

Research Analysis on the Microscopic Properties and Damping Performance of Carbon Nanomaterial-Modified Cement Mortar

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Abstract

The application of carbon nanomaterials, particularly graphene and carbon nanotubes, in cement-based composites is highly significant. These materials demonstrate the multifunctionality of carbon and offer extensive possibilities for technological advancements. This research analyzes how the integration of graphene into cement-based composites enhances damping and mechanical properties, thereby contributing to the safety and durability of structures. Research on carbon nanomaterials is ongoing and is expected to continue driving innovation across various industrial sectors, promoting the sustainable development of building materials.

Keywords

Carbon Nanomaterials, Cement-Based Composites, Microscopic Properties, Damping Properties, Modified Cement Mortar

1. Introduction

Cement-based materials are extensively utilized in the engineering sector due to their superior mechanical strength, durability, and cost-effectiveness. As a fundamental construction material, they are integral to a wide range of engineering projects, including civil infrastructure, bridge building, road construction, tunnel development, and dam engineering. Technological advancements have further enhanced the characteristics of cement-based materials. For instance, incorporating nanomaterials and fiber reinforcements has improved their resistance to cracking, impact, and vibration, broadening their application in specialized engineering

areas like seismic zones and environments with high levels of vibration [1] [2].

Graphene, a novel carbon nanomaterial with a two-dimensional single-layer carbon atom structure, has broad application prospects in many fields, especially its excellent mechanical properties, electrical conductivity, and strength, which have attracted widespread attention to its potential in cement-based composite materials. In many engineering structures, damping performance is an important factor to resist vibration and reduce noise. Graphene has good adhesion and elasticity, significantly enhancing the damping performance of cement-based composite materials. This not only helps to improve the stability and durability of the structure but can also reduce vibration damage in bridges, roads, and other engineering projects.

When combined with cement, graphene can form a more robust and wear-resistant structure. Its outstanding elastic modulus and tensile strength can strengthen the compressive and flexural performance of composite materials. By adjusting the content and form of graphene, it is also possible to fine-tune the structural properties of the composite materials to meet different engineering requirements. Graphene can act as a renewable material, contributing to the sustainability of cement-based composite materials. Compared to traditional reinforcing agents, the addition of graphene can reduce the material's energy consumption and environmental impact. Graphene-enhanced cement-based composite materials can be applied in the construction and maintenance of infrastructure such as bridges, tunnels, and roads. The aim of this study is to explore the influence of carbon nanomaterials on the performance and damping characteristics of cement-based composites [3]. By incorporating graphene into the cement matrix, the study seeks to strengthen the composite's mechanical durability, crack resistance, and damping capabilities to meet engineering demands under dynamic conditions such as vibrations and impacts. The research will delve into the interaction mechanisms between graphene and the cement matrix, evaluating graphene's role in improving crack resistance, impact absorption, and energy dissipation. Ultimately, the goal is to develop a high-performance composite material with enhanced damping properties for use in demanding structural and building applications.

2. Analysis of Research Status

Both domestic and international scholars have conducted extensive research on improving the damping properties of cement-based composite materials. By incorporating additives such as fibers and polymers into the cement, attempts have been made to strengthen the damping of cement-based composite materials, thereby improving the material's energy dissipation capacity under cyclic loading. Polymer cement-based composite materials can significantly improve material damping due to the viscous damping of the polymer [4] [5], but this often comes with a reduction in the composite material's stiffness, strength, and durability [6]-[9]. Cement-based composite materials incorporating micron-level fibers can

enhance material damping through interface debonding and Coulomb damping at the interface [10] [11]. However, the number of interfaces between the fiber and the cement matrix is greatly affected by the amount of fiber added. The uneven mixing, reduced flowability, increased porosity, and defects caused by high fiber content are significant obstacles to the application of micron-level fibers in cement-based composite materials [12]. Graphene materials can avoid problems such as fracture and large-scale agglomeration of micron-level fibers in cement-based composite materials, as well as the overall performance degradation of the composite materials after incorporation. At the same time, graphene materials can optimize material properties at the nanoscale [13], Facilitate the development of cement hydration products and refine the pore structure of cement-based composite materials, and enhance material properties [14] [15]. Therefore, graphene materials have gradually become a research hotspot in the field of damping enhancement for cement-based composite materials.

Considering the safety, stability, displacement control, anti-fatigue durability, noise reduction, and comfort of the structure, it is necessary to reduce and avoid structural vibrations. This can be achieved by increasing the damping ability of the building structure and enhancing its stiffness. The methods to increase structural damping include two methods: passive and active. The active method refers to the use of damping devices such as sensors and actuators to achieve vibration sensing and activation, in order to suppress vibrations in real time; When using this method, damping devices are mostly attached to the building, increasing the difficulty of structural design and construction [16]; While this method solves problems related to intense dynamic loads like those generated by earthquakes, it is not effective in addressing the vibrations caused by low amplitude dynamic loads like wind loads [17] [18]. The passive method involves leveraging the natural capacity of structural or non-structural materials to absorb vibrational energy, thus facilitating passive energy dissipation; Using the passive method to enhance the inherent damping ability of building materials is relatively low in cost and easy to implement; by enhancing the ability of cement-based materials to passively absorb vibrational energy, damping can be improved from the material's perspective [19]. Therefore, high-damping cement mortar has promising prospects in terms of structural self-vibration control, extending the lifespan of the structure, and reducing noise pollution.

