

Research Topic for the Arts et Métiers ParisTech - CSC PhD Program

Multiscale fully coupled thermomechanical modeling of fatigue in short fiber-thermoplastic composites accounting for viscous and damage mechanisms

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The tremendous growth of the materials science and the significant complexity of many modern engineering applications has led to the increasing utilization of composite materials. Many engineering industries, like the automotive and the aerospace, require smart composites with advanced multi-functionality that can be applied in complicated structures with high demands in mechanical performance, strength and durability, and at the same time to have extended lifetime during repeated mechanical, thermal, electrical, magnetic etc loading cycles. To match those high requirements, composite materials are often exposed in conditions where dissipative phenomena occur, i.e viscoelasticity, rate-independent or rate-dependent plasticity, damage and phase transformation. Such mechanisms are usually accompanied by a significant temperature change, which influences in return the material behavior. To account for the thermo- mechanical couplings that arise from a structural application it is a vital issue in the case of polymeric composites. Polymers are extremely sensitive to temperature variations, especially in regimes close to the glass transition zones, and their mechanical response can be altered quite significantly due to heat dissipation.

Polyamide/short glass fiber composite materials (PA/GF) are widely used in automotive industry due to their high strength-to-weight ratio and the ability of injection molding to produce affordable geometrically complex parts. It is well understood nowadays that the mechanical response of this composites is characterized by the interplay between viscous (viscoelastic/viscoplastic) and damage phenomena and they have strong dependence on the environmental conditions (relative humidity, temperature etc).

The mechanical behavior of PA/GF composites and its sensitivity to temperature variations has been well examined in the literature, both from experimental and modeling point of view. In terms of modeling, the majority of the proposed models are phenomenological and they account only macroscopically the effects of the composite microstructural characteristics. On the other hand, the various micromechanics studies on PA/GF are focused on the mechanical response and they do not consider the thermal effects, arising from the energy balance, on the overall behavior.

The aim of the proposed Ph.D. is to develop a novel micromechanics framework that accounts for the microstructural complexity, the various nonlinear mechanisms and the thermo-mechanical couplings of the polyamide/short glass fiber composites during low cycle fatigue tests. When considering repeated loading/unloading conditions at relatively high stresses, the activation of viscoelastic and viscoplastic mechanisms produce significant intrinsic dissipation, causing in return a strong interaction between thermal and mechanical fields. This interaction needs to be integrated properly into the proposed homogenization scheme, in order to obtain a better estimation of the macroscopic response of the composite and a more accurate prediction of the various fields that effect the fatigue life.

Specifically, a proper homogenization scheme in such complicated material systems requires to:

- identify the geometrical characteristics and the short fibers distribution due to the injection molding process,
- consider in a thermodynamically consistent manner the coupling between the various inelastic mechanisms (viscoelasticity / viscoplasticity) with the accumulated damage,
- correctly identify the damage propagation, with appropriate evolution laws, in all the composite phases (matrix, fibers, interphases),
- take into account the sensitivity of the polymer matrix with temperature, through appropriate thermomechanical constitutive law, and
- develop novel homogenization tools that consider simultaneously the equilibrium and the energy equation, permitting the strong full coupling between the mechanical and thermal fields through the various dissipation processes. Due to the random structure of the PA/GF, the homogenization scheme is going to be based and extend the classical mean-field methods (for instance, the Mori-Tanaka).

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