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Research on the Electrical Conductivity of Cement Mortar with Graphene Nano-Platelets

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***Abstract**: The resistance value of the conductive cement-based composite were measured using the two-electrode method to study the effect of different graphene nano-platelets (GNPs) content on the resistivity of cement mortar specimen. The test results show that in 3d and 7d graphene has no significant effect on the electrical conductivity of cement mortar, while the addition of graphene in the late hydration (14d, 28d) Has a significant effect on improving the conductivity of cement mortar, and it tends to increase first and then decrease with the increase of graphene content.*
***Keywords**: Graphene nano-platelets; cement mortar; electrical resistivity*

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I. Introduction

Cement-based materials are one of the most common important engineering materials used worldwide. Other admixtures can be blended with cement materials to achieve better performance. At present, the development trend of cement-based composite materials is high performance and high durability [1-3]. Among the properties of cement-based materials that we are already familiar with, its electrical conductivity has always been of concern. The resistivity of traditional cement-based materials is very high. In the dry state, it acts almost as an insulator [4], which greatly limits the scope of application of cement-based materials. What we can usually think of is combining cement-based materials with other admixtures to improve their electrical conductivity. And when cement-based material is electrically conductive it can be used in structural health monitoring and smart sensing [5-12].

The conductive components commonly incorporated in cement matrix are mainly divided into metal and carbon systems [4]. The conductive components of the metal system have the characteristics of high resistivity, but their shortcomings are also very prominent. The metal admixtures are easily passivated in the alkaline environment of composite, and the durability is not very good. The carbon system is mainly graphite and carbon nanotubes.

Among the nanomaterials, graphene, as a new type of excellent electrical conductor, is the smallest conductive material in the world that has been discovered so far. This makes its combination with cement-based material highly anticipated. many studies have explored the advantages of graphene, and its electrical conductivity in cement matrix [13-24], the literature shows the addition of graphene can greatly improve mechanical properties, durability and the electrical conductivity of cement-based material.

In order to uniformly disperse the graphene in the cement mix polycarboxylate superplasticizer was used as a surfactant and an ultrasonic method was employed to disperse the GNPs in water. This paper study the electrical conductivity of graphene cement mortar, to evaluate the effect of different amount of graphene content at different curing age using the two-electrode method connected with copper wire to find the optimal amount of GNPs which enable good conductivity.

II. Experimental details

2.1 materials and specimen preparation

the GNPs used in the experiment were supplied by Shanghai Lisheng Enterprise Group Co.ltd, the properties of the GNPs are shown in table 1. Superplasticizer polycarboxylic acid water reducer (SPC white powder) used was supplied by shanghai chenqi chemical technology co. ltd. The sand used was china ISO standard sand GB/T17671-1999 ISO 0676:1989 were supplied by Xiamen ISO standard sand co.ltd, No. 42.5 Portland cement (PC) was used during the experiment and its chemical composition is shown in table 2.

The GNPs and water reducing agent were added to water and stir for 20 minutes with magnetic force, then ultrasonically disperse for 40 minutes to produce GNPs aqueous solution. The GNPs aqueous solution and the cement were stir in the pot of cement mixer with a flat beater for 4 minutes. Cement mortar specimens are formed according to JTG E30-2005 "Testing Regulations for Cement and Cement Concrete of Highway Engineering", cement mortar mixing method. The cement mortar slur was loaded into a triple mold with preinstalled copper mesh as an electrode, 45mm × 39mm connected with a copper wire with the length of 60mm and 4mm in diameter, and then placed on vibrator for compaction, The size of the specimen is 40mm × 40mm × 160mm. As shown in figure 1.the specimens were cured for 24h at natural room temperature, then demolded and placed in a standard curing chamber, Conditions: temperature (20 ± 1) ℃, humidity: 90%).

Table 1
graphene properties

properties	values
Appearance	black power
Density	$\leq 0.1\,\mathrm{g/m^3}$
Surface area	$9\sim15\ \mathrm{m^2/g}$
purity	$\geq 98.0\ \mathrm{w.t\%}$
0 content	$\leq 2.0\ \mathrm{w.t\%}$
D50	$10\sim30\mu m$
Diameter	$\leq 10\mu m$
Thickness	$45-90nm$

Table 2
chemical composition of cement

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	LOI
Content (%)	21.6	4.3	2.6	65.8	1.2	1.6	0.7	0.4	1.8

2.2 Test method

In this experiment, three groups of specimens were prepared with different GNPs content as shown in table 3. and were tested at 4 different ages 3d, 7d, 14d, and 28d respectively. The test was performed immediately after taking out the specimen from the curing chamber and tested for resistivity.