3. Research Progress

Since British scholar Novoselov and others mechanically exfoliated single-layer graphene from graphite flakes by repeated scraping with tape in 2004, graphene has quickly become a hot research topic in the field of materials due to its outstanding mechanical, thermal, optical, and electrical properties [20]. Graphene is a two-dimensional (2D) nanoscale material consisting of carbon atoms arranged in a hexagonal honeycomb lattice with an SP² hybridized orbital, having a high specific surface area (2630 m²/g) [21]. Graphene's mechanical properties are

exceptional, with ultimate tensile strength and elastic modulus reaching as high as 125 GPa [22] and 1.1 TPa [23], respectively, along with excellent toughness. This makes it a potential reinforcing agent and an ideal choice for new composite materials (as shown in **Figure 1**).

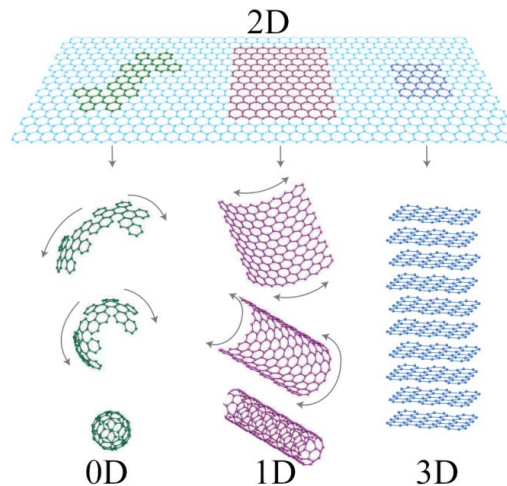


Figure 1. Graphene-based nano carbon materials.

The addition of fiber to enhance the mechanical and damping properties of latex-modified mortar has a long history. In 1995, scholars used different types of synthetic short-cut fibers (length 5 mm) in Latex Modified Concrete (LMC) and found that they could enhance the tensile and bending strengths of LMC [24]. However, the efficiency of synthetic fibers in enhancing the mechanical properties of LMC was limited, due to these fibers not chemically bonding to the polymer latex matrix, and thus only serving to prevent cracking when the polymer latex film hardened. Wang Bo and Jian Bin, (2021) [25] studied the effects of Styrene-Butadiene Rubber Latex (SBR) and Recycled Polypropylene Fiber (RPF) on the durability and mechanical properties of concrete, finding improvements in durability and mechanical properties under acidic solution soaking with optimal content of 1.0% for RPF and 15% for SBR, resulting in a compressive strength increase of 23.46%, splitting tensile strength improvement of 72.5%, and flexural strength increase of 27.7% compared to regular concrete. Research by Srivastava S *et al.* (2018) [26] summarized that graphite materials could be used as effective nano-fillers in polymers even at very small loads, significantly enhancing tensile strength, impact strength, fracture elongation, Young's modulus, storage modulus, etc. Esmaili *et al.* (2021) [27] prepared modified concrete with polymers and different quantities of steel fibers and tested for compressive strength, revealing that by increasing the fiber content from 0.5% to 1%, compressive strength increased by 6.22%. However, an increase from 1% to 2% led to a decrease of 8.34% in compressive strength, due to the high steel fiber content causing uneven distribution. Thus, to harness fibers for mechanical enhancement in polymer-modified cement-based materials, uniform dispersion is key.

Graphene materials, as a type of carbon nanomaterial, have been extensively applied in the field of cement-based materials. There have been some reports on the pore structure, mechanical properties, durability, and damping properties of carbon nanotube-reinforced cement-based materials, graphene nanosheets, and oxidized graphene. Currently, in the research on the damping performance of graphene-enhanced cement-based composite materials, there have been some reports on the damping performance of carbon nanotube-enhanced cement-based composite materials. Cavazos *et al.* (2017) studied the influence of nanoparticles such as MWCNT and HNT on the mechanical properties of cement mortar; after enhancing the nanomaterial dispersion with a sonic processor, compression and bending tests were conducted on 7-day-old samples; the results showed that compared to ordinary cement mortar, the compressive strength of the specimen with 0.1% MWCNT increased by 56%, and the compressive strength of the specimen with 0.1% HNT increased by 31% [28]. Yu *et al.* (2019) [29] studied the damping enhancement effects of Carbon Nanofibers (CNF) and carboxyl-functionalized carbon nanotubes on cement paste through a Dynamic Mechanical Analysis (DMA), finding that both could improve the composite material's loss factor, storage modulus, and loss modulus at a frequency of 0.2 Hz. Additionally, carboxyl-functionalized carbon nanotubes, due to their ability to form strong chemical bonds with the cement matrix interface, had a better damping improvement than carbon nanofibers.

