French Polytech network form for PhD Research Grants from the China Scholarship Council

This document describes one of the PhD subjects proposed by the French Polytech network. The network is composed of engineering schools/universities. The document also provides information about the supervisor.

Supervisor information	
Family name	HIVET
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PhD information	
Title	Homogenized mechanical behavior law of textile yarns using multiscale modeling, simulation and experiments
Main topics regards to CSC list (3 topics at maximum)	VI-1. New theory and technology of manufacturing

	IV-6. Calculation of materials and simulation for design
Required skills in science and engineering	At least, high knowledge in general mechanical and and knowledge in numerical simulation tools and theory. Moreover, high capacities in project management and team work, capacities in oral and written communication, have some affinity for experimental study

Subject description (two pages maximum including biblio)

Respect for the challenges and constraints of the new energy and environmental situation is undoubtedly the key point for the future of the transport sector. One way, used for several years now in the aeronautics and currently strongly activated in other transport applications, is to minimize the masses while maintaining the quality of the service provided. The use of composite materials with fibrous reinforcements whose performance in this area is well established provides substantial gains. This is also the reason why the rate of composites increases significantly especially in recent years in aeronautics (53% by weight in the A350). As a result, many national and European projects are emerging in order to generalize the use of fiber-reinforced composites in many applications (transports, sports, etc.). Although the use of composites already makes it possible to increase the ratio service / mass performance of vehicles, their potential is still very far from being fully exploited for two main reasons:

- Manufacturing processes are insufficiently advanced, mastered and optimized
- Models, calculation and optimization tools of associated structures are not efficient enough.

As regards these two topics, the main issue is to obtain representative and exploitable models of the mechanical behavior of composites trough sizing or process simulation tools. The crucial point, in order to better understand and characterize the mechanical behavior of fibrous composites is undoubtedly to master the mechanical behavior of the textile reinforcement. These are by nature multi-scale materials because they are composed yarns, themselves composed of thousands of fibers. The heterogeneity of these materials and their very strong anisotropy related to the entanglement of the fibers as well as the non-ideally ordered distribution, leads to an important complexity for the analysis and the modeling of their mechanical behavior.

If some models start to develop, at different scales, there is no homogenized behavior model that is consistent and truly representative of textiles. The C2MP (Comportement Mécanique des matériaux et des procédés - Mechanical behavior of materials and processes) team of the Laboratoire de mécanique Gabriel Lamé is working on these issues. Very promising results, both in terms of experimental characterization and mechanical models, have been obtained thanks to multi-scale approaches. These different studies have indeed enabled to increase significantly the understanding of the mechanical behavior of reinforcements and in particular to analyze and model the response of textiles with simple stresses (traction, bending, shearing, compression ...). Nevertheless, a long way remains to be done to move from a sum of "merged" responses as the definition of the mechanical behavior to a rigorous homogenized constitutive law satisfactory and usable in continuous approaches. Among the fundamental locks, the constitutive laws of continuous materials, known as Cauchy, do not easily accommodate the specificity of the bending behavior of fibrous reinforcements. In addition, the models of mechanical behavior of the fibrous media are still very poorly known, especially in compression and bending.

One of the possibilities that has been considered by the team is to start from the behavior of the fiber and the fiber packet to enrich the models at the higher scales. Indeed, if the modeling of an entire textile is not possible considering each fiber due to their huge number, considering and understanding the response of a fiber bundle to different loadings is essential to propose consistent mathematical shapes and parameters for the behavior law of textiles. Initial work has been done to create a virtual estimator of the mechanical behavior of a fiber bundle (Oussama HAJI: 10/12/18 and Xinling SONG: 17/07/24 [1]); this work has attempted to simulate the compaction/compression behavior of a fiber bundle validated by experimental studies. It highlighted the consistency and the potential of the proposed strategy. It also enabled to define and analyze some indicators involved in compaction behavior; thanks to the PhD of Xinling SONG, the virtual estimator is now fully validated and operational and the first sensitivity studies for some parameters have been performed illustrating here again the high potential of this virtual estimator. It is then of a main importance to continue the work to achieve the goal of the mechanical behavior law of a real yarn.

Consequently, the objective of the thesis work proposed here, is to operate intensively the virtual estimator and to go further in the analysis of the indicators. Numerous loading paths have to be tested and experimentally validated in order to improve the understanding of the fiber bundle response. The virtual estimator has also to be improved to consider the presence of sizing and residual stresses between the fibers. The influence of the fiber number as also to be investigated. Finally, a new form of the behavior law at the upper scale has to be proposed regarding also the corresponding behavior law by a coupled approach of experimental characterization and multi-scale modeling. The candidate will therefore:

• Take ownership of the virtual estimator

• Operate and improve the virtual estimator performing simulations with different loading paths to understand the phenomena

- Perform sensitivity studies in order to quantify the influence of the microstructure and material parameters
- Validate the estimator using micro-CT experiments on complex loading paths.
  - Implement the behavior law in the mescoscale model
  - Perform the validation tests on real yarns to validate the created behavior law.

[1] *Haji O, Song X, Hivet A, Rolland du Roscoat S, Orgéas L, Sinoimeri A, et al. Modeling of Quasi-Parallel Fiber Networks at the Microscopic Scale. Applied Composite Materials. 2023;30(2):653-75*