Numerical modelling for polymers – applications to wind turbine blades

The present paper is the second of a series of three articles that aim to introduce why and how numerical modelling is carried out for polymeric materials.

As discussed in our last article, modelling pervades the field of polymers. Several objects in our everyday life represent applications that benefit from numerical modelling. These models may have different ranges both in terms of subject studied, from mechanics to chemistry, and in terms of modelling length scale. More complex and challenging designs, along with the required modelling, are constantly driving materials science research. A topical example of such applications are wind turbines, and specifically, wind turbine blades. The need to improve their efficiency, together with evolving fabrication technology, constantly drive improvements: for example, modern wind turbine blades can reach lengths of more than 100 meters. Moreover, blades need to stay functional for decades, often in harsh environments, which include moisture, temperature variation, impacts and damage in highly loaded locations. Understanding the capabilities and limitations of fibre-reinforced polymers (FRPs) is crucial to navigate these challenges.

Numerical modelling can be utilised in most stages of the design; figure 1 depicts some prominent examples of modelling problems at different length scales in wind turbines. Aerodynamic performance can be analysed using computational fluid dynamics (CFD) to define the structural loads, which are needed through the design and optimization process. Ply layout optimization − determining the optimal number of plies and their orientation − is one of the major problems to be considered at the macroscopic scale, requiring consideration of both the capabilities of the manufacturing process and the effect of external loads on the structure − a complex problem that transcends several length scales. Other aspects, such acoustical behaviour and

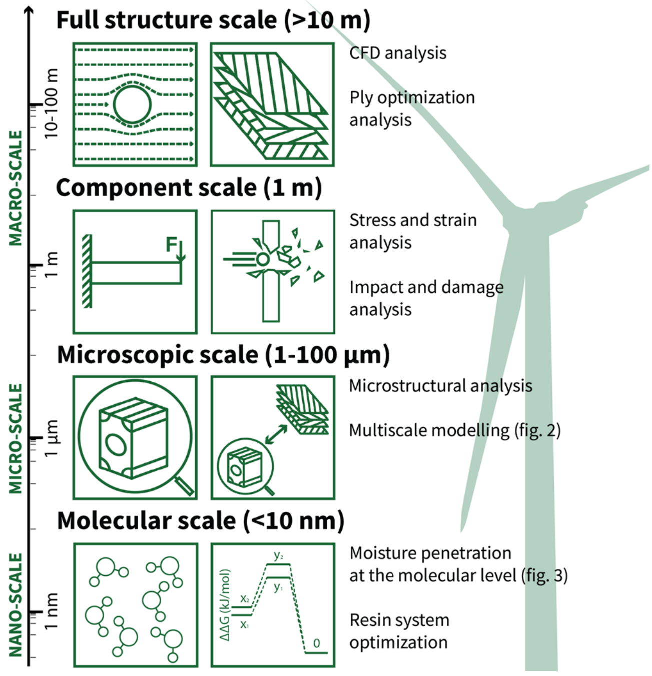

Figure 1 - Examples of wind turbine modelling at different scales.

fatigue must also be considered at the early design phases.

From a computational point of view, structural behaviour of composites can be analysed by means of multiscale modelling, which combines approaches at the micro- and macroscales. This strategy takes advantage of separation of length scales among the structural entities (component, laminate and ply) with the constituents defined from macro- to microscopic levels. Consequently, multiscale modelling allows the transfer of information between the scales to simulate phenomena that were traditionally modelled as separate problems. A major advantage of the technique is that it allows the analysis of damage that might initially occur e.g. at ply level (failures in fibres/matrix) that can also drastically affect other scales. In this way, deformations and mechanical loads at the constituents scale can be predicted simultaneously up to fracture. Figure 2 shows an example of this kind of multiscale analysis as a simulation of an axial test in a joint tension bolt of a bearing connecting the turbine blade to the whole structure.

