

# Experimental Study on Mechanical Properties of Graphene Oxide Concrete

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## Abstract

To study the influence of different water-cement ratios and graphene oxide doping amounts on the mechanical properties of concrete. In this test, graphene oxide concrete with 4 water-cement ratios (0.35, 0.38, 0.41, 0.44) and six graphene oxide dopings (0, 0.02%, 0.04%, 0.06%, 0.08%, 0.1% (cement mass)) were prepared for mechanical properties. The results show that graphene oxide has a significant enhancement effect on the mechanical properties of concrete. As the water-cement ratio increases, the compressive strength and splitting strength of concrete show parabolic changes that first rise and then fall. Under the condition of water-cement ratio of 0.38, the concrete performance when graphene oxide dosages of 0, 0.02%, 0.04%, 0.06%, 0.08% and 0.1% were tested, and the compressive strength was increased by 10.11%, 15.81%, 22.78%, 30.04% and 24.48%, respectively, and the split tensile strength was increased by 3.87%, 6.25%, 18.75%, 27.97% and 22.02%, respectively. When the graphene oxide doping amount is 0.08%, the mechanical properties of the test piece are optimal.

## Keywords

Concrete; water-cement ratio; graphene oxide; mechanical properties.

## 1. Introduction

Concrete materials are widely used in the construction industry due to their advantages of high strength, low price, and easy to obtain materials. However, they have some shortcomings such as high brittleness, poor bending ability, poor crack resistance and poor strain ability, which are prone to cracks under the action[1, 2, 3, 4]. At present, the main technical way to improve the performance of concrete is through the incorporation of functional admixtures. This modification method can effectively improve the compressive strength and split strength of concrete. At the same time, by optimizing the microstructure of cement matrix composite materials, the invasion and expansion of microcracks are inhibited, thereby significantly enhancing the overall mechanical properties of concrete.

Graphene Oxide (GO), as an important graphene derivative, is a two-dimensional nanomaterial prepared by introducing oxygen-containing functional groups such as hydroxyl, carboxyl and epoxy to the base surface and edges of graphene[5]. GO can improve the microstructure of cement-based composite materials, promote the hydration reaction, make the distribution of the generated hydration products more regular, and improve the mechanical properties of concrete[6, 7, 8]. The current research focus is mainly on cement slurry systems. However, from the perspective of engineering practice, concrete materials have a wider range of applications in actual engineering and have more important engineering value.

As a key parameter in concrete mix design, the water-cement ratio has a significant impact on the mechanical properties of concrete. When the water-cement ratio is too large, the cement particles in the concrete are smaller, the spacing between the particles is large, the bonding

area between the colloid and aggregate is reduced, the bonding force is reduced, and the pores in the middle of the colloid filled particles produced by hydration cannot be met. The moisture evaporates too much, leaving more water pores, reducing the strength of the concrete. When the water-cement ratio is small, the spacing between particles is also relatively small. The pores between the particles are filled with colloids generated by cement hydration, and the concrete has high strength. However, the water-cement ratio should not be too low, otherwise the moisture will be too low, which will cause difficulties in the hydration process. Some cement cannot be fully hydrated, which is not conducive to the increase in strength, and the test blocks cannot even be formed [9, 10].

To sum up, through systematic experimental research, this paper reveals the evolution law of concrete compressive strength and split tensile strength under the dual-factor coupling of water-cement ratio and graphene oxide doping. In this experiment, four water-cement ratios (0.35, 0.38, 0.41, 0.44) and six graphene oxide doping amounts (0%, 0.02%, 0.04%, 0.06%, 0.08%, 0.1%) were designed, and 144 concrete cube test blocks were made.

