PHD STUDIES (RESEARCH ASSISTANT): FATIGUE MODELLING IN TEXTILE COMPOSITES

KATHOLIEKE UNIVERSITEIT LEUVEN

Position opens: immediately. Project duration 2006-2009.

Project description: Micro-meso-macro homogenization of the fatigue degradation of textile reinforced composites

Damage model for fatigue of textile reinforced composites is developed at the micro-level. By integration of these micromechanical fatigue damage models into the finite element simulations of the unit cell of the textile composite, it is possible to calculate the degradation of the homogenized elastic properties of this unit cell. By comparison of these results with the predictions of phenomenological fatigue damage models at the meso-level, the material constants of these latter models can be determined in a physically more correct and more generic manner. The models will be implemented in software tools.

Position description

PhD studies at K.U.Leuven, combined with Research Assistant position at Department MTM, K.U.Leuven, in the Composite Materials Group http://www.mtm.kuleuven.be/Research/C2/poly/index.htm.

The project offers full funding of a 4-year PhD program.

Note for non-EU applicants: the work can start with a delay of few months due to Belgian residence formalities.

NB: the funds do NOT allow hiring a post-doc.

Supervisors at K.U.Leuven

Prof Ignaas Verpoest, Prof Stepan Lomov

Collaboration

University of Gent, Prof Joris Degriek, Prof Wim Paepegem

Requirements

1. *Master degree* (in order of preference) in
   - Composites materials
   - Mechanics of solids
   - Applied mathematics
   - Mechanical engineering (including courses on composite materials)

In any case the educational background should include
   - Advanced course(s) on mechanics of solids
   - Course(s) on composite materials
   - Numerical methods
   - Programming

2. *Research experience*
   - Master thesis work involving modeling of material behaviour
   - Candidate having publications (also submitted) and/or conference papers, will have an advantage
3. *Programming and software skills*
   - C++ with experience in practical programming
   - Finite element packages
4. *Communication skills*, ability to work in a team
5. *Language*: English, Dutch-speaking candidates are welcome

Job contents

- Development of mathematical models of fatigue of textile composites on meso-level (unit cell of the composite structure)
- Validation of the models: fatigue testing
- Implementation of the models in software tools
- Integration of the meso-models with macro-scale criteria and FE simulations, developed in UGent

See full project description below.

CHECK-LIST FOR THE APPLICANTS

(information to accompany your CV)

√	I have a Master degree in one of the fields mentioned above	*Provide details*
√	I have done research work in modelling of mechanical properties of composite materials… … and have published/submitted for publication the results	*Provide details; give a synopsis of the research* *Provide bibliographic details*
√	I am familiar with C++ … … moreover, I have practical experience with programming in C++	*How did you study it?* *Provide details: brief descriptions on the codes*
√	I am familiar with FE packages … … and have practical experience in using FE	*How did you study them? Specify the packages* *Provide details: brief description of the solved problems*
√	I understand the project description and it interests me	*Write one-page comment on the project, relating it to your own experience and education*
√	I speak and write good English or Dutch	*Do it in your application!*

CONTACT

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PROJECT DESCRIPTION (K.U.LEUVEN & UGENT)

1. Aim

Composites are heterogeneous materials, consisting of two or more separate phases. The most important class of composites are the fibre-reinforced plastics. In these materials, fibres are embedded in the plastic matrix *(micro-level)* . The fibre reinforcement can be a textile, a mat of chopped fibres, a layer of unidirectional fibres,... *(meso-level)*. Several plies of this fibre-reinforced plastic can be stacked under different angles to form a laminate *(macro-level)*. As the application of these composites in structural components is growing steadily, the fatigue issue is becoming part of the design criteria. Examples of fatigue-critical applications of composites can be found in wind turbine blades, aircraft components, automotive parts. In contrast to their metallic counterparts, the stiffness properties of composites can decrease significantly as fatigue loading continues, indicating a steady development of damage [1-5].

Different types of damage may occur: (i) small cracks in the plastic matrix, (ii) debonding of the fibre/matrix interface, (iii) delamination between two adjacent layers of the composite. Currently, fatigue simulation tools exist to predict the crack density in one layer of unidirectional fibres (=one UD-ply) [6-8], or to predict the degradation of the homogenized elastic properties of a UD-based laminate [9-11], but none of these simulation tools bridges the gap between the micromechanical damage phenomena and the structural response of the damaged laminate. Moreover, very little work has been carried out on the fatigue behaviour of textile based composites [12-14].

Hence, the main aim of this proposal is the development of generic simulation tools for the fatigue damage evolution in textile-reinforced composites, based on the integration of structural calculations and micro- or meso-mechanical damage evolution laws.

The promising approach to these problems is multi-level modelling, which allows to include mesoscopic behaviour features in macroscopic descriptions, without the need for an a priori postulated macroscopic constitutive law [15-18]. Macroscopic constitutive relations (material properties on the laminate level) are obtained from scaling up material modelling at lower (meso- and micro-)scales, where the detailed material structure with its specific material behaviour is represented. The multi-scale approach couples the advantages of a pure micro- or mesomechanical approach to those of a pure macroscopic modelling. The complex material behaviour is properly captured by the modelling at lower scales, while large-scale analyses at the macroscale remain numerically feasible.

