Experimental Study on Working and Mechanical Properties of Geopolymer Modified Clay

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Abstract: In order to promote the implementation of China's "carbon peak in 2030, carbon neutrality in 2060" strategic goals and promote the construction industry towards the direction of low-carbon, energy saving and environmental protection, it is urgent to develop green energy saving and ecological environmental protection curing agent that can effectively replace cement/lime for residue treatment. Geopolymers are considered to be ideal substitutes for traditional curing agents. In order to study the work and mechanical properties of geopolymer modified clay, the slump and initial setting time of geopolymer modified clay were studied, and the effect of geopolymer content on the mechanical properties of geopolymer modified clay was studied. The results show that: (1) When the water content is 12.5%, slump performance is the best; (2) When the content of retarder is 2.3%, the initial setting time of the material meets the requirements, and when the content of retarder is more than 2.3%, the retarding effect is not significantly enhanced after increasing the content of retarder. (3) Geopolymer can significantly improve the compressive strength of clay. When the content of geopolymer in clay is 50%, the compressive strength of geopolymer modified clay is the best. The compressive strength of geopolymer clay was higher in the early stage and decreased slightly in the later stage. The research results in this paper can provide a theoretical basis for the application of geopolymer modified clay.

Keywords: Geopolymer, Modified Clay, Slump, Initial Setting Time, Compressive Strength

1. Introduction

At present, common Portland cement and lime are still widely used as curing agent for foundation treatment. According to the research report, the production of 1t of cement will emit about 0.8~1.0t of CO_2 [1], the energy consumption is about 87.6~116.6 kJ [2], and the energy consumption of production of 1t of lime is about 6.98~9.31 MJ [3]. In addition, although the cement/lime solidified soil has good mechanical properties, there are some disadvantages such as poor water stability, easy cracking, large shrinkage and insufficient durability [4]. Liu Hanlong [5] put forward the green foundation treatment technology aiming at the problems of high cost, high energy consumption and large environmental pollution of the traditional foundation treatment technology, and suggested to select materials with low energy consumption, no pollution or little pollution and recyclable materials. In addition, there is an urgent need to develop green, energy-saving, ecological and environmentally friendly curing agents to replace cement/lime treatment residue, to promote the development of the construction industry to the direction of low-carbon, energy-saving and environmental protection.

In the 1970s, French scientist J. Davidovits proposed the concept of geopolymers. It is a kind of three-dimensional network inorganic cementing material formed by depolymerization, monomer reconstruction and polycondensation process with aluminosilicate-rich industrial solid waste as precursor under the action of alkali activator [6], which is considered as an ideal substitute for cement and other traditional curing agents. The existing researches mainly focus on geopolymer concrete, and there are few reports on geopolymer-solidified clay.

In this paper, the curing test of geopolymer modified clay was studied in the face of the curing treatment of clay in the hilly area of Zhejiang Province. Firstly, the slump and initial setting time of geopolymer modified clay were tested, and the influence of geopolymer content on the compressive properties of geopolymer modified clay was further studied. The research results can provide theoretical reference for geopolymer solidified clay.

2. Test

2.1 Raw Materials

See Table 1 for relevant parameters of water glass.

Table 1. Parameters of Water Glass

Na_2O content/%	SiO_2 content g/%	Modulus	Baume/°Bé
8.35	26.54	3.28	39.9

The components of fly ash and slag used in the test are shown in Table 2.

Table 2. Chemical Composition of Fly Ash and Slag (%)

Chemical composition	SiO_2	CaO	MgO	Al_2O_3	Other
Fly ash	50.61	2.17	0.54	37.94	8.84
Slag	32.42	33.47	9.81	18.65	6.64

The main physical and mechanical properties of clay are shown in Table 3.

Table 3. Main Physical Property Indexes of the Clay

Water content (%)	Dry density (g/cm^3)	Specific gravity	Void ratio	Liquid limit (%)	Plastic limit (%)	Plasticity index	Saturation (%)
39.2	1.05	2.70	1.56	68.2	39.4	27.3	95

FDN: It is produced by Shandong Yousuo Chemical Technology Co., Ltd. in China, a water-soluble yellow-brown powder with stable physical and chemical properties and good effect. Retarder: Lambo brown sugar, raw sugar cane, protein 1.6g, carbohydrate 93g, sodium 29mg per 100g.

2.2 Preparation of Test Specimen

The specimen was made according to GB/T 50081-2019 "Test Method Standard for Physical and Mechanical Properties of Concrete". Mix water glass and NaOH uniformly until it is clear to prepare the alkali activator. Weigh the clay, the fly ash and the slag according to the mixing ratio, put the clay, the fly ash and the slag into a stirrer in sequence, add the mixture for dry stirring uniformly, then add water, the alkali activator and the additive, wherein the total feeding time is not more than 2min, and continuously stir for 3min.

