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The Influence of Unidirectionally or Randomly Oriented CNTs on the Elastic Properties of Reinforced Composites

Kazakov IA* and Krasnovskii AN*

Department of Composite Materials, Moscow State Technological University STANKIN, Russia

ISSN: 2770-6613

***Corresponding author:** Kazakov IA and Krasnovskii AN, Department of Composite Materials, Moscow State Technological University STANKIN, 127055 Moscow, Russia

Submission: September 23, 2020

Published: November 30, 2021

Volume 2 - Issue 4

How to cite this article: Kazakov IA, Krasnovskii AN. The Influence of Unidirectionally or Randomly Oriented CNTs on the Elastic Properties of Reinforced Composites. Polymer Sci peer Rev J. 2(4). PSPRJ. 000542. 2021.
DOI: 10.31031/PSPRJ.2021.02.000542

Abstract

The paper studies the influence of CNTs on the elastic properties of unidirectionally aligned composites. The nano-inclusions, whose properties could be characterized by three parameters (length, diameter, Young's elastic modulus), are assumed to be ellipsoidal and oriented along a macro-filler (for example, glass fibers). The elastic properties of two systems: Matrix+CNT+Glass fibers and Matrix+Glass fibers were determined and compared.

Keywords: Nano-inclusions; CNTs; Eshelby; Mori-tanaka; Nidltrusion; Pultrusion

Introduction

In recent years, in connection with the development of technologies for the production of nano-modified composites (in particular, pultrusion and nidltrusion technologies [1,2]), there is a need to assess the effect of CNT on the properties of composites with unidirectionally aligned fibers. By a proper combination of fibers, matrix and aligned CNTs as additives a wide range of elastic properties can be achieved. In our previous work [3], an effective tool for determining the elastic properties of nano-reinforced composites based on the Eshelby-Mori-Tanaka's method [4-7] was proposed. The model with an ellipsoidal inclusion in an infinite medium for an epoxy matrix reinforced with randomly oriented nanotubes allows obtaining a set of two independent elastic properties of the isotropic Matrix/CNT system. In the case of unidirectional CNTs, we obtain a set of five independent elastic constants of the transversely isotropic Matrix/CNT system. However, in the case of nanotubes oriented along a macro-filler (for example, glass fibers) the elastic properties of the Matrix+ CNT/Fiberglass system (we denote such a system as "compIICNT" for brevity) cannot be applied using the model with an ellipsoidal inclusion. This is due to the fact that the matrix with CNTs has not isotropic, but transversely isotropic properties. The goal of the current research is to explore Eshelby-Mori-Tanaka' model for predicting effective elastic properties of unidirectionally aligned composites with unidirectionally or randomly oriented CNTs.

Theoretical Modeling

For a qualitative comparison of the two systems (compXCNT and compIICNT), we use the equations for engineering constants [8]. The longitudinal Young's modulus E_1 (1):

$$E_1 = E_{1f} v_f + E_{1m}(1-v_f) + \left(\frac{4\left(\mu_{12m} - \mu_{12f}^2\right) k_f k_m G_{23m}(1-v_f) v_f}{(k_f + G_{23m}) k_m + (k_f - k_m) G_{23m} v_f} \right), \quad k = \frac{E_1 E_2}{2(1-\mu_{23})E_1 - 4\mu_{12}^2 E_2},$$

$$\mu_{12} = \mu_{13} = \mu_f v_f + \mu_{12m}(1-v_f) + \left(\frac{(\mu_{12m} - \mu_f)(k_m - k_f) G_{23m}(1-v_f) v_f}{(k_f + G_{23m}) k_m + (k_f - k_m) G_{23m} v_f} \right),$$

$$\mu_{23} = \frac{2E_1 k_T - E_1 E_2 - 4\mu_{12}^2 k_T E_2}{2E_1 k_T},$$

$$k_T = \frac{\left(k_f + G_{23m}\right)k_m + \left(k_f - k_m\right)G_{23m} v_f}{k_f + G_{23m} - \left(k_f - k_m\right)v_f}. \quad (1)$$

where indices f, m refers to fibers and matrix, respectively, ν–the mass fraction, μ–Poisson's ratio, k–the bulk modulus at plane strain, k_T–the effective composite modulus, in-plane shear modulus G_{12}, G_{13} (2):

$$G_{12} = G_{13} = G_{12m}\left[\frac{\left(G_f + G_{12m}\right) + \left(G_f - G_{12m}\right)v_f}{\left(G_f + G_{12m}\right) - \left(G_f - G_{12m}\right)v_f}\right],$$

$$G_{23} = G_{23m}\frac{k_m\left(G_{23m} + G_f\right) + 2G_f G_{23m} + k_m\left(G_f - G_{23m}\right)v_f}{k_m\left(G_{23m} + G_f\right) + 2G_f G_{23m} - \left(k_m + 2G_{23m}\right)\left(G_f - G_{23m}\right)v_f}. \quad (2)$$

The transverse Young's modulus E_2 (3):

$$E_2 = E_3 = 1\Bigg/\left(\frac{1}{4k_T} + \frac{1}{4G_{23}} + \frac{\mu_{12}^2}{E_1}\right), \quad (3)$$

Having these constants defined, all the elastic properties of the composite will be fully determined. It should be noted that the properties of the matrix reinforced by CNTs are calculated using Eshelby-Mori-Tanaka's model described in [3].

