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The Effect of Graphene Oxide on Mechanical Properties of Cement Mortar

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Abstract

Cement is widely used in engineering applications, but it has both the characteristics of high brittleness and poor bending resistance. In this paper, the effects of different amounts of graphene oxide on the flexural strength and compressive strength of cement mortar were studied by doping a certain amount of graphene oxide with cement mortar, and the strengthening mechanism of graphene oxide on cement mortar was obtained through microstructure detection. It is found that graphene oxide has a significant enhancement effect on the macroscopic mechanical properties of cement mortar, and graphene oxide provides nano-nucleation sites and growth templates for cement mortar, accelerates the hydration process, reduces the voids between hydration products, greatly increases the compactness, and improves the macroscopic properties of cement-based materials.

Keywords: *Graphene oxide; Cement mortar; Mechanical properties; Microscopic analysis*

1 Introduction

Cement is an essential material component in the construction of engineering buildings [1]. When cement is mixed with other building materials, it forms a high-strength cement mortar [2]. However, its own characteristics such as high brittleness and poor bending resistance restrict the performance of construction projects [3] Therefore, improving the performance of cement-based materials has become a research hotspot for scholars at home and abroad. The mechanical properties of cement-based materials mainly depend on the ratio of aggregate, water, cement and the amount and shape of hydration products formed [4]. Many scholars use reinforcing materials such as steel bars, glass fibers, and polypropylene fibers to achieve the purpose of improving cement-based materials, but these materials can only inhibit the generation of cracks at the macro and micro scales, and cannot affect the shape and quantity of hydration products, and cannot do anything about nanoscale cracks [6].

Graphene oxide, known as an oxide of graphene, has entered the field of vision of scholars with more activity and can improve the material properties through oxygen-containing functional groups. Lu Shenghua et al [6-7] Graphene oxide was prepared by improved Hummers method and ultrasonic dispersion method, and mixed into cement slurry, and its microscopic morphology was observed by scanning electron microscopy (SEM), and it was found that graphene oxide had a promoting effect and template effect on the formation of cement hydration crystal products, and could promote the formation of neat and regular flower-like nanocrystals in cement hydration products, so as to achieve the effect of enhancing toughening. Zhu Pan et al [8]. The mechanical properties of ordinary Portland cement with graphene oxide were studied, and combined with the images under the scanning electron microscope, it was found that the addition of graphene oxide improved the pore structure of the cement-based materials, and made the cement hydration process form a strong interfacial force, thereby greatly improving the mechanical properties of the cement-based composites.

In 2023, Team Lei Fan [9] used the large-scale Atoms/Molecular Parallel Simulator (LAMMPS) to confirm that carbon nanotubes (CNTs) enhance the interfacial interaction and overall coherence of double graphene oxide (GO) layers and calcium silicate hydrate (CSH) matrix, despite a slight marginal deterioration in tensile strain. Adding one CNT increases the normalized pull-out energy ($E^{nor}_{pull-out}$) and normalized shear stress (τ^{nor}_{shear}) values of the D-GO/CSH model by 24.56% and 25.93%, respectively. Furthermore [10], incorporating hexagonal boron nitride (hBN) nanosheets with defect sizes enhances the interfacial interaction between hBN and the CSH matrix compared to pure hBN-reinforced

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CSH nanostructures. Specifically, introducing defective hBN with an R3 defect size of 17.275 Å boosts failure strain and stress by 35.53% and 31.58%, respectively. In 2024 [11], demonstrated that employing sp3 bonds, different functional group types, and chirality can augment the interfacial interaction between CSH and GO. The $E^{nor}_{pull-out}$ and τ^{nor}_{shear} of the OH-sp3 model increase by 44.93% and 49.25%, respectively, compared to the control group, while those of the zigzag-cen model increase by 12.36% and 9.89%, respectively. Wang. Z M, et al. [12] conducted mechanical property tests on GO-modified cement mortar. The results showed that the highest compressive and indirect tensile strength of cement mortar at 28d were enhanced by 13.1% and 41.3%, respectively, after the incorporation of GO. Lv. S H, et al. [13] Investigated the effect of graphene oxide of different sizes and contents on the shape of cement hydration crystals and the strength of cement paste, and found that the graphene oxide could promote the formation of rod-like crystals and polyhedral structures, which made the cement paste denser. Long. W J, et al. [14] showed that after doping 0.05% and 0.2% of GO, the compressive and flexural strengths of cementitious composites were increased by 12-26% and 2-20%, respectively, at the age of 28d. For this reason, we investigated the effect of graphene oxide on cement mortar, and explored the strengthening mechanism of graphene oxide on cement mortar based on two different scales: macro and micro.