Fill the trial mould with the mixed geopolymer modified clay one time, use the vibrating rod for preliminary tamping to make the mixture higher than the trial mould, place it on the vibration table, hold the trial mould with one hand, and apply pressure and trowel on the upper surface of the concrete with the other hand to ensure that the test block can be tamped compactly. At the end of vibrating, the excess polymer concrete on the surface shall be scraped off with an iron trowel and the surface shall be trowelled smooth. The vibration time of each test block in the same group shall be the same. The test specimen after vibration is shown in Figure 1.

The specimens were numbered immediately after forming, covered with a layer of plastic film, and placed in a 1d-2d room with a temperature of 20 ° C ±5 ° C and relative humidity of more than 50%. After demoulding (as shown in Figure 2), the specimen was placed in a standard curing room with a temperature of 20℃±2℃ and relative humidity greater than 95%.

Figure 1 Photo after Vibration

Figure 2 Demoulding of Test Specimen

WAW-100B microcomputer-controlled universal testing machine of Jinan Pinde Testing Machine Co., Ltd. was used to test the anti-compression performance of the test specimen. The maximum measuring range of the testing machine is 1000KN. According to GB/T 50107-2010 “Standard for evaluation of concrete compressive strength”, the compressive properties of the specimens at 3d, 7d and 28d are tested.

3. Test Design and Result Analysis of Geopolymer Modified Clay

3.1 Slump and Initial Setting Time Test of Geopolymer Modified Clay

The mix ratio scheme of geopolymer modified clay adopted in the test is determined according to theoretical calculation analysis and reference [7] (Table 4). The slump is tested according to the mix ratio test scheme in Table 4 and the optimal water content ratio is determined accordingly.

Table 4. Slump Test Scheme (g)

Test group	Clay	Fly ash	Slag	NaOH	Water glass	Water reducing agent	Water
Q-1	400	100	100	30.2	69.9	26	25
Q-2	400	100	100	30.2	69.9	26	50
Q-3	400	100	100	30.2	69.9	26	75
Q-4	400	100	100	30.2	69.9	26	100
Q-5	400	100	100	30.2	69.9	26	125

Refer to requirements on the “Standard for quality control of concrete” (GB50164-2011) [8] to conduct slump test on 5 groups of geopolymer modified clay. The test steps are as follows: place the slump cylinder on a leveling iron plate, pour the geopolymer modified clay mixture into the cylinder, vibrate once every one third of the height, and pour and vibrate in three times. Lift the slump cylinder and place it aside to allow the mixture to collapse naturally. Use a straight ruler to horizontally place it on the cylinder mouth, and then use a ruler or tape to measure the distance from the cylinder opening to the highest point of the mixture, and this is the slump.

During the test, a large number of voids were observed on the sides of test specimens Q-1 and Q-2, which were in a dry-cracked state. After the slump bucket is lifted, the height of the Q-3 and Q-4 test specimens drops rapidly, and then start to continuously and slowly drop until stable. The collapse height of Q-3 test specimen is 60mm and that of Q-4 test specimen is 90mm. When the slump bucket of Q-5 test specimen is not lifted, a small amount of water flows out from the bottom of the slump bucket. After the slump bucket is taken out, the test block collapses and separates, with the slump of 226mm.

It can be seen from the experimental phenomena and results that the water added into Q-1 and Q-2 test specimens is too small, there are obvious gaps between the aggregates, a large amount of water is absorbed, which is not enough to form enough fluidity, and the geopolymer cementing material cannot form the clay. The slump of Q-3 and Q-4 test specimens is 60mm and 90mm respectively, ranging from 50mm to 90mm, which is equivalent to that of plastic concrete. The water consumption of Q-5 test specimen is too much, and the viscosity of geopolymer soil is insufficient, resulting in bleeding phenomenon. Therefore, the water content in the mix ratio of Q-4 test specimen (12.5%) is selected to further test the impact of retarder on the initial setting time. See Table 5 for the test scheme.

Table 5 Mixing Ratio of Initial Setting Time Test (g)

Test group	Fly ash	Clay	Mineral powder	NaOH	Water glass	Water	Water reducing agent	Retarder
SA	100	400	100	30.2	69.9	100	26	0
SB	100	400	100	30.2	69.9	100	26	5
SC	100	400	100	30.2	69.9	100	26	10
SD	100	400	100	30.2	69.9	100	26	15
SE	100	400	100	30.2	69.9	100	26	20

The initial setting time test of geopolymer modified clay was carried out in accordance with the Standard of Performance Test Method for ordinary fresh concrete (GB/T

50080-2016) [9]. The ambient temperature shall be maintained at 20 ± 2°C throughout the test. The setting time shall be measured from the time when the mixture is stirred and added with water, and shall be tested every 5 minutes thereafter. The test results are shown in Figure 3.