The electrical conductivity of GNPs conductive cement-based composites is evaluated by measuring the resistivity of the specimen. the two-electrode method was used to measure the resistance of each group of GNPs conductive cement-based composite specimen. As shown in Figure 1. electrodes I and II were connected in series to a multimeter

Table 3
Mixing ratio of cement mortar

Numbering	Mass ratio (w.t %)	Cement /g	Sand / g	GNPs / g	SPC / g	Water / g
GNP00—01 ~ 04	0	450	1350	0	0.9	191.25
GNP1.2—01 ~ 04	1.2	450	1350	5.4	0.9	191.25
GNP2.0—01 ~ 04	2.0	450	1350	9	0.9	191.25

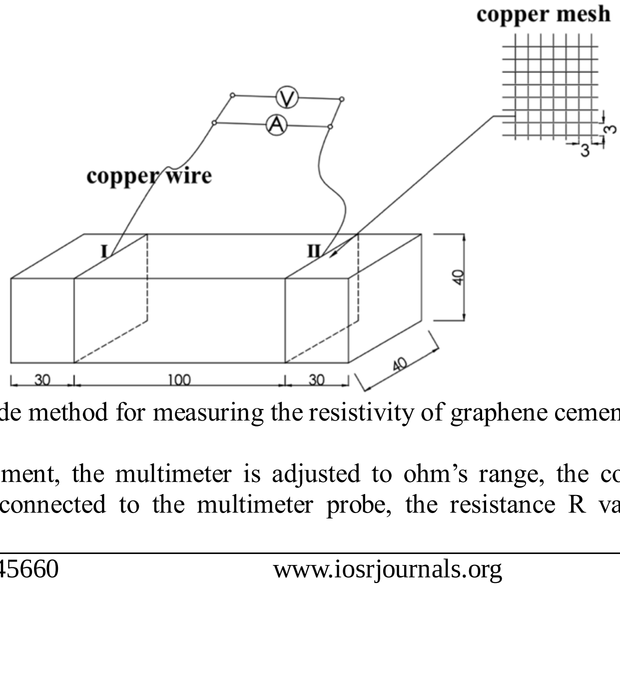

Fig. 1. Two-electrode method for measuring the resistivity of graphene cement-based composites

During the experiment, the multimeter is adjusted to ohm’s range, the copper wire attaches to two electrodes in series were connected to the multimeter probe, the resistance R value can be read from the multimeter, the resistance data as shown in table 4. were collected at a set time of 30 minutes for all specimen and then the formula (1) is used to calculate the resistivity ρ

$$\rho = R\,\frac{S}{L} \qquad (1)$$

where, R is the resistance value, Ω; S is the cross-sectional area of the test piece, m^2; L is the distance between the two electrode poles (100mm)

Table 4
the resistance data unit: Ω

Curing age / d \ Mass ratio (w.t%)	3d	7d	14d	28d
0	2.41	3.01	3.28	2.67
1.2	11.18	14.42	1.87	0.64
2.0	0.59	0.5	2.63	0.72

III. Results and discussion

3.1 Graphene cement mortar conductivity

Using the above test methods and formulas, the resistivity of graphene cement mortar with different GNPs content and graphene cement mortars at different ages were measured. A line chart of Graphene cement mortar composite with 0% and 2.0% GNPs content with the resistivity changes at 3d, 7d, 14d, and 28d ages with respective error bars, shown in Figure 2. by comparing the changes in resistivity of the same GNPs content at different ages and the resistivity of different GNPs content at the same age, in order to evaluate The effect of the added graphene particles to cement mortar resistivity.

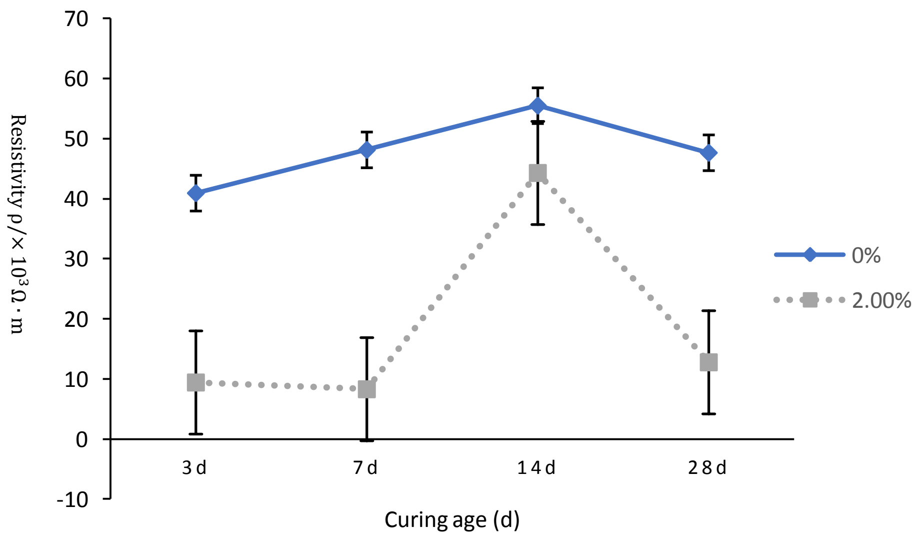

Fig. 2. The effect of adding graphene on the resistivity of cement mortar

3.2 Effect of different contents of graphene on the resistivity of cement mortar

From the experimental data and the graph of resistivity of graphene cement mortar:

