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Experimental Study on the Effect of Graphene Oxide on the Compressive Strength of Cement Curing Body with Medium Level Radioactive Waste Liquid¹

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ABSTRACT: This paper focuses on the effect of graphene oxide on the compressive strength properties of cement curing body of radioactive waste liquid, in order to consider the interaction effect between the experimental factors, a full factorial experiment with 3 factors at 2 levels plus 3 centre points was carried out in which the 3 factors were GO addition, water-cement ratio and mixing time, respectively. The experimental results show that; the factors with significant effect on compressive strength are water-ash ratio and GO addition, mixing time is a non-significant factor, and the main effects of each factor of compressive strength are as follows: the main effect of GO is -1.20066, the main effect of liquid-ash ratio is -2.30584, and the main effect of mixing time is -0.46473. This experiment explores the effect of graphene oxide on the properties of cement curing body of radioactive waste liquid to provide a reference for subsequent research.

KEYWORDS: Graphene oxide, Cement curing body, Experimental design, Radioactive waste liquid, Compressive strength.

I. INTRODUCTION

A large amount of medium-level radioactive wastes, in which the typical nuclides are ¹³⁷Cs and ⁹⁰Sr, are generated during the operation of nuclear fuel element processing and spent fuel reprocessing. Currently, cement curing is the main treatment method for medium-level radioactive wastes. However, the silicate cement curing body of medium-level radioactive waste fluid has problems such as high porosity and limited nuclide blocking performance, which are key scientific issues for the safe and proper treatment and disposal of radioactive waste fluid. As a nanomaterial, graphene oxide (GO) has been successfully used as a mixture in cementitious materials to improve their mechanical and durability properties. A large number of scholars at home and abroad have conducted experimental studies on the mechanical properties of GO-modified reinforced cementitious materials, and the results show that a small amount of GO added to cementitious materials can significantly improve the mechanical strength of the cement curing body [1], such as the experimental results of Lv et al [2] showed that GO in the range of doping from 0.01wt% to 0.03wt%, the tensile and flexural strengths of the cement stone were significantly increased with the increase in the doping of GO. increased significantly, after which the tensile and flexural strength of cementite increased only slightly with the increase of GO doping; Wang et al [3] found that the 28d flexural and compressive strength of cement mortar increased by 70.5 wt% and 24.4 wt%, respectively, by doping 0.05 wt% GO; Babak [4] added mass fractions ranging from 0.1 wt% to 2 wt% of GO was added to cement and found that the added content of GO was positively proportional to the compressive and flexural strengths of cement; Wang Minggang[5] found that 0.03wt% of GO could increase the 28d flexural and compressive strengths of cement mortar by 28.5% and 21.2%, respectively; although the conclusions on the optimum amount of GO added in the various experimental studies were inconsistent, it can be seen that the amount of GO added varied between 0.03wt% and 0.08wt%, and the amount of GO added varied between 0.03wt% and 0.08wt%. -0.08 wt% can greatly improve the mechanical properties of the cured body. At present, there is no research

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on the use of graphene oxide (GO) and other nanomaterials as additives in cementitious materials to achieve efficient curing of radionuclide ions.

In this paper, the effect of graphene oxide on the compressive strength of cement curing body with medium level radioactive wastewater is investigated based on the design of experiments approach, so as to provide a reference for the curing of radioactive wastewater cement.

II. EXPERIMENTAL MATERIALS AND METHODS

2.1 Experimental materials

The simulated radioactive liquid waste used in this experiment, with a salt content of 420 g/L and pH=13, was prepared by commercially available chemical reagents, and its chemical composition was: Na_2CO_3 : 45 g/L; NaNO_3 : 275 g/L; and NaAlO_2 : 100 g/L. In order to simulate the radioactivity level of the major nuclides ^{137}Cs and ^{90}Sr in radioactive liquid waste, CsCl and SrCl_2 were added to the simulated waste solution. The concentrations of Sr^{2+} and Cs^+ in the radioactive liquid waste were all 1g/L.

The cement used in this experiment was from PC42.5 ordinary silicate cement of Hunan Taojiang Southern Cement Co. Ltd. The graphene oxide was a high-purity monolayer graphene oxide solid produced by Shenzhen Suiheng Technology Co. .The deionised water used was produced by Gaoke Group Environmental Biotechnology Co.

