

# Preparation and properties of graphene oxide modified concrete

*Hai Cao\**, *Tingting Wang*, *Jing Xu*

Huangshan University, School of Civil Engineering and Architecture,  
HuangShan 245041, China

\* [hscaohai@163.com](mailto:hscaohai@163.com)

*Received August 12, 2025, approved February 14, 2026*

Graphene oxide is often used in cement-based materials due to its high strength, toughness and strong surface activity, which can not only improve mechanical properties but also enhance durability. Modified concrete with different graphene oxide dosings (0,0.04%, 0.08% and 0.12% (mass fraction)) was prepared by doping graphene oxide into concrete. The effects of graphene oxide dosage on the microstructure, crystal structure, mechanical properties, slump and porosity of the modified concrete were studied. The results show that an appropriate amount of graphene oxide doping accelerates the hydration reaction of the modified concrete, refines the pore structure and improves the density. With the increase of the doping amount of graphene oxide, the compressive strength and flexural strength of the modified concrete first increase and then decrease, while the slump and porosity first decrease and then increase. When the doping amount of graphene oxide is 0.08% (mass fraction), the compressive strength and flexural strength both reach the maximum values of 46.3MPa and 7.5 MPa respectively at 28 days. The slump and porosity reached the minimum values of 27.6 mm and 25.1% respectively. It should be noted that with a graphene oxide content of 0.08% (by mass fraction), the comprehensive performance of the modified concrete is the best.

**Keywords:** Graphene oxide Concrete; Crystal structure Mechanical properties; Slump and porosity

**Приготування та властивості бетону, модифікованого оксидом графену.** *Hai Cao, Tingting Wang, Jing Xu*

Оксиграфен часто використовується у цементних матеріалах завдяки своїм перевагам, таким як висока міцність, пластичність та сильна поверхнева активність. Це не лише покращує механічні властивості, але й збільшує довговічність. У дослідженні було приготовано модифікований бетон із різними вмістами оксиграфена (0, 0,04%, 0,08% та 0,12% масової частки) шляхом додавання оксиграфена до бетону. Досліджено вплив кількості оксиграфена на мікроструктуру, кристалічну структуру, механічні властивості, осаджуваність та пористість модифікованого бетону. Результати показали, що помірне додавання оксиграфена прискорює гідратаційну реакцію модифікованого бетону, поліпшує структуру пор та підвищує щільність. Зі збільшенням вмісту оксиграфена міцність на стиск та згин модифікованого бетону спочатку зростає, а потім знижується; осаджуваність та пористість спочатку зменшуються, а потім зростають. При вмісті оксиграфена 0,08% масової частки міцність на стиск та згин досягають максимальних значень — 46,3 МПа та 7,5 МПа відповідно, осаджуваність та пористість — мінімальних значень — 27,6 мм та 25,1%. Таким чином, можна зробити висновок, що при вмісті оксиграфена 0,08% масової частки модифікований бетон має найкращі загальні властивості.

## 1. Introduction

Concrete is one of the most widely used civil engineering materials today, which is

involved in construction, tunnels and bridges, ports and coastal structures, as well as dams, etc. It plays an important role in the construction of buildings and infrastructure. However,

ordinary concrete is a brittle material. Due to its low flexural strength, poor crack resistance and poor strain capacity, cracks will appear inside and on its surface under load [1-4]. The current main drawbacks of concrete materials are heavy self-weight, low tensile strength, low early strength, and insufficient carbonation resistance, etc. [5]. Therefore, the preparation of concrete with high strength and toughness has become a research hotspot in concrete materials in recent years [6-7]. Graphene oxide, as a derivative material of graphene, has a large number of functional groups on its surface, such as carboxyl groups, hydroxyl groups, epoxy groups, etc. This makes graphene oxide have strong surface activity and wettability, and also easily combines and reacts with organic substances [8-10]. In addition, graphene oxide has excellent mechanical properties and electrical conductivity, so it has also become an excellent reinforcing filler [11-14]. Graphene oxide has high water demand which leads to overuse of superplasticizer in concrete and also it is expensive material. In recent years, research on the modification of concrete using graphene oxide has been increasing [15-20]. Lin et al. [21] believe that the oxygen-containing functional groups of graphene oxide can provide adsorption sites for cement and water, and have catalytic properties, thereby promoting the hydration reaction of cement. Yang Zhenghong et al. [22] and Zhang Jianwu et al. [23] stated that graphene oxide can promote the early hydration of cement, enhance the compactness of the microstructure, and thereby significantly improve the performance of cement-based materials. Lu Shenghua et al. [24] established that graphene oxide does not participate in the cement hydration reaction and mainly plays a template role in cement-based materials, regulating the formation of regular microstructures of cement hydration products. Therefore, it is particularly necessary to study graphene oxide cement-based composites.

