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Review

Graphene-based nanosheets for stronger and more durable concrete: A review

Ezzatollah Shamsaei [a], Felipe Basquiroto de Souza [a], Xupei Yao [a], Emad Benhelal [b], Abozar Akbari [c], Wenhui Duan [a,*]

[a] Department of Civil Engineering, Monash University, Clayton, VIC 3800, Australia
[b] Department of Chemical Engineering, Priority Research Center for Energy, Newcastle University, Callaghan, NSW 2308, Australia
[c] Center for Multidimensional Carbon Materials (CMCM), Institute for Basic Science (IBS), Ulsan 44919, Republic of Korea

HIGHLIGHTS

- Progress on graphene-cement composites have been comprehensively reviewed.
- Graphene-based NanoSheets (GNS) significantly enhance cement composites properties.
- Three main challenges to implement GNS in the construction field were identified.

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ABSTRACT

Graphene and graphene-based nanosheets (GNS) possess extraordinary mechanical, chemical, thermal and electrical properties, enabling attractive applications, ranging from structural strength/durability improvement, anti-corrosion, to self-cleaning surfaces and energy saving. Recent extensive research demonstrates that GNS also have the ability to transform conventional construction materials into smarter, stronger and more durable advanced composites. This review provides a comprehensive overview on developments and novelties in the fabrication, properties and applications of GNS in enhancing the strength and durability of concrete composites, pointing out the main challenges and future perspectives for GNS in the construction field.

Contents

* Corresponding author.
E-mail address: Wenhui.Duan@monash.edu (W. Duan).

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1. Introduction

Recent developments in the construction industry, seeking out a way to advance conventional construction materials, have stimulated the use of different materials at the nanometre scale [1–7]. Graphene-based nanosheets (GNS), possessing extraordinary chemical and physical properties [8,9], have exhibited potential to enhance crucial properties of construction materials such as mechanical strength and durability [10,11]. In addition, GNS can provide useful functionalities such as self-cleaning, self-sensing, electromagnetic shielding and thermal interfacing [12–14]. Similar to other nanomaterials (e.g. nanosilica, nanoalumina, titania), GNS are likely to be increasingly employed in the construction industries [1,15–18]. This great interest in GNS is associated with: (1) their potential in enhancing the mechanical properties and adding invaluable functionalities to materials at very low addition ratio; (2) the increasing knowledge about their nanoscale properties and new applications of these materials and (3) their decreasing manufacturing cost due to the ongoing development of large-scale manufacturing processes.

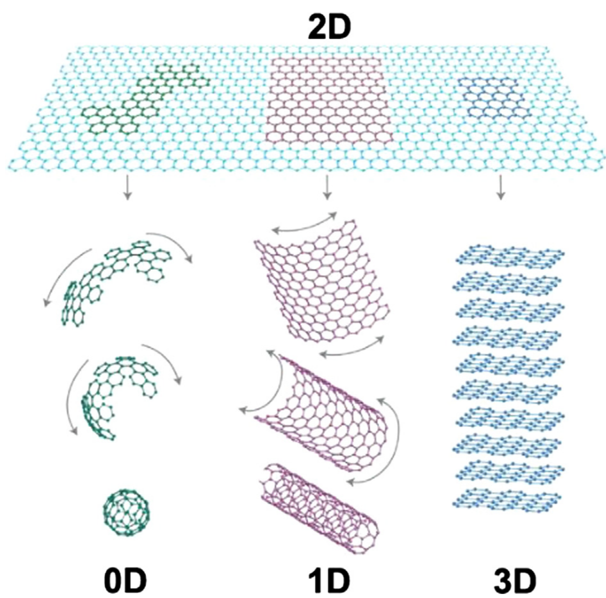

Fig. 1. Graphene is a 2D building material for carbon materials of all other dimensions. It can be wrapped up into 0D buckyballs, rolled into 1D nanotubes or stacked into 3D graphite [20].