2 Experimental Studies

2.1 Raw materials

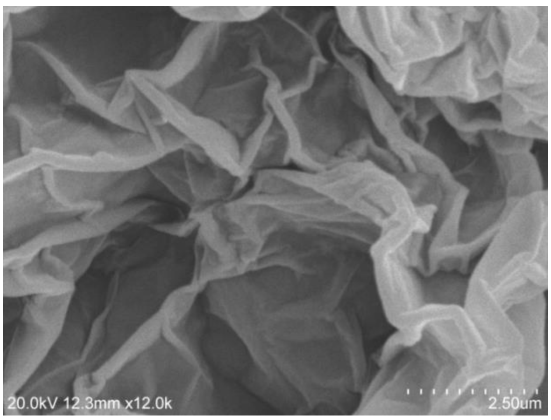

Figure 1 Graphene oxide microstructure diagram

In this experiment, Conch brand P O42.5 grade ordinary Portland cement was used, the main physical indexes are shown in Table 1, the sand used is river sand, the particle size is 0.01-4mm, the fineness modulus is 2.7, the water reducer is FK-A polycarboxylic acid high-performance superplasticizer powder, the water reduction rate is 26%, the graphene oxide is SH-GO-1280 type graphene oxide, which is prepared by the improved Hummers method, the thickness is ～1nm, the oxygen content is ＞54%, and the purity is 99.9% , the peelability rate is 99%, and the graphene oxide microstructure is shown in Figure 1.

2.2 Preparation process

2.2.1 Dispersion preparation

Preparation of graphene oxide standard dispersion: first take the whole mass of polycarboxylate superplasticizer (cement mass fraction is 0.6%) and put it in a 500ml beaker, add deionized water (0.35 times the mass of cement), and stir thoroughly until no agglomeration appears. Graphene oxide with cement mass fractions of 0.02%, 0.05% and 0.08% was weighed and added to the evenly mixed superplasticizer solution, and the magnetic heating mixer was used to stir evenly for 10 min. Then, it was dispersed in an ultrasonic cleaner (JP-040S) for 20 min to obtain a graphene oxide standard dispersion.

2.2.2 Specimen preparation

The standard dispersions of graphene oxide with different dosages were controlled separately, and the fixed water-cement ratio was 0.35, and the cement mortar specimens without graphene oxide were used as the control group, and a total of 4 groups were set up.

Accurately weigh the corresponding quality of cement and river sand, now mix the cement with graphene oxide standard dispersion and stir slowly with a cement mortar mixer for 30 s, then pour river sand, slow stirring for 1 min, high-speed stirring for 2 min, in accordance with GB\T17671-1999 "Cement Mortar Strength Test Method (ISO Method)" on the cement mortar vibrating table, the frequency is 60 times/min, the vibrating is 2 min, and the compaction is formed. Demold within 20～24 h and put it into a standard curing box for curing.

2.2.3 Test methods

According to GB\T17671-1999 "Cement Mortar Strength Test Method (ISO Method)", the compressive strength and flexural strength of each group of specimens are tested in 3D. The cross-section of the specimen that has undergone 3D flexural strength and compressive strength tests was observed and tested with SU1510 scanning electron microscope.

3 Test Results and Analysis

3.1 Experimental macroscopic observation

In the process of preparing cement mortar, under the premise of a certain ratio, with the continuous increase of graphene oxide content, the experimental group showed poor fluidity, increased viscosity, and darkened color of cement mixture. Mainly because the specific surface area of graphene oxide is much larger than that of cement, the water consumption of cement mortar increases significantly with the increase of graphene oxide content in the case of consistent water-cement ratio.

3.2 Macroscopic mechanical properties

The compressive strength and flexural strength of graphene oxide in 3D were recorded in different amounts. After the addition of graphene oxide, the 3D compressive strength and flexural strength of cement mortar were increased by 8.87% and 8.11%, respectively, and the compressive strength and flexural strength increased by 16.8% and 12.36%, respectively. It can be found that when the content of graphene oxide in cement mortar is within a certain range, increasing the content of graphene oxide can significantly improve the macroscopic mechanical properties of cement mortar. This is because graphene oxide can promote the formation of more hydration products of different shapes in cement, fill the cracks at the nanoscale, inhibit development, and act as a link in the cement hydration products.