In this paper, graphene oxide was selected as the reinforcing material to prepare a series of graphene oxide concretions with different graphene doping contents on the basis of ordinary Portland cement P.O42.5. By analyzing their lattice structure, microstructure, infrared spec-

tra, and various physical and mechanical properties, the graphene oxide concrete with the optimal graphene doping content was explored. It provides a research basis for the preparation of high-performance and long-life concrete.

## 2. Experimental

### 2.1 Experimental raw materials

Ordinary Portland cement P.O42 5 with a grinding fineness of 12% and loss on ignition  $\leq 4\%$  manufactured by Conch Cement Co., LTD was used. The chemical composition of the cement is shown in Table 1. Graphene oxide used had a purity  $> 99.5\%$ , a thickness 1.3-1.5nm, a layer diameter 15-40 $\mu\text{m}$  and a specific surface area 240-300 $\text{m}^2/\text{g}$ . Coarse aggregate used was crushed stones of 10 to 20 mm in size. Mechanical sand had a  $\text{SiO}_2$  content of  $\geq 99.3\%$ , a specific gravity of 2.65 and a porosity of 43%. Grade II fly ash had a specific surface area of 425  $\text{m}^2/\text{kg}$ . Polycarboxylate superplasticizer was a light yellow powder with a content of  $\geq 93\%$ , a pH value of 7-9 and a water absorption rate of 23.5%.

### 2.2 Sample Preparation

Weighed mass fractions of cement respectively as 0, 0.04%, 0.08% and 0.12% graphene oxide powder were placed in water and uniformly stirred for 15 minutes. Then polycarboxylate superplasticizer was added to the above graphene solution and stirred evenly for 30 minutes. The aggregates and cement were mixed according to the ratio in Table 2 and stirred. After stirring was complete, the concrete mixture was poured into the mold and vibrated to give it integrity. After 24 hours, the mold was removed and the mixture was taken out. It was placed in an environment with a temperature of  $20 \pm 3$  °C and a humidity of over 95% for maintenance. The water-binder ratio was 0.35.

### 2.3 Performance Testing

*Scanning Electron Microscope (SEM)*. The microscopic morphology of the samples was analyzed by using the Hitachi S SU8600 cold field scanning electron microscope from Hitachi, Japan. Infrared Spectroscopy Test (FT-IR)

*X-ray diffraction test (XRD)*. The SmartLab 9kW X-ray powder diffractometer produced by

Table 1. Chemical Composition of Ordinary Portland Cement

Chemical composition	$\text{SiO}_2$	$\text{SiO}_3$	$\text{Fe}_2\text{O}_3$	$\text{Al}_2\text{O}_3$	CaO	MgO	$\text{K}_2\text{O}$	$\text{Na}_2\text{O}$
Content / %	23.5	2.52	2.67	5.35	62.3	2.14	0.93	0.59

Table 2 Mix Proportions of graphene oxide concrete / kg · m<sup>-3</sup>

No.	Cement	Fly ash	Silica fume	White sand	Crushed stone	Graphene oxide/%	Water	Water-reducing agent
1	319	68	26	690	1192	0	162	6.2
2	319	68	26	690	1192	0.04	162	6.2
3	319	68	26	690	1192	0.08	162	6.2
4	319	68	26	690	1192	0.12	162	6.2

Rigaku Corporation of Japan was used. The maximum output power of the X-ray generator was 9 kW. The tube voltage is 20 to 45 kV. The tube current is 10 to 200 mA. The 2 $\theta$  angle range of was from 5° to 160°. The minimum readable step size was 0.0001°. The angle reproducibility was 0.0001°. The instrument was equipped with zero-dimensional and one-dimensional detectors, with a maximum linear count of  $\geq 2.5 \times 10^8$  cps and a background of  $< 0.1$  cps. The dual optical path system was used.

