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# Bending and free vibration analysis of functionally graded graphene vs. carbon nanotube reinforced composite plates

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**Highlights**

- A comparison of the stiffening effect of graphene and CNTs is presented
- Agglomeration effects on the vibrational behavior of composite plates are studied
- Agglomeration on functionally graded nanocomposites is taken into account
- Power-law distributions of fillers across the thickness are studied
- Restacking of graphene sheets into graphite platelets is considered.

**Abstract**

Carbon-based nanomaterials have drawn the attention of a large section of the scientific community in recent years. Most research has focused on carbon nanotubes after some experimental studies reported outstanding enhancements of the mechanical properties of polymeric matrices doped with small filler concentrations. Nevertheless, some limiting factors such as high manufacturing cost and difficulty in obtaining adequate uniform dispersions still remain an obstacle to the extensive manufacturing of these composites. Conversely, recent investigations demonstrate the superior properties of graphene, as well as better dispersion and relatively low manufacturing cost. Although these recent findings have begun to turn the attention towards graphene, the number of publications dealing with the theoretical analysis of graphene-reinforced structural elements is rather scant. In this context, the present work reports the bending and vibrational behavior of functionally graded graphene- and carbon nanotube-reinforced composite flat plates. The macroscopic elastic moduli of the composites are computed by means of the Mori-Tanaka model. The results demonstrate superior load bearing capacity of graphene-reinforced composite plates for both fully aligned and randomly oriented filler configurations. In addition, defects in the microstructure stemming from agglomeration and restacking of graphene sheets into graphite platelets are also analyzed.

*Keywords:*
Agglomeration, Carbon nanotubes, Functionally graded, Graphene, Micromechanics, Restacking

## 1. Introduction

Over the last two decades, a broad cross section of the scientific community has endeavored to develop carbon-based nanomaterials for high-strength and multifuntional composite materials. In particular, Carbon NanoTubes (CNTs) and graphene have shown promise for developing novel multifunctional nanocomposites [1–6]. CNTs, which can be considered as a rolled-up graphene sheet, have been reported to provide remarkable enhancements of the mechanical properties of polymeric matrices when dispersed at low concentrations [7, 8]. For instance, Qian *et al.* [9] doped polystyrene with a concentration of 1 wt% of Multi-Walled Carbon NanoTubes (MWCNTs), reaching improvements with respect to the neat polymer in the elastic modulus and in the break stress of 36-42% and ~25%, respectively. Notwithstanding the potential of CNTs, aspects such as their high manufacturing cost, difficulty in obtaining adequate uniform dispersions, as well as their highly anisotropic properties, remain an obstacle to the extensive development of CNT-reinforced polymer composites. In contrast, recent investigations agree to indicate the superior properties of graphene and its derivatives [10–13]. It is noteworthy the experimental study of Rafiee *et al.* [14] who compared the effective mechanical properties of epoxy loaded with graphene, Single-Walled

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