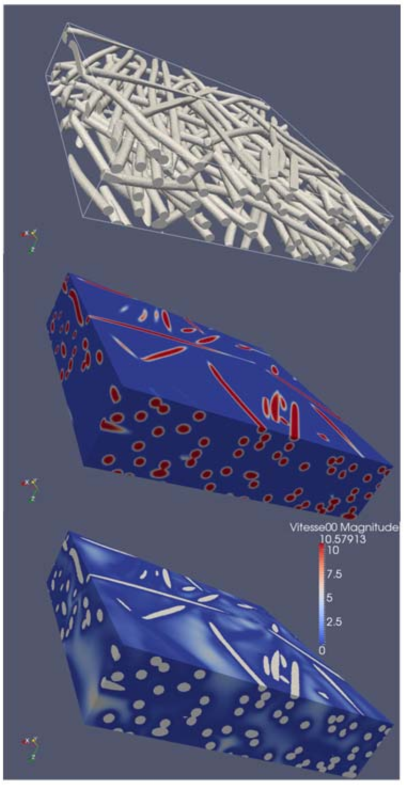
Tec 21: *Engineering solutions*
for the 21st century's increasingly complex challenges

Labex Tec 21 – PhD proposal for 10-2013/10-2016

3D Micro-Rheology of Concentrated Fiber Suspensions with Non-Newtonian Suspending Fluids

Context and Objectives of the PhD Project

Owing to their very interesting specific physical and mechanical properties and their cost-efficient processing, short (nano)fiber reinforced polymer (bio)composites are being increasingly used to make semi-structural, structural and multi-functional components in the aeronautic, electric and automotive industries. Such structures are constituted by complex networks of connected and entangled straight or wavy fibers or fiber bundles impregnated by a polymer (see the figure). Knowledge and comprehension of the material evolution during its lifecycle is of great importance for the optimization of these applications. However, during their forming process, these composites behave as highly concentrated suspensions and therefore usually exhibit very complex rheological behaviors. The suspending fluid, *i.e.* the liquid polymer matrix often exhibits a non-Newtonian rheology and may flow through the complex anisotropic fibrous reinforcement. This latter undergoes severe deformation phenomena (compaction, elongation and shear) that can induce its consolidation, reorientation, tearing and/or clustering of fibers. These phenomena drastically alter the end-use properties of these composites, reducing by the same their performances. They are induced by the high connectivity and the deformability of fibers together with the non-Newtonian rheology of the matrix. They remain still not very well characterized, understood and modeled. For instance, literature analytical models or microscale simulations dedicated to dilute or semi-dilute fiber suspensions with Newtonian suspending fluid fail in properly reproducing them, and extension to the highly concentrated case is far from being solved.



3D segmented image of a typical concentrated fibre suspension with slender of copper rods immerged inside a polymeric non-Newtonian suspending fluid (upper picture), colormap showing the levelsets values used to track fiber-fluid interfaces (middle picture), colormap showing the velocity magnitude in the case of a flowing fluid through immobile fibers (lower picture).

Numerous experimental studies have been achieved to better understand the complex mesoscale rheology of these particular types of fibrous suspensions. These studies have raised the leading roles of the non-Newtonian fluid, the initial fiber content and orientation, the imposed strain rate and the type of mechanical loading on recorded macroscopic stress levels. However, experimental results are often limited because of the difficulties to characterize and analyze properly the 3D evolving suspension microstructures.
In parallel, many theoretical and numerical studies were carried out to model the rheology of such complex systems by adopting an upscaling approach. These studies may often be questionable because of their assumptions stated at the fiber scale. For example, the fibrous structures are often idealized as networks of rigid rods with rather simple fiber-fiber contact laws. Besides, the non-Newtonian hydrodynamic interactions between fiber and the suspending fluid, far from contact zones, is surprisingly not taken into account or modeled by simple analytical Newtonian drag interactions. Thus, despite the information brought by the existing literature studies, crucial questions concerning the evolution of fibrous microstructures during the flow and its impact on the rheology of these suspensions still remain unclear:

What are the spatial and orientation distributions of fibers? How do fibers or fiber bundles translate, rotate and deform during the suspension flow? How many fiber-fiber contacts per fiber are there? How do these contacts evolve? What are the impacts of such microstructural changes on the mesoscale stress levels required to induce the suspension flow? Is a continuum mesoscale description relevant? If yes, what are its properties? What information can we use to improve the knowledge and the control at the process scale?

A possible, original and suitable way to answer some of the above questions and therewith to propose a relevant mesoscale rheological model is to combine simultaneously:

(i) **micro-rheometry experiments** (elongational and shear flows) **with 3D (fast)** ***in situ*** **observations** of the fibrous suspensions **and proper image analysis** subroutines to analyze the flow-induced evolution of relevant microstructure descriptors. This is possible by using standard and synchrotron X-ray microtomography (see the upper picture of the figure).

(ii) **micro-rheometry simulations with a 3D High Performance Computation approach (HPC),** able to describe accurately the topology of the observed microstructure, given the important concentrations and capture (a) the motion and the deformation of fibers within the networks, (b) the complex interactions of fibers between themselves and with the surrounding matrix. This is possible with dedicated finite elements techniques that can account for suitable constitutive equations for the fluid (non-linear viscoplasticity and visco-elasticity) and fiber (anistropic (visco)elastic solids) and for a precise description of fiber-fluid interfaces and fiber-fiber contacts, *e.g.* by using a diffuse interface approach through the levelset method, mesh adaptation techniques and parallel computation (see the middle and the lower pictures of the figure).

(iii) **a rigorous upscaling process to build and propose relevant rheological mesoscale models** by incorporating the above experimental and numerical results. For that purpose, the framework proposed by the homogenization with multiple scales asymptotic expansions is appropriate.

This is the method we will adopt in this project.

Additional Information

Project Organization

The proposed project is a collaborative work between two TEC 21 labs, 3SR Lab and LGP2 (CNRS – Université de Grenoble Alpes, France) and the CEMEF Mines Paristech (Sophia Antipolis, France).

The 3SR Lab and LGP2 team (Pierre Dumont, Laurent Orgéas and Sabine Rolland du Roscoat) has an expertise in 3D imaging techniques and modeling the microstructure and the rheology of concentrated fiber suspensions. The CEMEF team (Patrice Laure and Luisa Silva from the CEMEF group “Advanced Computing in Material Forming”) has a recognized expertise in the numerical simulation of complex soft systems such as the considered fiber suspensions.

Research Profile of the future PhD student

Rheology, mechanics of materials, 3D imaging and kinematical field measurements, computational mechanics

If you are interested

Please send before the end of June 2013 your CV together with the marks obtained during your Master to:
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Some useful links

• Labex TEC21:	http://www.tec21.fr/
• 3SR Lab:	http://www.3s-r.hmg.inpg.fr/3sr/
• CEMEF – Mines ParisTech:	http://www.cemef.mines-paristech.fr/
• LGP2:	http://pagora.grenoble-inp.fr/recherche/