**Mechanical property tests.** The concrete composite materials with different dosages of graphene oxide were cured for 28 days in accordance with GB50204-2015 “Code for Acceptance of Construction Quality of Concrete Structures”. The sample size was 100mm  $\times$  100mm  $\times$  100mm. The mechanical property tests were conducted in accordance with GB/T50107-2010 “Standard for Inspection and Evaluation of Concrete Strength”;

**Porosity tests.** The porosity of the concrete composite materials with different graphene oxide contents mentioned above was tested according to Archimedes’ principle.

**Slump tests.** The slump tests were conducted in a standard trapezoidal cylinder with a height of 300 mm and upper and lower diameters of 100 mm and 200 mm respectively. The slump was determined by measuring the distance between the most protruding point of the concrete slurry after its spreading and the highest point of the cylinder.

### 3 Results and discussion

#### 3.1 Microscopic morphology test of graphene oxide modified concrete

The secondary electron resolution of the field emission scanning electron microscope: 0.7 nm @ 1 kV (WD = 1.5 mm).

Figure 1 shows the SEM images of modified concrete with different doping amounts of graphene oxide. As can be seen from Figure 1 (a),

the concrete material without graphene oxide doping has a loose structure and a large number of pores of clearly different sizes. It can be seen from Fig. 1 (b) - (d), that after adding graphene oxide, the pores of the concrete decrease and the structure becomes more compact. This is because the surface of graphene oxide is rich in hydroxyl groups and functional groups. After being introduced into concrete, it can create points for hydration reaction, accelerate its progress, refine the pore structure, ensure a more thorough combination between the mortar and aggregates of the concrete, and thereby improve the density. It can be seen from Figure 1 (c) that when the doping amount of graphene oxide is 0.08% (mass fraction), the pore number of the modified concrete is significantly reduced, the structure is the densest, and the morphology is the best. As can be seen from Figure 1 (d), when the doping amount of graphene oxide is 0.12% (mass fraction), the hydration gel in the modified concrete forms flocculent aggregates with large pores in the hydration products and a clear agglomeration phenomenon. It can be seen that an appropriate amount of graphene oxide doping can accelerate the hydration reaction and increase the density. However, excessive doping of graphene oxide will reduce the progress of the hydration reaction, resulting in larger crystals being difficult to grow uniformly after aggregation. Moreover, excessive graphene oxide will cause agglomeration, leading to insufficient hydration reaction of cement.

#### 3.2 XRD testing of graphene oxide modified concrete

The diffraction peaks of the concrete sample without graphene oxide doping are mainly composed of calcium hydroxide (CH), dicalcium silicate (C<sub>2</sub>S), and tricalcium silicate (C<sub>3</sub>S), among which the diffraction peak of CH appears at 16.8°, 36.2°, 49.5°, and 52.4°. The diffraction peak of C<sub>2</sub>S appears at 34.8°, and that of C<sub>3</sub>S appears at 34.3°. After the addition of graphene