2. Objectives

The applicants each have their expertise in certain subdomains of the project, but are convinced that joining of the competences is invaluable for the success of this project. The individual expertise of the two research groups, UGent-MMC and K.U.Leuven-MTM, will be shortly described, because the objectives can only be seen in light of the past research activities. In the past few years, research on fatigue of composites has been carried out in the *Mechanics of Materials and Structures* group at Ghent University (UGent-MMC) [19-22], while in the *Composite Materials Group* at K.U.Leuven (K.U.Leuven-MTM) research has been carried out on the mesoscopic modelling of textile based composites [23-26]. The activities are schematically represented below for UGent-MMC (section “fatigue”) and K.U.Leuven-MTM (section “static”) and are shortly described hereafter

UGent-MMC has developed phenomenological damage models for fatigue of textile-reinforced composites. Damage models are applied at the level of the *homogenized* ply (*meso-level*) ;the individual fibre and matrix phase are not considered in the model. Damage state variables describe the degradation of the stiffness properties in terms of mesoscopic properties (the homogenized ply stress, the damage state itself, temperature, moisture,...). The formulation of the model and the determination of the model constants is done by comparison with experimental fatigue tests. These so-called phenomenological damage laws can be applied to a structural calculation of the composite component (*macro-level*), but lack generality. Indeed, if the fibre architecture is changed, the damage laws need to be redefined

At K.U.Leuven-MTM, models for static loading are applied at the mesomechanical level. The yarn architecture (yarn=fibre bundle), the matrix phase and the yarn/matrix interface are taken into account. This is done by modelling a so-called unit cell (the unit cell is the smallest repetitive unit of the individual ply). By applying the correct periodic boundary conditions to this unit cell, different loadings of the composite ply can be simulated (bi-axial tension, shear,...). The elastic response of this unit cell can be calculated by using finite element methods, cell methods or inclusion methods. Local stress and strain fields in the matrix, the fibre bundle and the interface region can be obtained. However, the prediction of damage initiation and growth inside the unit cell of a textile composite is much more difficult and research is far from complete. The main reason for this lies in the complexity of the damage description. At unit cell-level, the description of damage should account for the internal micro/meso-structure of the composite ply, but a direct coupling with macro-level structural calculations is very difficult. Indeed, in the latter calculations, damage is described by a decrease of the elastic properties of the homogenized composite plies for reasons of computational efficiency. The effect of local damage in the yarn and matrix phase should hence be translated into a degradation of the mesoscopic elastic properties of the individual composite plies.

In this project, the developed synergy of both approaches should lead to a fatigue analysis of the composite component, that accounts for the mesomechanical architecture of the textile composite and the local damage states, but is still efficient in terms of accuracy and calculation time for large composite components.