## 2. Experimental Design

### 2.1. Experimental raw materials and mix proportions

Raw materials: (1) Cement: Made of P · O 42.5 grade ordinary Portland cement produced by Zhucheng Yangchun Cement Co., Ltd; (2) Coarse aggregate: 5-31.5mm continuous graded crushed stone, with a bulk density of  $715\text{kg/m}^3$  and an apparent density of  $2686\text{kg/m}^3$ ; (3) Fine aggregate: ordinary river sand (medium sand), fineness modulus 2.81, bulk density  $1483\text{kg/m}^3$ , apparent density  $2768\text{kg/m}^3$ , moisture content 4.6%; (4) Additive: HLC (Standard Comprehensive) high-performance polycarboxylate water reducer (solid content 40%) produced by Shanxi Feike New Material Technology Co., Ltd; (5) Graphene oxide: High purity industrial grade single-layer graphene oxide provided by Suzhou Carbon Feng Graphene Technology Co., Ltd., with a thickness of 0.8-1.2nm and a sheet size of 10-50  $\mu\text{m}$ .

According to the "Code for Design of Ordinary Concrete Mix Proportion" (JGJ 55-2011), mix proportion design is carried out with 4 water cement ratio levels (0.35, 0.38, 0.41, 0.44) and 6 graphene oxide content gradients (0%, 0.02%, 0.04%, 0.06%, 0.08%, 0.10%). The specific mix proportion parameters are shown in Table 1.1.

### 2.2. Experimental Plan

The specimen is formed using a  $100\text{mm} \times 100\text{mm} \times 100\text{mm}$  cube test mold. After forming, the specimen is left to stand in a standard curing box (temperature  $22 \pm 1\text{ }^\circ\text{C}$ , relative humidity  $\geq 95\%$ ) for 48 hours before being demolded. It is then transferred to a standard curing room (temperature  $20 \pm 2\text{ }^\circ\text{C}$ , relative humidity  $\geq 95\%$ ) for continuous curing until 28 days of age. The mechanical performance testing is strictly carried out in accordance with GB/T 50081-2002 "Standard Test Methods for Mechanical Properties of Ordinary Concrete". The YAW-2000 microcomputer controlled electro-hydraulic servo pressure testing machine is used for loading, among which: compressive strength test: the loading rate is controlled at  $0.5\text{MPa/s}$ ; Splitting tensile strength test: The loading rate is controlled at  $0.05\text{MPa/s}$ . The schematic diagram of the experimental loading device is shown in Figure 1.

**Table 1.** Concrete Mix Proportion (Kg/m<sup>3</sup>)

Water-cement ratio	Cement	Sand	Stone	Water	Water reducing agent	Graphene oxide
0.35	542	500	1168	190	2.71	0
	542	500	1168	190	2.71	0.11
	542	500	1168	190	2.71	0.22
	542	500	1168	190	2.71	0.33
	542	500	1168	190	2.71	0.43
	542	500	1168	190	2.71	0.54
0.38	500	513	1197	190	2.50	0
	500	513	1197	190	2.50	0.10
	500	513	1197	190	2.50	0.20
	500	513	1197	190	2.50	0.30
	500	513	1197	190	2.50	0.40
	500	513	1197	190	2.50	0.50
0.41	463	524	1223	190	2.32	0
	463	524	1223	190	2.32	0.09
	463	524	1223	190	2.32	0.19
	463	524	1223	190	2.32	0.28
	463	524	1223	190	2.32	0.37
	463	524	1223	190	2.32	0.46
0.44	431	534	1245	190	2.16	0
	431	534	1245	190	2.16	0.09
	431	534	1245	190	2.16	0.17
	431	534	1245	190	2.16	0.26
	431	534	1245	190	2.16	0.34
	431	534	1245	190	2.16	0.43