2.2 Experimental apparatus

The main experimental instruments are as follows: cement mixer JJ-5 planetary cement mortar mixer(Fig. 1), electronic balance with a range of 2kg and an accuracy of 0.01g(Fig. 2). Fuyang brand ultrasonic cleaner with a power of 240W(Fig. 3), microcomputer-controlled pressure tester with an accuracy level of 1 and a range of 300KN(Fig. 4), and moulds for cement test blocks.



Fig. 1 JJ-5 planetary cement mortar mixer



Fig. 2 Electronic balance



Fig. 3 Ultrasonic cleaner



Fig. 4 Microcomputer-controlled pressure tester

2.3 Design of experiments

2.3.1 Factorial screening and experimental design

The influencing factors were screened by reviewing the information combined with the laboratory conditions, and the factors screened were: the amount of GO added, the water-cement ratio, and the mixing time. In order to better observe the effect of each factor on the response variable and the interaction effect between the factors, this thesis conducts a full factorial experimental design. The experimental design was carried out using Minitab software and the experiment was a 3-factor, 2-level full factorial experiment. The full factorial experiment orthogonal table is shown in Table 1.

Table 1 Full factorial experimental orthogonal table

Standard sequence	Operational sequence	Centre point	Water-cement ratio	GO (wt%)	Mixing time
6	1	1	0.08	0.6	20
3	2	1	0.00	0.8	10
1	3	1	0.00	0.6	10
10	4	0	0.04	0.7	15
8	5	1	0.08	0.8	20
5	6	1	0.00	0.6	20
9	7	0	0.04	0.7	15
7	8	1	0.00	0.8	20
4	9	1	0.08	0.8	10
11	10	0	0.04	0.7	15
2	11	1	0.08	0.6	10

2.3.2 Preparation of graphene oxide dispersions

The concentration of the GO dispersion made in this experiment was 10 mg/ml. The steps of making the dispersion were as follows: Graphene oxide and deionised water were put into a beaker at the ratio of 1:100, and then stirred with a glass rod for 1 to 3 minutes, and then sonicated for 10 minutes in a room temperature water bath. The GO dispersion produced was thicker, as shown in Fig.5.



Fig.5 GO dispersion at a concentration of 10 mg/ml

2.3.3 Compressive strength test

Compressive strength test with reference to the method specified in GB/T 17671-2021^[6].

2.3.4 Mixing process

This experiment referred to the mixing procedure in the literature^[7] for cement curing of horizontal radioactive wastes in high salt and high alkali, which is known to start with slow mixing for 2 minutes, pause mixing for 15 seconds, and then finally carry out rapid mixing for 10 minutes. In order to further explore the influence of mixing time cement curing body performance, the experiment was adjusted against the mixing procedure of the second stage in

GB/T1346-2011^[8] standard. In this experiment, the rapid mixing time was divided into three stages: 10 minutes, 15 minutes and 20 minutes, in order to observe the differences in the performance of cement curing body under different mixing times.

III. RESULTS AND DISCUSSION

The compressed surface of both ends of the experimental cement samples after 28 days of standard curing will be smoothed with sandpaper, as shown in Fig.6.



Fig.6 Experimental samples of polished cement

The compressive strength was tested and the results are shown in Table 2.

Table 2 Compressive strength results

Operational sequence	1 (KN)	2 (KN)	3 (KN)	4 (KN)	5 (KN)	6 (KN)	Compressive strength (MPa)
1	14.7	10.8	13.6	15.1	9.8	8.0	7.36951
2	12.4	12.6	13.4	12.9	11.1	11.1	6.28980
3	20.0	12.7	13.9	16.1	9.3	13.3	9.42197
4	9.4	9.5	13.2	7.4	11.8	16.1	7.46118
5	10.0	10.0	9.8	10.2	6.6	9.2	5.01147
6	16.9	7.9	14.5	16.7	13.9	14.7	7.81260
7	12.6	10.7	10.5	13.9	16.4	14.0	7.34659
8	9.9	13.0	10.9	11.6	10.8	8.2	5.72448
9	7.4	9.4	10.0	9.7	7.5	11.0	5.21010
10	11.4	11.5	12.0	12.1	9.3	16.1	6.42731
11	11.0	12.7	13.2	14.0	13.3	14.1	6.85512

As can be seen from Table 2, the compressive strength and running order as a whole show random fluctuations, in line with the law of randomness of the running order, and the compressive strengths of the three centre points (experimental samples with running order of 4, 7 and 10) are approximately equal.