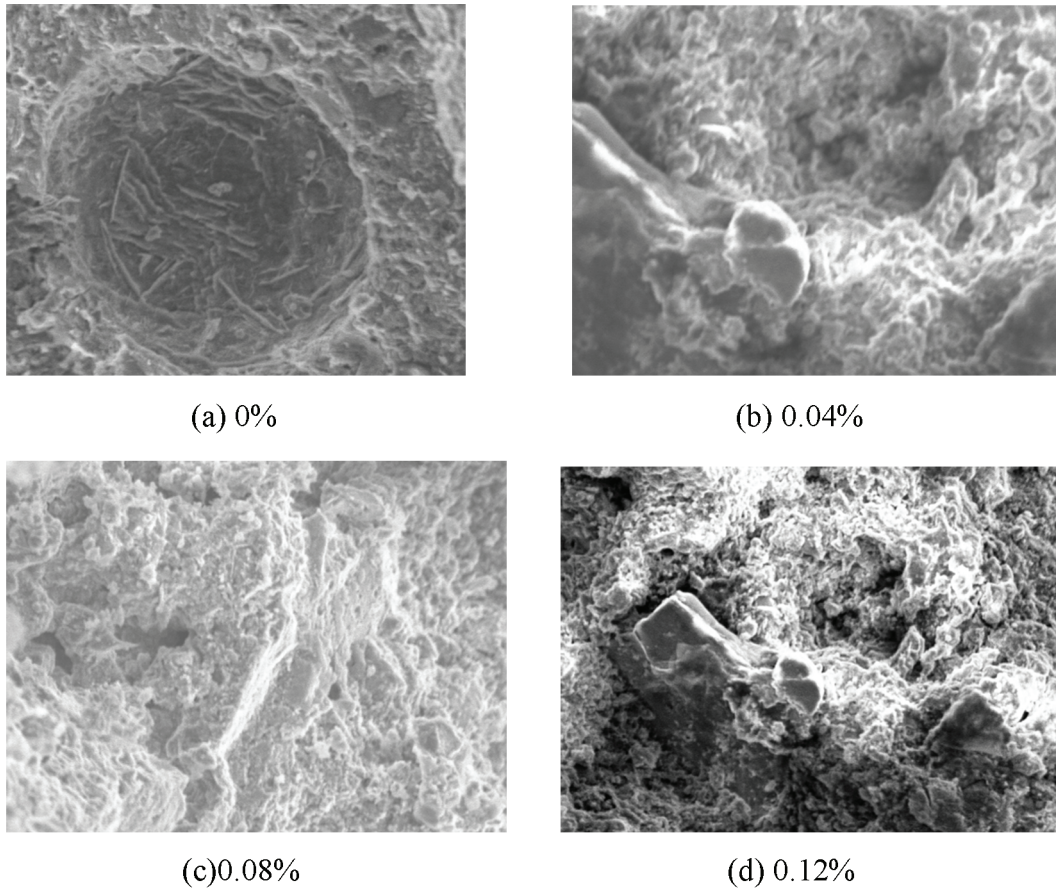


Fig. 1. SEM images of graphene oxide modified concrete

oxide, with an increase in the doping amount, the diffraction peak intensity of CH in the modified concrete gradually increases, while the diffraction peak intensities of  $C_2S$  and  $C_3S$  gradually decrease. This indicates that the doping of graphene oxide accelerates the consumption of cement raw materials and the formation of hydration crystals, and no new diffraction peaks appear. It has no effect on the crystalline composition of the cement hydration products.

### 3.3 Mechanical property testing of concrete composites with different dosages of graphene oxide

Figures 2 and Figure 3 respectively show the compressive strength and flexural strength of concrete composites with different amounts of graphene oxide at 7 days and 28 days. From Figures 2 and Figure 3, it can be seen that as the content of graphene oxide increases, the compressive strength and flexural strength of the concrete composites show a trend of increasing first and then decreasing. When the doping amount of graphene oxide is 0.08%, the compressive strength at 7 days and 28 days reaches

the maximum values of 37.1 MPa and 46.3 MPa respectively, which are 10.42% and 8.94% higher than those of the concrete without graphene oxide doping. The flexural strength at 7 days and 28 days also reaches the maximum values of 5.5 MPa and 7.5 MPa respectively, which are 27.91% and 29.31% higher than those of the concrete without graphene oxide doping. When the content of graphene oxide is 0.08%, both the compressive strength and flexural strength reach their maximum values, which are 46.3 and 7.5 MPa respectively. Compared with the concrete without graphene oxide doping, the compressive strength and flexural strength increase by 8.94% and 29.31% respectively. When the content of graphene oxide continued to increase, both the compressive strength and the flexural strength decreased. Thus, the addition of an appropriate amount of graphene oxide can effectively improve the morphology of concrete composites and increase their density. It can also enhance the strength of concrete by filling its pores and promoting hydration reactions. However, the presence of excessive graphene