3.3 Microscopic analysis

In this experiment, SEM microscopy was carried out on the cross-sections of cement mortar with different graphene oxide dosage in the control group with an age of 3 days, and the results are shown in Figure 2.

Figure 2a and 2b are the microstructure scans of the cement mortar control group, and it can be observed that the connections between the hydration products of the cement mortar control group are relatively scattered, and the hydration products are mostly flower cluster crystals and the distribution and stacking are relatively random, resulting in a large number of voids between the crystals inside the cement matrix. Figure 2c and 2d are microscopic scans of cement mortar doped with a small amount of graphene oxide, and it can be observed that the volume of the granular crystal hydration products of cement increases significantly after a small amount of graphene oxide is added, and these crystals are stacked on top of each other and distributed more evenly. This is because graphene oxide acts as a nano-nucleation site, which accelerates the hydration process. Figure 2e and 2f are microscopic scans of cement mortar with increased graphene oxide dosage, and the directional rod-like structure of C-S-H and C-H phases is formed in the cement. These rod-like structures act as a link and act as a bridge in the hydration products, with significantly reduced voids compared to the control group. Figure 2g and 2h are the microscopic scans of cement mortar after the further increase of graphene oxide incorporation, and it can be found that the hydration products appear in the regular C-H phase block and polyhedral state, and the needle rod crystals are significantly reduced. This is due to the fact that graphene oxide provides a growth template for cement mortar and makes the hydration products intertwine and penetrate into a dense and uniform microstructure during the aggregation process, which significantly improves the strength of cement mortar.

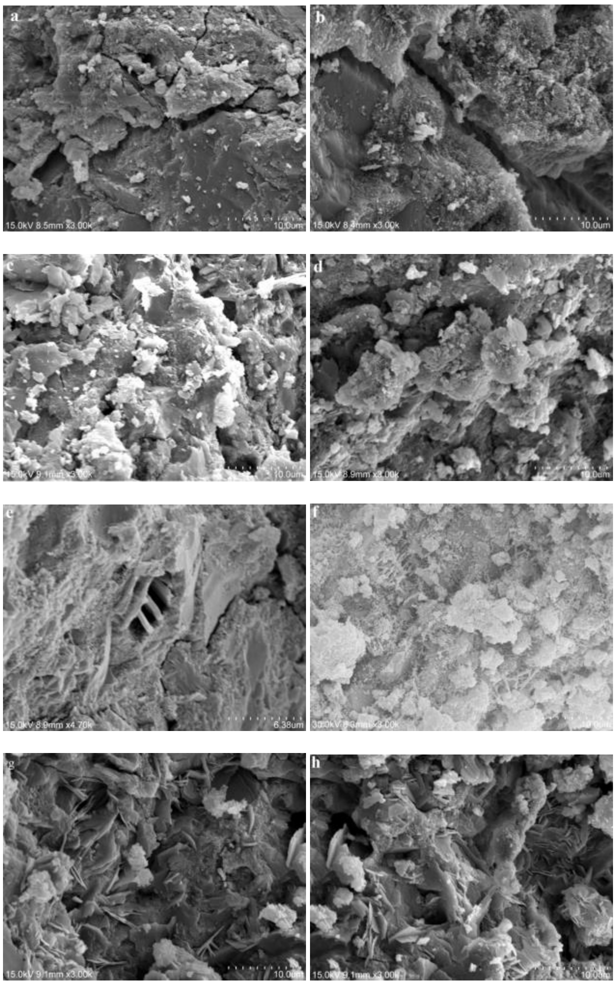

Figure 2 (a) (b) cement mortar control group, (c) (d) cement mortar test group mixed with some GO, (e) (f) cement mortar test group with increased GO content, (g) (h) cement mortar test group with further GO content

4 Conclusion

The incorporation of graphene oxide leads to an increase in water consumption per unit of cement. If the water consumption is not increased or the use of superplasticizer is increased, the fluidity of the cement mortar will become poor, the viscosity will become larger, and the strength will be reduced.

In a certain dosage range, the macroscopic properties of cement mortar can be significantly improved by increasing the amount of graphene oxide, and the compressive strength and flexural strength can be increased by up to 16.8% and 12.36%.

The mechanism of action of graphene oxide reinforced cement mortar is to produce different shapes and more quantities of hydration products to increase the compactness of cement mortar and reduce porosity.

The microstructure and crystalline composition of hydration products greatly influence the macroscopic mechanical properties of cement-based materials.

Graphene oxide can promote the hydration process of cement mortar, and has a promoting effect on the properties and quantity of hydration products.

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