

## Review

## A holistic review of cement composites reinforced with graphene oxide

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## HIGHLIGHTS

- The research adopted scientometric review in graphene oxide (GO).
- Science mapping and in-depth review were adopted as research methods.
- GO-reinforced cement composites remain a new research area.
- Durability in GO-reinforced cement composites has not been widely investigated.
- Main research themes and research directions in GO-reinforced cement composites are provided.

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## ABSTRACT

Adopting a holistic review approach, this study started from the scientometric analysis by analyzing the mainstream journals, keywords, scholars, publications, and institutions active in the research of cement composites reinforced with graphene oxide (GO). Further statistical summary of research themes and in-depth discussion addressed the current research findings and gaps in terms of workability, mechanical properties, durability, and other issues when adding GO into cementitious materials. Recommendations for future research were provided, including but not limited to the necessity to study the long-term mechanical properties of cement composites reinforced with GO, and the application of GO in concrete.

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## 1. Introduction

The properties of cement pastes are believed to have the most important influence on the cement-based composites (e.g., concrete) [1]. As the cement hydration products, crystal shapes and numbers, if controlled properly, could lead to great improvements in properties of cement pastes [2]. Graphene oxide (GO) is a graphene derivative, consisting of several layers of wrinkled two-dimensional carbon sheet with various oxygen-containing functional groups such as hydroxyl, carboxyl, and epoxy groups on its surface or between the inter-sheet layers [3]. GO has been adopted by researchers [1,4–6] in controlling the formation of crystals in the cement hydration process. To improve the mechanical properties of concrete, adding fiber reinforced polymer (FRP) has been a widely adopted approach [7,8]. GO, as a promising option of a nano-reinforcement in cement composites [9,10], has been studied as a complement to FRP [11]. For example, GO was added in cementitious adhesive to enhance the bonding between NSM FRP and concrete substrate [7]. As a novel class of two-dimensional nanoscale material [12], GO has attracted attention due to its high specific surface area, dispersibility in water, high aspect ratio and superior mechanical performance [13,15]. Another advantage of using GO is its lower cost by being synthesized in large quantities from inexpensive nature graphite flakes [9]. GO has been studied in the form of nanosheets [9,12,16], which could be compounded by Hummer's method [16]. GO nanosheets provides a new method and direction towards the cement modification [16]. More research [4,17–21] in GO-reinforced cementitious composites have been found in recent years.

Although it remains a relatively new research area in cement composites, the booming trend can be expected. There has been so far limited investigation on the current research status of applying GO in cementitious composites, specifically: 1) what have been the main research themes (e.g., mechanical properties); 2) what are the current research gaps (e.g., understanding of the mechanism of how GO affects the cement hydration); 3) what should be studied in the future for applying GO in cementitious composites. More research related to GO-reinforced cement composites remain to be performed, such as properties of composites containing recycled aggregates and GO as recommended by Long et al. [22]. There is a need for a holistic review to shed light on the state-of-the-art research on GO-reinforced cementitious composites. Adopting a comprehensive review approach consisting of a scientometric analysis with science mapping technology followed by the in-depth discussion, this study aims to achieve these following objectives: 1) to identify the influential publication sources, frequently studied themes (i.e., keywords), productive scholars and institutions, as well as literature with highest impacts in the field of GO-reinforced cement composites; 2) to analyze the ongoing mainstream research focuses (e.g., microstructure); 3) to address the current research gaps and to provide recommendations for the near-future research in cement composites reinforced with GO. This review-based study provides the long-term direction of how the emerging GO can be applied in material and structural engineering to meet the modern construction needs.

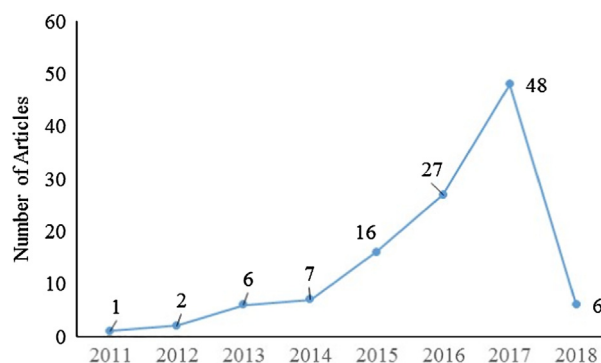
## 2. Methodology

This review-based study incorporated a scientometric review [23–25] and follow-up in-depth discussion of the ongoing research themes in GO-reinforced cementitious materials. The rationale of adopting scientometric review is that multiple previous review-based studies in the fields of construction engineering, management, and materials [26] may be relying on subjective judgements which might be unreliable [27]. The scientometric analysis is able to prevent this subjectivity and tends to be more unbiased [28]. In this study, the scientometric review started from keyword search in *Scopus*, which was defined by AghaeiChadegani et al. [29] as the database with a wider coverage of journals and more recent publications compared to other search engines (e.g., *Web of Science*). *Scopus* has also been recommended by other studies [30,31] as the search engine of literature. The keyword search in *Scopus* was set as denoted below:

**TITLE-ABS-KEY** (“graphene oxide” AND (cement OR “cement paste” OR “cement composites” OR “cementitious materials”))

The keywords input in the search included different types of construction materials with cement in the mix design, such as mortar and concrete. The type of documents in the search was set limited to journals, excluding conference proceedings. Conference papers have been published in a larger number but with limited contribution to literature review considering the extra amount of complexity added to analyze them [32]. After these key journal articles were downloaded from *Scopus*, their abstracts were read by the research team members in this study to ensure that all articles fall into the research of cement composites reinforced by GO.

Science mapping was involved in the scientometric analysis. It describes and evaluates research policy purposes and process immense reservoirs of bibliometric data [33]. Science mapping also displays the structural and dynamic aspects of a scientific research [34], and represents spatially how disciplines, fields, and individual publications or authors related to one another [35]. The text-mining tool, *VOSviewer* [36], was adopted to assist the science



**Fig. 1.** Summary of publication years of journal articles focusing on graphene oxide applied in cement composite. Note: the number of publication in 2018 is based on literature published up to 10 February 2018. Therefore, publications in 2018 are not completely counted.

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