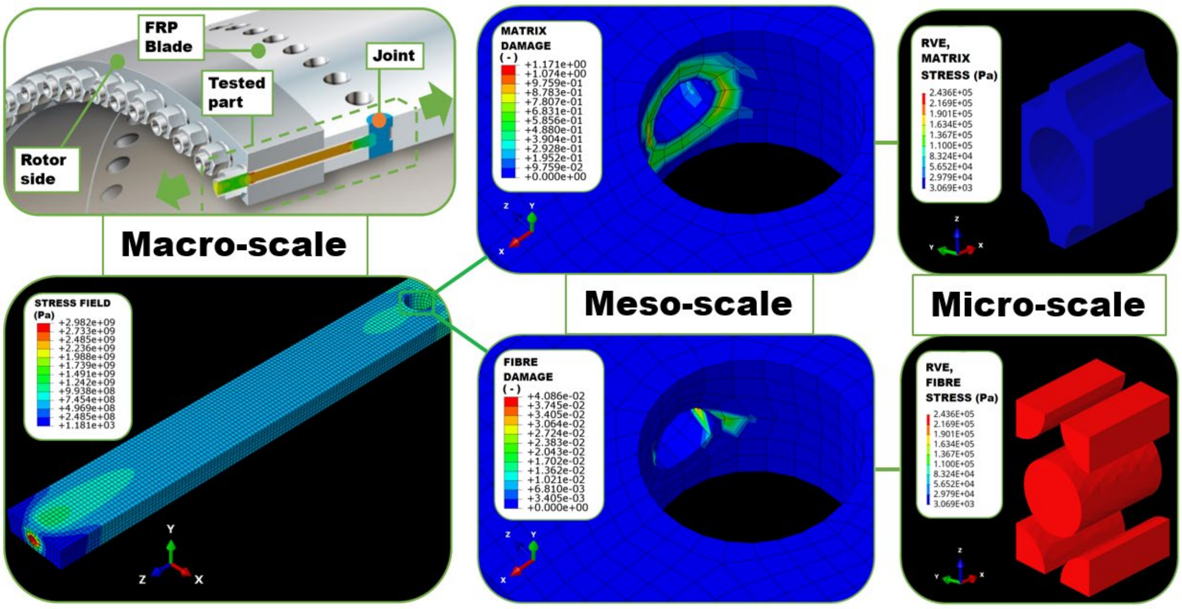

Figure 3 - Modelling of damage at macro, meso and micro scales in a notched specimen. Analysis simulated using finite element software Abaqus and the Multiscale Designer module of the Altair software.

The manufacturing process of a turbine blade is often very specific and its limitations – for example in terms of curing conditions – well known. Therefore, screening potential resin systems to attain adequate performance in said curing conditions represents a useful application for atomistic scale modelling. In addition, the life cycle of a wind turbine is in part determined by the environmental durability of the FRP. Many wind turbines operate overseas and experience high levels of humidity along with temperature variation. Therefore, understanding how moisture interacts with the FRP is crucial to understanding the durability of the material in those conditions. Molecular dynamics simulations can explore these aspects of the material, as presented in figure 3.

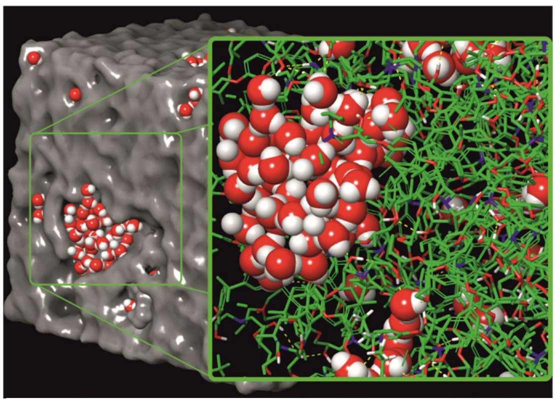

Figure 2 - Moisture diffusion simulation of epoxy. Visualised with Maestro, a part of the Schrödinger Materials Suite.

Multiscale computation allows broadening the applicability of traditional modelling approaches by studying relations between phenomena that might happen at different scales. This translates to models that can mimic the phenomena in more detail. The currently widespread simulation-experiment practices have enabled efficient lightweight structures, which utilise modern materials close to their currently understood limits. However, further improvements and future applications require a more comprehensive understanding of the materials to both further develop their possibilities while precisely locating their structural safety limits. Wind turbines are just one of the possible applications that can benefit from these advances of numerical modelling in materials engineering.

The manuscript, prepared together by D. Di Vito, P. Laurikainen, O. Rodera Garcia and J. Jokinen, represents current modelling themes in the Plastics and Elastomers Technology group of Tampere University.

For more information

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