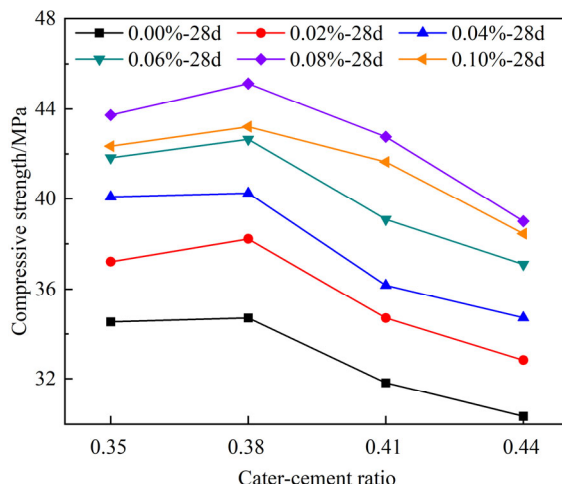
**Figure 1.** Testing Device

### 3. Results and Discussion

#### 3.1. Compressive strength

##### 3.1.1. Effect of water cement ratio on compressive strength of graphene oxide concrete

Based on the experimental results, draw the variation curve of compressive strength of concrete with different water cement ratios and the amount of graphene oxide as shown in Figure 2.

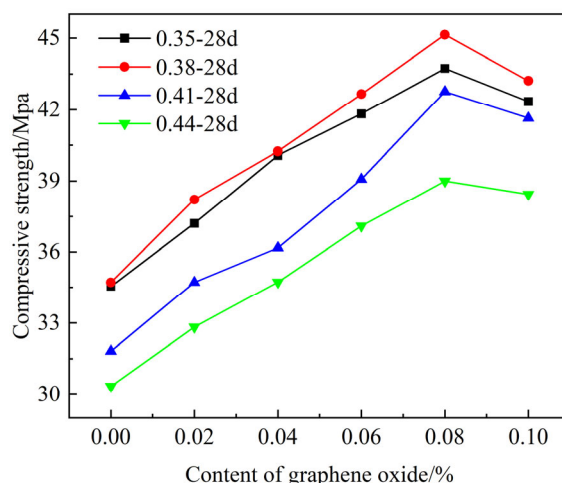


**Figure 2.** Influence of water cement ratio on compressive strength of GO concrete

From Figure 2, it can be seen that in each case, the compressive strength of concrete cubes with a water cement ratio of 0.38 is the highest, and the water cement ratio of 0.44 is the lowest. Taking the compressive strength of concrete with a 28 day curing period as an example, at a dosage of 0, the compressive strength of concrete with a dosage of 0.38 increased by 0.57%, 9.1%, and 14.5% compared to water cement ratios of 0.35, 0.41, and 0.44, respectively. At a dosage of 0.02%, compared to the water cement ratios of 0.35, 0.41, and 0.44, the compressive strength of concrete with a dosage of 0.38 increased by 3.2%, 10.08%, and 16.46%, respectively. At a dosage of 0.04%, compared to the water cement ratios of 0.35, 0.41, and 0.44, the water cement ratio of 0.38 is close to that of 0.35. Compared to the water cement ratios of 0.41 and 0.44, the compressive strength of concrete increased by 11.36% and 15.85%, respectively. At a dosage of 0.06%, the compressive strength of 0.38 concrete increased by 1.91%, 9.23%, and 15.14% compared to water cement ratios of 0.35, 0.41, and 0.44. At a dosage of 0.08%, the compressive strength of 0.38 concrete increased by 0.89%, 5.62%, and 15.64% compared to water cement ratios of 0.35, 0.41, and 0.44. At a dosage of 0.1%, the compressive strength of 0.38 concrete increased by 2.13%, 3.85%, and 13.01% compared to the water cement ratios of 0.35, 0.41, and 0.44.

**3.1.2. Effect of graphene oxide content on compressive strength of concrete**

As shown in Figure 3, with the addition of graphene oxide, the compressive strength of the four types of water cement ratio concrete exhibits a parabolic trend, reaching its maximum value at a dosage of 0.08% and showing a decreasing trend at a dosage of 0.10%.