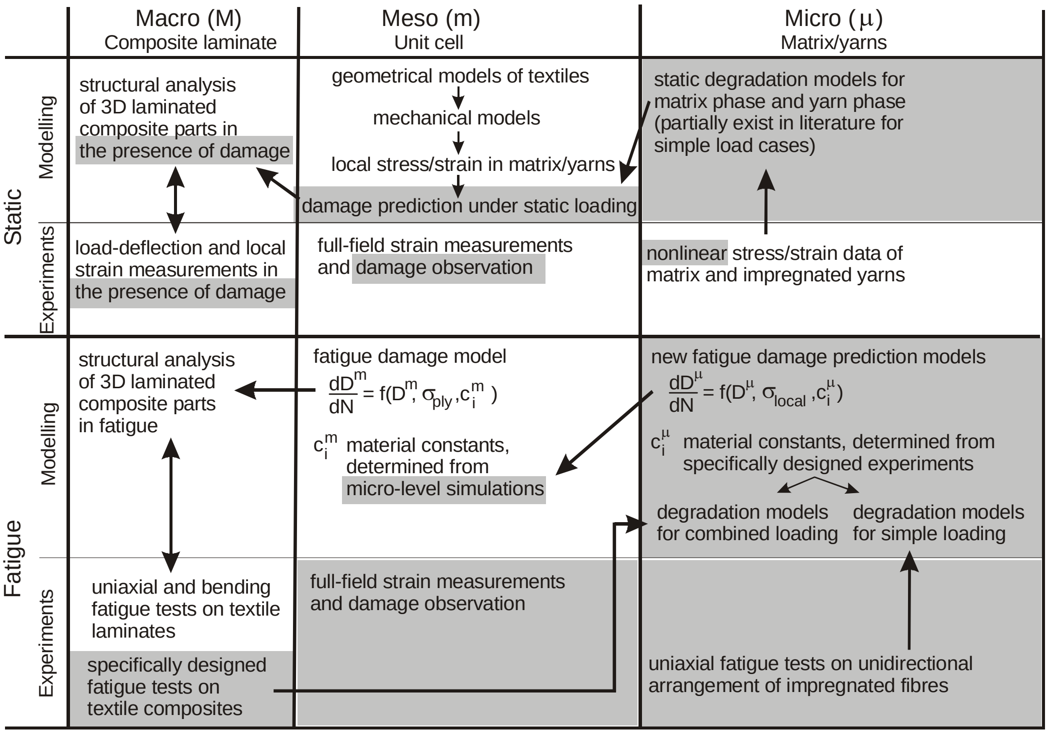
3. Design and methodology

The methodology will be discussed by means of the scheme on the next page. The grey areas indicate dedicated project activities in the static and fatigue domain, as compared to the previous partners' activities in the first scheme.

The key challenge of the project is the construction of new fatigue damage prediction models at the micro-level. Based on these developed models, the material constants in the fatigue damage models at the meso-level are no longer determined phenomenologically, but are derived from micro-level simulations. As a consequence, if the textile architecture is changed, or the fibre volume fraction is changed, the material constants can be re-calculated without any need for new experiments. This leads to a very generic set of fatigue simulation tools.

Development of these micromechanical fatigue damage prediction models will be done in two stages:

- **first,** damage prediction models will be constructed for ***static loading***. These models will employ the damage initiation and degradation models for (i) unidirectional (UD) composites (impregnated yarns are considered piecewise as straight "UD layers") and (ii) matrix material on micro-level . On the meso-level, the Wisetex-software developed at K.U.Leuven will be used to generate accurate volumetric descriptions of the yarn architecture inside a unit cell. This is then automatically transferred into a finite element mesh, so that local stresses and strains can be accurately calculated for any type of textile composites on the meso-level (unit cell). The prediction of the damage initiation site and the type of damage will be compared with observed local damage from tension, compression and shear tests on textile composites. Simulated local strains can be compared with measured local strains during testing. Strain mapping and digital image correlation will be a very valuable tool to measure the local strain fields in the matrix phase and yarn phase.



- **next** the micromechanical damage prediction models will be extended for ***fatigue loading***. These damage laws will be a function of the local stress/strain state and the local damage state in the individual matrix and yarn phase. For the matrix phase, these laws can be derived from fatigue experiments on pure matrix specimens, but for the yarns, it is much more complicated. For simple loading conditions, the analogy between the impregnated yarn and the unidirectionally reinforced ply can be used to derive experimental data from fatigue tests on unidirectionally reinforced laminates. For example, one could imagine that the fatigue test on a cross-ply laminate $[0°/90°]_{ns}$ could provide information about the transverse tension behaviour of the impregnated yarn, because the 90°-layers are constrained by upper and lower 0° layers, similar to the constrained position of the weft yarn between the warp yarns in a fabric. However, the curved nature of a yarn in (for instance) a woven textile composite will hinder the damage development, and create a more complex stress state. Hence, specific fatigue tests on textile laminates must be designed to derive the experimental data for a yarn, subjected to transverse tension or shear. Here again, strain mapping and digital image correlation will be used to measure the local strain fields in the matrix and the yarns under fatigue loading.

  It must be mentioned that this approach is not valid to describe delaminations, because the interface failure of adjacent plies cannot be described by the damage laws in the unit cell. Secondly, the growth of macro-cracks is excluded for the same reason. However, this is not a problem with textile-reinforced composites, because they show a very gradual degradation under fatigue and the matrix cracks in the matrix rich zones in between plies are contained by the wavy fibre architecture.

Once the micromechanical fatigue damage prediction models have been developed, they will be used to determine the material constants of the **fatigue damage models at the meso-scale**. As such, these material constants are no longer determined by "fitting" the simulation data with the observed experimental results, but by simulations of the unit cell behaviour with micromechanical fatigue damage laws for the individual matrix and yarn phase. This identification of the material constants will be done by comparing the degradation of the homogenized elastic properties of the unit cell, **(i)** as predicted by the application of the micromechanical fatigue damage laws to the unit cell mesh (micro-meso-link), and **(ii)** as predicted by the damage state variables of the phenomenological fatigue damage law (meso-macro-link).

Validation will be done throughout the whole project. In every development phase the agreement between finite element calculations and experimental observations will be assessed in terms of:

- the location of the local damage and its growth path, as predicted by the unit cell calculations and as experimentally observed (by microscopic analysis),
- local strain fields in the fibre and matrix phase, as calculated by the unit cell simulations and as measured by means of strain mapping and digital image correlation,
- the degradation of the homogenized elastic properties, as simulated by the finite element calculation and as experimentally measured (by extensometer, strain gauges,...).

Final validation will be done through the fatigue test on a real-life textile-reinforced composite component with a more complex stacking sequence. The experimental fatigue test must be instrumented very carefully, so that global stiffness reduction, local strains and damage patterns, and deflections can be measured. On the other hand, the results of the fatigue analysis should then agree in terms of predicted local damage areas, stiffness reductions, local strain fields and deflections.

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