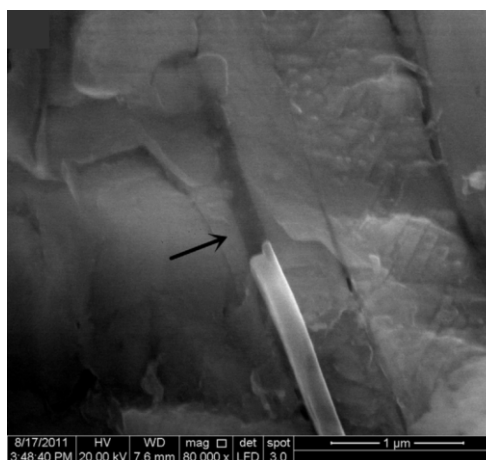


Figure 2. Image of a single CNT debonding in hydration products.

Zhang *et al.* (2020) [30] compared the damping enhancement effects of carbon nanotubes and Polyvinyl Alcohol (PVA) on MDF (macro-defect-free) cement-based composite materials and found that 0.1% carbon nanotubes and 1.0% Polyvinyl Alcohol fibers increased the loss factor by 43.7% and 76.9%, respectively. However, the addition of Polyvinyl Alcohol significantly increased internal defects in the cement matrix. Li *et al.* (2015) [31] studied the damping performance of carbon nanotube-enhanced cement mortar through logarithmic decay method

and DMA, finding that the damping performance of carbon nanotube-enhanced cement-based materials was mainly through friction energy consumption between the carbon nanotubes and the cement matrix interface and between the inner walls of the carbon nanotubes. Xu *et al.* (2015) [32] found that because the strength of carbon nanotubes under tension is much higher than that of the cement matrix, and the unmodified carbon nanotubes are mostly physically bonded with the cement matrix, carbon nanotubes easily detach and slip from the cement matrix under load. Xu *et al.* clearly observed this phenomenon through scanning electron microscopy (Figure 2).

4. Conclusions and Discussion

These types of carbon nano materials reflect the diversity and flexibility of carbon, providing researchers and practitioners with a wide array of possibilities for developing new technologies and products. From fundamental research to commercial applications, the unique attributes of carbon nanomaterials make them key materials in various fields. With continued research and technological advancements, the prospects for the application of carbon nanomaterials will broaden further, contributing to innovation and development across many industrial and technological areas.

4.1. Material Selection and Surface Modification

Select the appropriate form of graphene for the cement matrix, for example, single-layer graphene, oxidized graphene, or reduced graphene oxide. Graphene oxide, with its abundant functional groups, is particularly advantageous for improving interface bonding with the cement matrix. Additionally, surface modification of graphene, such as carboxylation or amination, can enhance its dispersion and bonding strength within the cement matrix. Incorporating other nanomaterials alongside graphene can significantly boost the composite's performance: combining carbon nanotubes (CNTs) with graphene can further strengthen the physical and conductive properties, while the addition of nanosilica can enhance early strength, crack resistance, and improve the interfacial structure of the material.

4.2. Dispersion Technology and Preparation Technology

Ultrasonic dispersion is effective in uniformly dispersing graphene within the cement matrix, preventing agglomeration and ensuring even distribution throughout the composite material. To stabilize the dispersed graphene in the cement slurry, an appropriate chemical dispersant, such as a polycarboxylate superplasticizer, can be employed. The preparation process can be further refined by incorporating high-shear mixing techniques, which ensure thorough integration of graphene with the cement matrix and improve the material's uniformity. Additionally, rolled forming technology can be utilized to achieve a consistent microstructural distribution, enhancing both the mechanical strength and damping properties of the composite material.

4.3. Experimental Test and Performance Evaluation

The composite material's performance is thoroughly evaluated using a range of tests. Tensile and three-point bending tests are employed to assess the impact of graphene on the material's tensile strength and fracture toughness. Compressive testing measures the composite's compressive strength, contributing to its overall mechanical enhancement. Microstructural analysis, including scanning electron microscopy (SEM), Offers understanding of the placement of graphene within the cement matrix and its influence on the microstructure. X-ray diffraction (XRD) is used to examine changes in the crystal structure and to analyze the interaction between graphene and cement hydration products. DMA measures the storage and loss modulus, offering an evaluation of the material's damping performance. Additionally, vibration attenuation tests assess the energy dissipation capability of the composite across different frequencies, determining its damping effectiveness in practical applications.

4.4. Practical Application and Evaluation

Applying the composite cement mortar to actual engineering projects and conducting application tests to obtain the most accurate evaluation. Testing the material's performance in real-world conditions, especially its performance under high humidity, high temperature, or high corrosive conditions, can provide results and recommendations for anti-aging and durability testing. Evaluating the economic feasibility of composite materials in large-scale engineering projects, including material costs, the feasibility of production processes, and the reduction of maintenance costs, can provide results and recommendations for economic feasibility and feasibility analysis.

By studying the application of graphene in cement-based composite materials, it is possible to design new composite materials with higher damping and mechanical properties. This not only helps to enhance the safety and durability of building structures but also contributes to the sustainable development of construction materials.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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