



# Fatigue of multiscale composites with secondary nanoplatelet reinforcement: 3D computational analysis



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## ARTICLE INFO

### Article history:

Received 9 October 2013  
Received in revised form 20 November 2013  
Accepted 24 November 2013  
Available online 8 December 2013

### Keywords:

A. Nanocomposites  
A. Polymer–matrix composites (PMCs)  
B. Fatigue  
C. Computational mechanics  
C. Finite element analysis (FEA)

## ABSTRACT

3D numerical simulations of fatigue damage of multiscale fiber reinforced polymer composites with secondary nanoclay reinforcement are carried out. Macro–micro FE models of the multiscale composites are generated automatically using Python based software. The effect of the nanoclay reinforcement (localized in the fiber/matrix interface (fiber sizing) and distributed throughout the matrix) on the crack path, damage mechanisms and fatigue behavior is investigated in numerical experiments. It was observed that the composites with secondary nanoreinforcement localized in the fiber sizing ensure higher lifetime and damage resistance than those with nanoreinforcement dispersed throughout the matrix. Crack bridging by nanoparticles was observed mainly in composites with randomly oriented nanoplatelets and clusters, while the crack path deviation was strongest in the composites with aligned nanoplatelets. Multiscale composites with exfoliated nanoreinforcement and aligned nanoplatelets ensure the better fatigue resistance than those with intercalated/clustered and randomly oriented nanoreinforcement.

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## 1. Introduction

The development of composites with hierarchical structures represents a promising reserve of the enhancement of service properties of composites [1,2]. Composite materials with hierarchical structures make it possible to combine the advantages of microscale reinforcement of composites with those of nanoreinforcement.

Since it is known that properties of polymer can be drastically enhanced by adding a few weight percents of nanoreinforcement [3], it can be also expected that comparable positive effects can be achieved by nanomodification of fiber reinforced polymer composites. The addition of nanoreinforcement to the polymer matrix can lead to the improvement in the elastic modulus and strength (clearly observed in rubbery epoxy and polyamide with exfoliated nanoclay (NC); less clear in glassy epoxy), as well reduced ductility and constrained plastic deformation [4,5]. However, the transfer of these effects on fiber reinforced composites is not always apparent: some properties of the composites are controlled by fiber properties, some by matrices and some by their interaction; further, the matrix is in much more complex stress state in the composite.

Here, we consider the composites with epoxy matrix, reinforced by glass fibers and nanoclays at nanolevel, and seek to analyze the effect of nanoclay reinforcement of the fatigue properties of these

materials, widely used among other for wind turbine blades. As for now, this combination of constituents is less expensive as compared with carbon and carbon nanotube (CNT) reinforcement and/or thermoset matrices, thus, allowing more broad potential use of the multiscale materials.

The effects of small additions of nanoreinforcement in fiber reinforced polymers on the mechanical properties and strength of materials have been investigated in a number of works [6–13]. The mechanical properties and strength improvement due to the nanoclay addition was observed in numerous studies: e.g., increase of tensile strength, strain and tensile modulus to failure (~20%, 13% and 60%, respectively, at wt% 5%). The increase of fatigue life up to 74% with 3 wt% clay content (NC/carbon fibers/epoxy TT fatigue, [8]), 53% and 85% increase of mode I interlaminar FT by with 2 and 4 phr NC respectively, (NC/carbon fiber/epoxy [9]), 26% increase of flexural modulus 26% at 3 wt%, 30% increase of quasi-static FT increases by 60% at 3 wt% (peak value). (NC/carbon fibers/epoxy [4]), 4–5 times increased fatigue life under WISPERX loading (glass fiber/hybrid particles/epoxy [10]), UTS, Young's modulus, flexural strength, ILSS and microhardness increase up to 5 wt% of NC (by 30%, 38%, 120%, 25%, 70% and 25% respectively) and decrease after that (NC/glass/epoxy [11]), 21–30% improvement on the interfacial shear strength at 2–14 vol.% silica (epoxy/carbon fiber/silica nanoparticles under single fiber fragmentation [14]). In these studies, it was also observed that the secondary nanoclay reinforcement changes the damage and fracture mechanisms of composites: narrower dimples on fracture surfaces and more dimples of smaller sizes, more damage at early cycles (crack initiation

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