Pareto plots of standardised effects of compressive strength is as shown in Fig.7. The names of factors A, B and C are graphene oxide addition, water-cement ratio, mixing time, respectively.

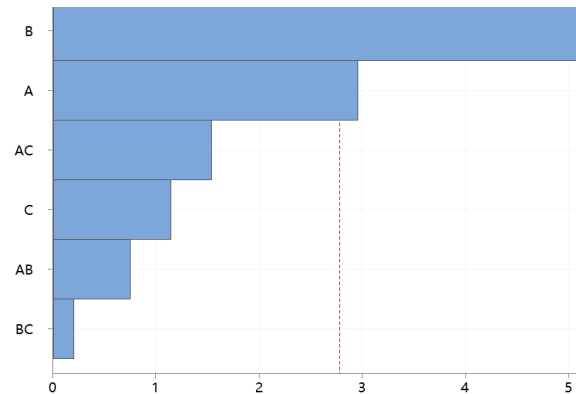


Fig.6 Pareto plots of standardised effects of compressive strength (response as compressive strength, $\alpha=0.05$) As shown in Fig.6, the significant terms affecting the compressive strength are GO and water-cement ratio. The residual plots show randomness in all the data, indicating that the data and the regression model developed are normal. According to the calculation results of MINITAB, the main effects of the factors were -1.20066 for GO addition, -2.30584 for water-ash ratio, and -0.46473 for mixing time. There was no interaction effect for liquid-ash ratio and mixing time, and there were interaction effects for GO and liquid-ash ratio and GO addition and mixing time.

According to the MINITAB calculations, the compressive strength increases in the direction of decreasing liquid-ash ratio and decreasing GO and varies linearly.

Although mixing time did have some degree of effect on compressive strength in this experiment, this effect was relatively small and its main effect was not significant according to this study and experimental data. Therefore, it can be assumed that the effect of mixing time is insignificant. This is because the main effect of mixing time is the homogeneity of concrete. Within a certain range, the longer the mixing time, the better the homogeneity of concrete, which is beneficial for improving flow and compressive strength. However, when the mixing time is too long, the friction and crushing action between the cement particles reduces the activity of cement setting, which in turn reduces the strength of the concrete. It is recommended that the mixing time for similar experiments using the same equipment be set at 120s for slow mixing, 15s for stopping, and then 10min for fast mixing.

The relationship between compressive strength and GO addition in this experiment is linearly decreasing with the increase of GO addition, which is not the same as the results of other papers in which the compressive strength is increased due to the addition of GO. The reason for this may be that the horizontal interval of the GO addition is too large, which just misses the bending interval, and the values of GO addition in this experiment are 0.00wt%, 0.04wt%, 0.08wt%, much larger than those of other papers in which the GO addition is 0.01wt%, 0.02wt%, etc., in which the spanning interval is too large, and just misses the bending interval. , which are much larger than other papers where the GO addition is 0.01wt%, 0.02wt%, etc., where the spanning intervals are too large and just miss the bending intervals, which are just linearly varying.

IV. CONCLUSION

This paper focuses on the effect of GO on the compressive strength properties of cement curing body with radioactive waste liquid. In order to consider the interaction effect between the experimental factors, the water-cement ratio and mixing time were added to design a full factorial experiment with 3 factors and 2 levels plus 3 centre points, and the following conclusions were drawn:

- 1) In this experiment, the factors that have significant effect on the compressive strength are water-ash ratio and the amount of GO added, and the mixing time is a non-significant factor, which has little effect on the compressive strength.
- 2) The level interval selected for GO addition is large, which can only determine the approximate trend of the effect, and a more detailed level interval needs to be selected for the experiment in order to observe a more accurate effect curve.

3) This experiment is only to test and analyse the fluidity and compressive strength of the cement curing body, if the conditions allow, it should also test and analyse the leaching resistance of the cement curing body.

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