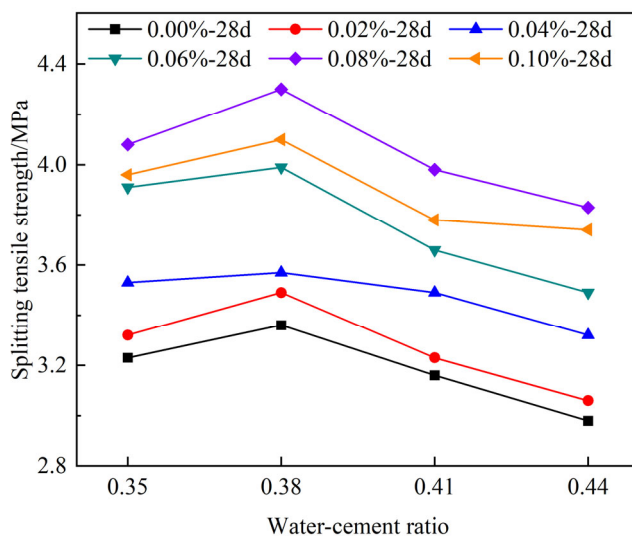
**Figure 3.** Effect of GO content on compressive strength of concrete

When the water cement ratio is 0.35 and the dosage is 0.02%, 0.04%, 0.06%, 0.08%, and 0.1%, the compressive strength of GO concrete increases by 7.24%, 15.94%, 21.16%, 26.67%, and 22.61% compared to ordinary concrete, respectively. When the water cement ratio is 0.38 and the dosage is 0.02%, 0.04%, 0.06%, 0.08%, and 0.1%, the compressive strength of GO concrete increases by 10.11%, 15.81%, 22.78%, 30.04%, and 24.48% compared to ordinary concrete, respectively. When the water cement ratio is 0.41 and the dosage is 0.02%, 0.04%, 0.06%, 0.08%, and 0.1%, the compressive strength of GO concrete increases by 9.12%, 13.52%, 22.64%, 34.28%, and 30.82% compared to ordinary concrete, respectively. When the water cement ratio is 0.44 and the dosage is 0.02%, 0.04%, 0.06%, 0.08%, and 0.1%, the compressive strength of GO concrete with a 28 day curing period is increased by 8.25%, 15.52%, 22.11%, 28.71%, and 26.07% compared to ordinary concrete, respectively. From this, it can be seen that when the content of graphene oxide (GO) is 0.08%, the compressive performance of concrete can be significantly improved. The compressive strength of the 28 day old specimens increased by more than 26.67%, indicating the excellent reinforcement effect of GO on concrete materials.

### 3.2. Splitting tensile strength

#### 3.2.1. Effect of Water cement Ratio on Splitting Tensile Strength of Graphene Oxide Concrete

Based on experimental data, the variation curve of splitting tensile strength of oxidized graphene concrete under different water cement ratios was plotted, as shown in [Figure 4](#).



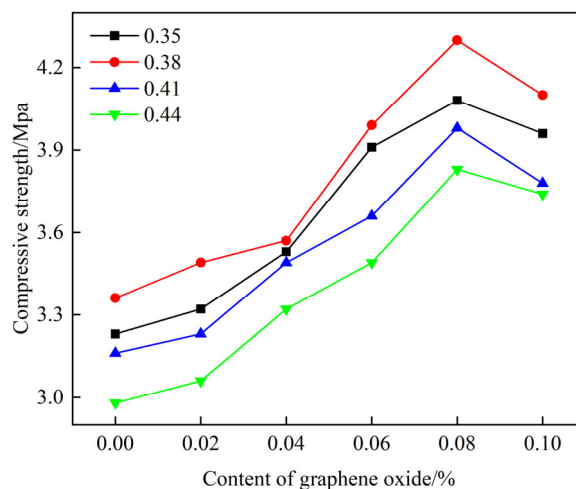
**Figure 4.** Influence of water cement ratio on the splitting tensile strength of GO concrete