Graphene is the basic structural unit for graphitic materials of any dimension. It is composed of a single-layer sheet of carbon atoms closely packed into a two-dimensional (2D) (with thickness of 0.335 nm) honeycomb framework [19]. It can be wrapped up into 0D fullerenes, rolled into 1D nanotubes or stacked into 3D graphite [20] (Fig. 1). Although the rapid progress on graphene-based cementitious composites has benefited from the relatively mature research on other carbon-based nanomaterials, especially carbon nanotubes (CNTs) [20], the use of graphene in concrete has some intrinsic advantages over them. Compared to CNTs, for example, graphene is: 2-dimensional, presenting larger specific surface area (SSA); easier to produce in large quantities with fully reproducible properties; less hazardous for health and environment; and more easily dispersed in a media [21,22]; which makes it more attractive for various applications in construction materials.

Different forms of GNS, with properties and microstructure derived from pristine graphene, are also often employed in construction materials. Graphene oxide (GO), the most researched GNS in cement composites, also consists of monolayer sheets with a hexagonal carbon network. The main difference from graphene is that GO bears hydroxyl, epoxide, carboxyl and carbonyl functional groups on its surface and thus exhibits higher reactivity with cement and superior dispersion in the matrix, making it attractive for cementitious composites [23,24]. Reduced graphene oxide (rGO) has less functional groups in its structure as compared to GO, presenting intermediate properties between GO and graphene. Graphene nanoplatelets (GNPs) are comprised of layers of graphene sheets (typically $10 < n < 100$, with n being number of layers) with thickness <100 nm and diameter of several micrometres. Due to its increased thickness, GNPs are a cheaper alternative to graphene [25] and therefore the preferred form of GNS for structural composites [10]. However, its smaller specific surface area compared to single graphene sheets decreases its reinforcement efficiency. Graphene can also be doped with nitrogen

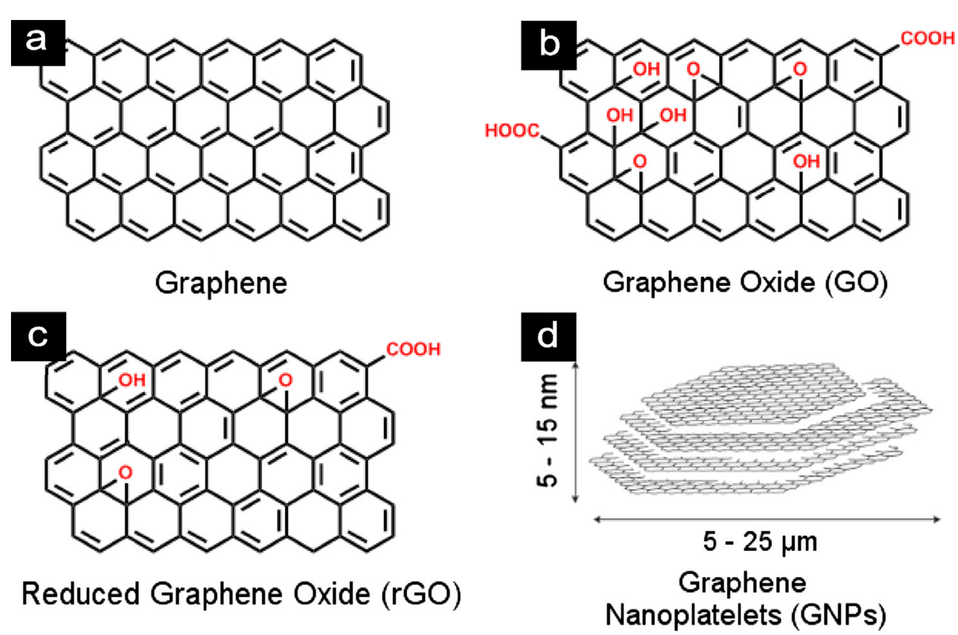

Fig. 2. Representation of (a) graphene, (b) graphene oxide (GO), (c) reduced graphene oxide (rGO) and (d) graphene nanoplatelets (GNPs) [28].