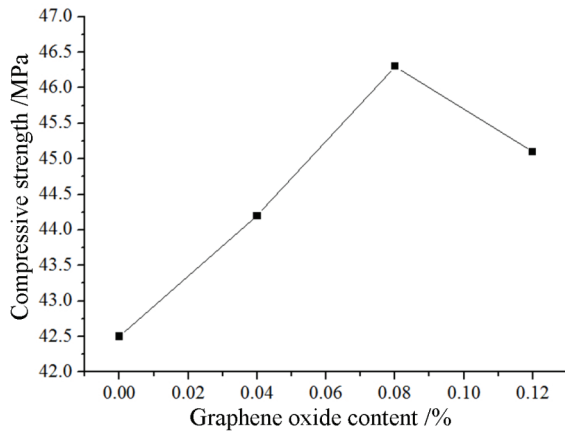


Fig.2. Relationship between the compressive strength and graphene oxide content

oxide not only leads to disordered lap joints and agglomeration, reducing the uniformity of graphene oxide distribution, but also generates a large number of gaps. This will affect the compressive strength and flexural strength of graphene oxide concrete composites and reduce the toughening effect.

#### 3.4. Slump and porosity tests of concrete composite materials

Table 3 shows the test results of slump and porosity measurements of concrete composites with different dosages of graphene oxide. As can be seen from Table 3, with the increase of graphene oxide content, both the slump and porosity of the concrete composite material first decrease and then increase. When the content of graphene oxide is 0.08%, the slump and porosity reach their minimum values of 27.6 mm and 25.1% respectively. When the content of graphene oxide increased to 0.12%, both the slump and porosity of the concrete composite material increased to varying degrees. This indicates that an appropriate amount of graphene oxide doping can effectively fill the gaps in concrete, thereby reducing the porosity of concrete. However, excessive graphene oxide will cause stacking in the base material, not only affecting the uniform distribution of graphene oxide but also generating more gaps due to disordered lap joints. Additionally, excessive graphene oxide can affect the hydration efficiency and hinder crystal growth, thereby reducing the mechanical properties of concrete composites.

### Conclusions

A series of modified concretes with different doping amounts of graphene oxide were prepared by modifying with graphene oxide. The

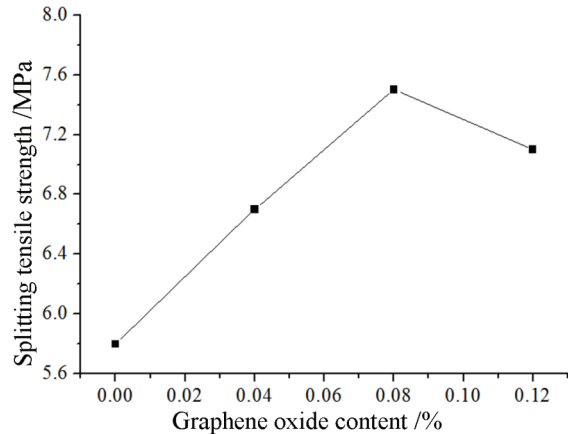


Fig.3. Relationship between the splitting tensile strength and graphene oxide content

effects of graphene oxide doping amount on the microstructure, crystal structure, mechanical properties, slump and porosity were studied, and the following conclusions were drawn:

(1) An appropriate amount of graphene oxide doping can accelerate the hydration reaction, refine the pore structure and increase the density, while excessive graphene oxide doping will cause agglomeration, resulting in insufficient hydration reaction of cement.

(2) After adding an appropriate amount of graphene oxide, the hydration reaction of the modified concrete was promoted, and the size of the hydration products gradually decreased. Moreover, the introduction of graphene oxide had no effect on the crystalline composition of the cement hydration products.