In each case, the splitting tensile strength of concrete cubes with a water cement ratio of 0.38 is the highest, while the water cement ratio of 0.44 is the lowest. In the case of zero dosage, the splitting tensile strength of concrete with a water cement ratio of 0.38 increased by 4.02%, 6.33%, and 12.75%, respectively, compared to water cement ratios of 0.35, 0.41, and 0.44. At a dosage of 0.02%, the splitting tensile strength of 0.38 concrete increased by 5.12%, 8.05%, and 14.05% compared to water cement ratios of 0.35, 0.41, and 0.44, respectively. At a dosage of 0.04%, the splitting tensile strength of 0.38 concrete increased by 1.13%, 2.29%, and 7.53% compared to water cement ratios of 0.35, 0.41, and 0.44, respectively. At a dosage of 0.06%, the splitting tensile strength of 0.38 concrete increased by 2.05%, 9.02%, and 14.33% compared to water cement ratios of 0.35, 0.41, and 0.44, respectively. At a dosage of 0.08%, compared to the water cement ratios of 0.35, 0.41, and 0.44, the splitting tensile strength of concrete at 0.38 increased by 5.39%, 8.04%, and 12.27%, respectively. At a dosage of 0.1%, compared to the

water cement ratios of 0.35, 0.41, and 0.44, the splitting tensile strength of concrete at 0.38 increased by 7.05%, 8.47%, and 9.63%, respectively.

### 3.2.2. Effect of Graphene Oxide Content on Splitting Tensile Strength of Concrete

According to the analysis of the experimental results in Figure 5, the addition of graphene oxide (GO) can significantly improve the splitting tensile strength of concrete. Under different water cement ratios, with the increase of GO content (0%~0.10%), the splitting tensile strength of concrete shows a nonlinear variation pattern of first increasing and then decreasing, and there is an optimal content range.



**Figure 5.** The Effect of GO Content on the Splitting Tensile Strength of Concrete

When the water cement ratio is 0.35 and the dosage is 0.02%, 0.04%, 0.06%, 0.08%, and 0.1%, the splitting tensile strength of concrete at 28 days of age is increased by 2.78%, 9.29%, 21.05%, 26.32%, and 18.58%, respectively. When the water cement ratio is 0.38 and the dosage is 0.02%, 0.04%, 0.06%, 0.08%, and 0.1%, the splitting tensile strength of concrete at 28 days of age is increased by 3.87%, 6.25%, 18.75%, 27.97%, and 22.02%, respectively. When the water cement ratio is 0.41 and the dosage is 0.02%, 0.04%, 0.06%, 0.08%, and 0.1%, the splitting tensile strength of concrete at 28 days of age is increased by 2.22%, 10.44%, 15.82%, 25.95%, and 19.62%, respectively. When the water cement ratio is 0.44 and the dosage is 0.02%, 0.04%, 0.06%, 0.08%, and 0.1%, the splitting tensile strength of concrete at 28 days of age is increased by 2.68%, 11.41%, 17.11%, 28.52%, and 25.50%, respectively.

## 4. Conclusion

This experiment conducted uniaxial compressive and splitting tensile tests on concrete specimens with 4 different water cement ratios and 6 different amounts of graphene oxide. The following conclusions were drawn:

(1) The compressive and splitting strength of concrete specimens with four different water cement ratios showed a parabolic trend, and the mechanical properties of the specimens were optimal at a water cement ratio of 0.38.

(2) When the water cement ratio is 0.38 and the amount of graphene oxide added is 0.02%, 0.04%, 0.06%, 0.08%, and 0.1%, the compressive strength of concrete increases by 10.11%, 15.81%, 22.78%, 30.04%, and 24.48%, respectively. The splitting tensile strength increased by 3.87%, 6.25%, 18.75%, 27.97%, and 22.02%, respectively. When the content of graphene oxide was 0.08%, the mechanical properties of the specimen were optimal.

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