Results and Discussion

We assess the influence of the nanotube reinforcement on the macroscopic properties of the unidirectionally aligned polymer composites. To make the effect of aspect ratio α=L/D and CNTs mass fraction WCNT (in percentage) more apparent, independent elastic constants were presented in the form of relations to the initial properties (WCNT=0) and plotted as a function of α and WCNT. This made it possible to understand how the addition of filler in the form of CNT affects the properties of the composite. It should be mentioned that WCNT is the mass fraction relatively to the volume occupied by resin+CNTs system. For example, WCNT=100% means that composite consists of 60% fiberglass and 40% CNTs (no resin). As was mentioned above, fiberglass volume fraction v_f=60% assumed constants for all numerical experiments.

As shown in Figure 1, we employed values of CNTs up to 2% to avoid intersections between different fibers (i.e., the interphase regions). Figure 1 shows that in unidirectional polymer composites with oriented along a macro-filler nanotube an overall reinforcement effect is noticed increasing by decreasing the diameter of the embedded nanotubes. The addition of CNT in fiberglass/epoxy composites of up to 2% by weight results in insignificant increasing the mechanical properties in main direction (E_1), since the fibers are the main component carrying the load. For the modified by CNTs composite of the variations of three independent relative elastic constants, the transverse Young's modulus E_2, in-plane shear modulus G_{12}, and out-plane shear modulus G_{23} appear to significantly increase with increasing CNT's concentration and length/diameter ratio for randomly oriented CNTs in the composite.

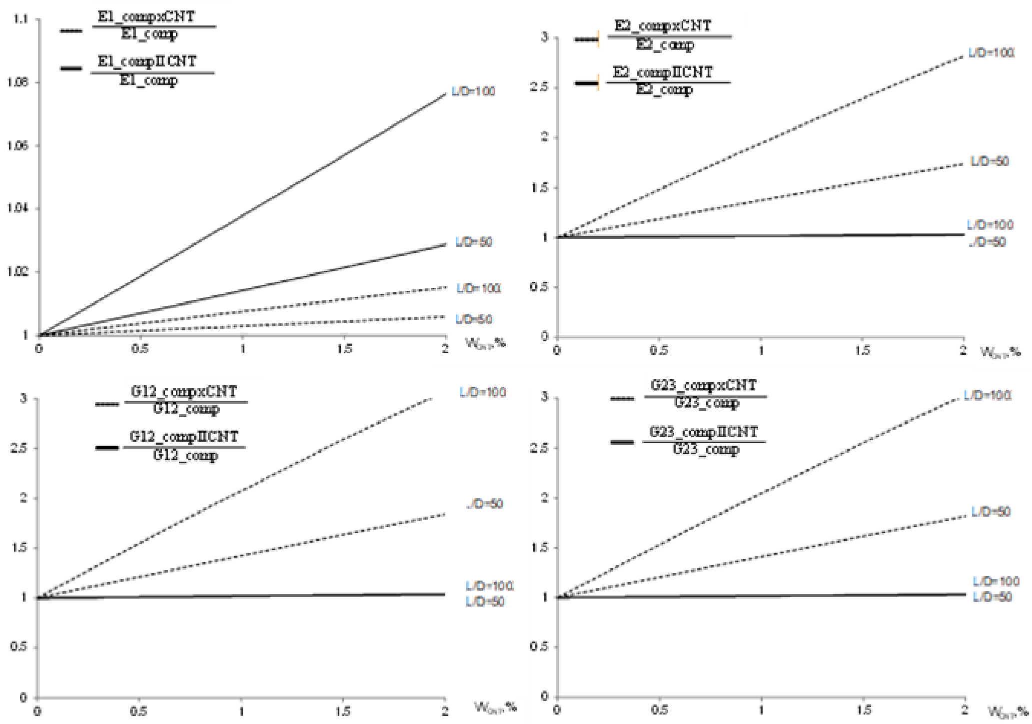

Figure 1: Normalized elastic properties E_1, E_2, G_{12}, G_{23} for polymer composites with unidirectional fiberglass filler (v_f=0.6) and oriented along a macro-filler CNTs.

Conclusion

The modification of composites is critically important to improve its strength and mechanical properties, and to widespread its practical applications in many areas of outdoor, construction buildings, engineering, and technology sectors. As was shown in this article, dispersed CNTs around the unidirectional fibers was found be very effective for reinforcing composites. The mechanical properties of two systems: Matrix+CNT+Fiberglass and Matrix+Fiberglass were determined and compared using of Eshelby's and Mori-Tanaka's theories of inclusions. However, the curing and aging of epoxy resins are complex phenomena and the composite can show the agglomeration of CNTs, which can in turn have a negative effect on the mechanical properties of the composite, which is not taken into account in the model. An estimation of the effect of CNT on the properties of unidirectional fiberglass, depending on the concentration of CNT and the geometric ratio α=L/D, was made.

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