(3) With the increase of graphene oxide content, both the compressive strength and flexural strength of the composite material first increase and then decrease, while the slump and porosity first decrease and then increase. When the content of graphene oxide is 0.08%, the compressive strength and flexural strength of the composite material both reach their maximum values, which are 46.3 MPa and 7.5

Table 3. Slump and porosity of concrete composites with different dosages of graphene oxide

Graphene oxide content /%	Slump /mm	Porosity /%
0	35.2	29.7
0.04	32.7	27.5
0.08	27.6	25.1
0.12	28.5	26.5

MPa respectively. The slump and porosity both reached the minimum values of 27.6 mm and 25.1% respectively. A comprehensive analysis shows that the optimal doping ratio of graphene oxide is 0.08%.

### Acknowledgements

Funded by the Anhui Philosophy and Social Sciences Planning Project(AhSKq2022D179), Horizontal Project of Huangshan University (hxkt2024035) Key Laboratory Project of Safety and High-efficiency Coal Mining Ministry of Education(Anhui University of Science and Technology)(JYBSYS2021210), the Open Project Program Foundation of Engineering Research Center of underground mine construction, Ministry of Education(Anhui University of Science and Technology)(JYBGCZX2021103),Anhui Province Housing urban and rural construction science and technology project(2021-YF64), Anhui University Student Innovation Training Program (S202410375066) the Humanities and Social Sciences Research Project of Anhui Universities (2024AH053273, 2023AH051350), Scientific Research of Huangshan University (2021xhwh005), Anhui Provincial Traditional Professional Transformation and Upgrading Project (2023zygzts062), Huangshan University Key Educational Teaching Reform Research Project (2023JXYJ07).

### References

1. Lu Z Y, Hou D S, Ma H Y, et al. Construction and Building Materials, 119,2016
2. Silvestre J, Silvestre N, Britoj D.European Journal of Environmental and Civil Engineering, 20,2015
3. Chuah S, Pan Z, Sanjayan J G , et al. Construction and Building Materials,73,2014
4. Imbabi M S, Carrigan C, Mckenna S, et al. International Journal of Sustainable Built Environment , 1, 2012
5. Ding D H, Zhang Q. Concrete, 10,2009
6. Du Y, Yan A Y, Qi H H. Journal of Building Materials,1,24, 2021
7. Gao G Y, Zhang C, Ma F H. Concrete, 6, 2020
8. Liu X, Zhou Z. Chemistry,7,84, 2021
9. Li D B, Liu Q L, Zhang H C, et al. Chinese Journal of Mechanics, 5,51,2019
10. Li P F. Wuhan: Wuhan University of Engineering, 2015
11. Lyu S H, Ma Y J, Qiu C C, et al. Concrete, 8,9,2013
12. Wang Y X, Chai J R, Cao J, et al.Chinese Journal of Applied Mechanics, 2,37,2020
13. Huang W R, Yang Y Z, Song P, et al. New Chemical Materials, 8,49,2021
14. Zhang L, Ma J Z, Zhang Y H ,et al. Fine Chemicals, 11,37,2020
15. Gui C, Xu Z F, Jiang Y J, et al. Journal of Composite Materials,5,38, 2021
16. Liu J B, Wang Y. Journal of Xi 'an University of Architecture and Technology (Natural Science Edition),5,52, 2020
17. Gong Z W, Wang Y. New Building Materials, 2,48,2021
18. Chuah S, Pan Z, Sanjayan J G, et al. Construction & Building Materials ,30,73,2014
19. Wang Q, Li S Y, Pan S, et al. New Carbon Materials, 2,33,2018
20. Qiu W J, Luo Q Z, Wu Y Y, et al. Journal of Foshan University (Natural Science Edition),2,38,2020
21. Lin C, Wei W,Hu Y H. Journal of Physics and Chemistry of Solids,89, 2016
22. Yang Z H, Xu Y F, Zhu H B, et al. Journal of Building Materials,4,24,2021
23. Zhang J W, Wang X, Li Z X, et al. New Chemical Materials, 6,49,2021
24. Lu S H, Sun T, Liu J J, et al. Acta Materiae Compositae Sinica, 3,31,2014