(1). When comparing the specimen with the different GNPs content at different age, the resistivity of the specimens with 0% and 2.0% GNPs content varies with age: 3d ~ 7d remains basically unchanged, 7d ~ 14d shows an upward trend, and 14d ~ 28d decreasing gradually. The increasing proportions of the specimens with 0% GNPs content at 3d, 7d, 14d, and 28d sequentially: 24.8%, 8.9%, -7.16%; the increasing proportions of the specimens with 2.0% GNPs content at 4 ages are: -15.25 %, 426%, -72.6%. The resistivity of the two test piece showed a downward trend after 14 days.

(2). Comparing the specimens with different GNPs dosages at the same age, the resistivity of 2.0% specimens compared with 0% specimens decreasing proportion at 3d, 7d, 14d, and 28d sequentially: 75.5%, 83.38%, 19.8 %, 73.03%. It can be seen that the resistivity of the test piece with 2.0% content is significantly lower than that without graphene added.

3.3 Analysis of the effect of graphene particles on the electrical conductivity of cement mortar
Due to early cement hydration and other reasons, the resistivity of cement mortar did change much, When measuring the resistivity of cement mortar with 1.2%. The measurement results are shown in Figure 3. With its error bar

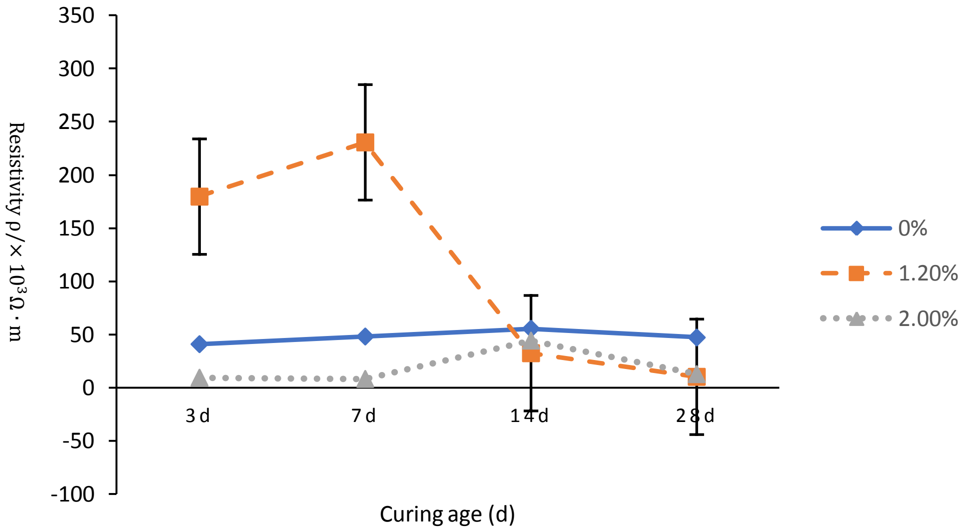

Fig. 3. The effect of different contents of graphene on the resistivity of cement mortar

From the experimental data and the graph of resistivity of graphene cement mortar,
(1). The resistivity of the specimen with 1.2% graphene content at 3d is very high and increases by 27.37% on 7d, significantly decreases by 87.87% on 14d and later decreases by 65.77% on 28d, it can be seen that during the late hydration the specimen with 1.2% GNPs content had the showed better resistivity when compared to the other two specimen.
(2). Comparing the specimen with 1.2% graphene content to that with 0% GNPs content at the same age, the specimen with 1.2% graphene content increasing proportion at 3d, 7d, 14d and 28d respectively are:363.9%, 372.3%, -42.9% and -76.03%.compared with the 2% specimen, the increase of 1794.9%, 2743.5%, -28.9% and -11.11%. when the resistivity of the specimen is showing upward trend 3d ~ 7d the 1.2% test piece had shown high resistivity and from 14d ~ 28d on downward trend it had shown lowest resistivity.

IV. Conclusion

Compared with the cement mortar with zero graphite content, the addition of 1.2% and 2.0% can improve the electrical conductivity of the cement mortar, and the specimen with 1.2% graphene content is better than the 2.0% content of the test piece at the late hydration. The resistivity of cement mortar will increase first and then decrease with the continuous increase of graphene content, during which there may be an optimal graphene content. Cement mortar can transmit electrical signals when it is conductive and may be used in some smart sensing components in the future, which needs future exploration and research.

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