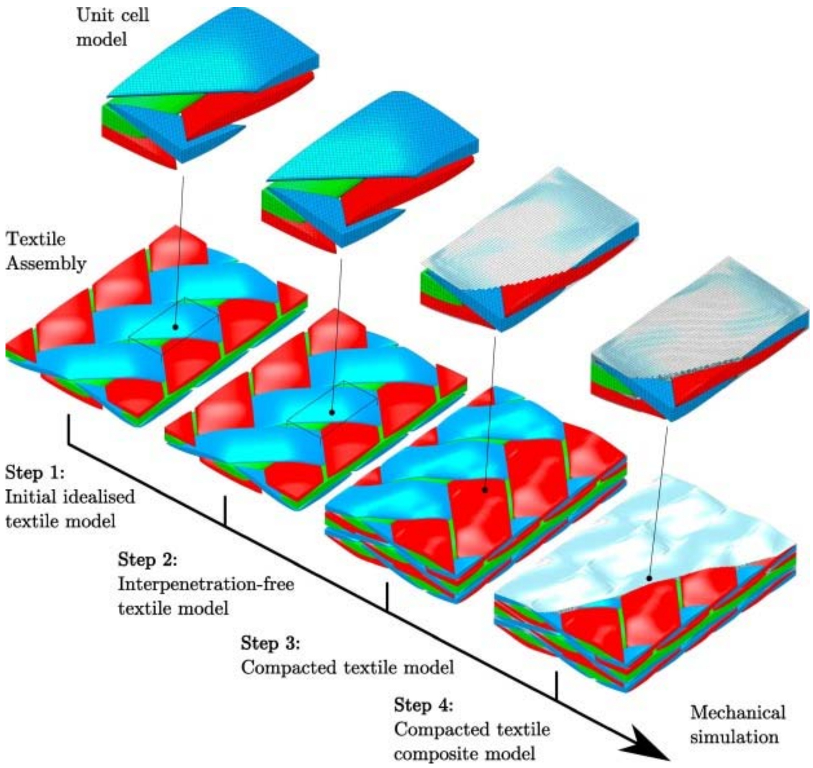

Figure 3: Roadmap and data flow for generating a realistic unit cell model

References

1. Wehrkamp-Richter T, Pinho ST, Hinterhölzl R. Modelling the non-linear mechanical behaviour of triaxial braided composites. ICCM 20 - 20th International Conference on Composite Materials; 2015 19-24th July 2015; Copenhagen, Denmark

2. Wehrkamp-Richter T, De Carvalho NV, Pinho ST. A meso-scale simulation framework for predicting the mechanical response of triaxial braided composites. Composites Part A: Applied Science and Manufacturing. 2018 Apr 30; 107:489-506.