



# Hybrid and hierarchical nanoreinforced polymer composites: Computational modelling of structure–properties relationships



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## ABSTRACT

Hybrid and hierarchical polymer composites represent a promising group of materials for engineering applications. In this paper, computational studies of the strength and damage resistance of hybrid and hierarchical composites are reviewed. The reserves of the composite improvement are explored by using computational micromechanical models. It is shown that while glass/carbon fibers hybrid composites clearly demonstrate higher stiffness and lower weight with increasing the carbon content, they can have lower strength as compared with usual glass fiber polymer composites. Secondary nanoreinforcement can drastically increase the fatigue lifetime of composites. Especially, composites with the nanoplatelets localized in the fiber/matrix interface layer (fiber sizing) ensure much higher fatigue lifetime than those with the nanoplatelets in the matrix.

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## 1. Introduction

Polymer based composites are used in many areas of industry as lightweight, durable and strong materials. Still, requirements toward the materials for structural applications become more and more challenging. For instance, an off-shore extra-large wind turbine should sustain in optimal case more than 25 years of permanent work, with no or minimum maintenance or repair [1].

Many scientific works have been carried out in order to ensure the high lifetime and reliability of machines built from polymer based composites. The approaches which are investigated now can be grouped as follows: improvement of fabrication technology and reduction of manufacturing defects; improvement of components of the composites, e.g. development of new, stronger and lighter fibers and fiber sizing; modification of structure and architecture of the composites (e.g., clustering of fibers), and development of new materials, for instance, using the hybrid composites or composites with secondary nanoreinforcements [2–5].

In order to evaluate the potential of different ways of the material optimization and to develop recommendations for the production of new, strong and reliable composites, computational studies of the various microstructures of materials and their behavior under service conditions are required.

In this paper, we present a short overview of the methods of computational modeling for the hybrid and hierarchical

nanoreinforced composites, numerical simulations of damage and strength of the composites and computational analysis of strength–structure relationships. Here, we pay most attention to the development and application of high strength composites in wind energy (wind blades). However, the ideas and results developed are also applicable for other areas of application of strong lightweight polymer composites.

## 2. Developments and applications of polymer composites with modified structures

### 2.1. Improved constituents

In long fiber reinforced polymer composites, fibers ensure longitudinal stiffness and strength, while the resin matrix is responsible for fracture toughness, delamination strength and out-of-plane strength and stiffness of the composite. Most often, E-glass (i.e., borosilicate glass called “electric glass” for its high electric resistance) fibers are used as main reinforcement in the composites. Many investigations are devoted to the development of fibers, which are stronger than the usual E-glass fibers. The high strength fibers (which are still used seldom in practice) include, among others:

- Glass fibers with modified compositions (S-glass, R-glass, etc.); High strength S-glass (40% higher tensile and flexural strengths, and 10%...20% higher compressive strength and flexural modulus; much more expensive, than the E-glass),

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