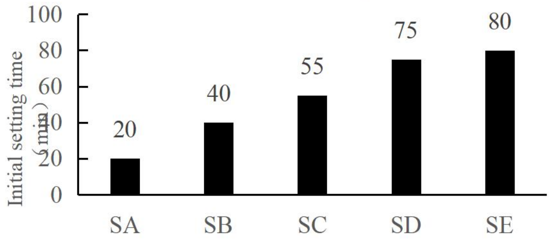

Figure 3. Effect of Retarder on the Initial Setting Time of Geopolymer Cementing Material

According to the analysis of Table 5 and Figure 3, it can be seen that the initial setting time of geopolymer modified clay is prolonged with the increase of the dosage of retarder. As the amount of retarder added increases, the retarder effect gradually slows down. The initial setting time of SB group was twice longer than that of SA group, and the initial setting time of SC group was 50% longer than that of SB group, SD group and SC group. When the content of retarder is more than 3.5% (SD group), the retarding effect increases slowly. When the amount of retarder is added from SD group to SE group, the increase of retarding time is only 6%. When the amount of retarder is 2.3% (SC group), the initial setting time is 55min, which meets the requirement of minimum initial setting time of 45min, and 2.3% (SC group) retarder is the best mixing amount.

3.2 Test on Influence of Geopolymer Content on Compressive Performance of Modified Clay

In order to analyze the influence of the amount of geopolymer on the compressive properties of clay, geopolymer cement was mixed into clay in the mass ratio of 3:7 (test specimen No. Z-1), 4:6 (test specimen No. Z-2), 5:5 (test specimen No. Z-3) and 6:4 (test specimen No. Z-4) respectively. After standard curing, conduct compressive performance tests on its cube for 3d, 7d and 28d.

During the test, it was observed that there was a gap between the clay aggregate in group Z-1 and the test blocks in other groups were normal. During the compression test, small cracks appeared in the middle side of the specimen. And continue to increase the load, the cracks become more and extend until the through cracks appear, and the angle is 70°~80°. By observing the front surface of the test specimen, it is also found that the micro-cracks are generated slowly at first, and when the load is continuously applied, the micro-cracks become more, expand and penetrate, and finally the test specimen is destroyed.

The overall comparative analysis shows that the strength of geopolymer soil increases with the increase of geopolymer content when the ratio of geopolymer is between 30% and 50%, and the strength of geopolymer soil decreases when the content of geopolymer is 60%, indicating that the optimum content of geopolymer is about 50%. When the content of geopolymer in geopolymer soil is low (Z-1), the compressive strength of geopolymer soil does not change much with time; with the increase of geopolymer content in geopolymer soil (Z-2, Z-3, Z-4), the early strength of geopolymer soil is higher and increases rapidly, but the strength decreases slightly with time.

The compressive properties of the 4 groups of test specimens at 3d, 7d and 28d are tested, and the results are shown in Table 6.

Table 6. Compression Test of Geopolymer Modified Soil

Mix ratio No.	Compressive strength (in MPa)		
	3d	7d	28d
Z-1	9.0	9.3	8.8
Z-2	15.1	17.5	15.3
Z-3	21.9	25.3	22.5
Z-4	14.7	17.7	17.8

Through the analysis of the test results that the compressive strength of clay can be significantly improved by adding geopolymer into clay. When the content of geopolymer is 30% (Z-1), the strength of 3d, 7d and 28d has little change, which is about 9 MPa; when the content of geopolymer is 40% (Z-2), the strength of 3d is 15 MPa, the strength of 7d is close to 18 MPa, and the strength of 28d is reduced to 15 MPa; when the content of geopolymer is 50% (Z-3), the strength of 3d is close to 22 MPa, the strength of 7d is about 25 MPa, and the strength of 28d is reduced to 23 MPa; when the content of local polymer is

60% (Z-4), the strength is reduced, the strength of 3d is nearly 15MPa, the strength of 7d is about 17MPa, and the strength of 28d was close to 18MPa.

4. Conclusion

This paper has studied the working and mechanical properties of geopolymer modified clay. The results show that: (1) when the content of water in geopolymer soil is 12.5%, the slump performance is the best; (2) when the ratio of retarder is 2.3%, the initial setting time of the material meets the requirement, however, when the ratio of retarder is more than 2.3%, the retarding effect is not obviously enhanced by increasing the ratio of retarder; (3) Geopolymer can significantly improve the strength of clay, and the compressive strength of geopolymer soil is best when its content in clay is 50%. The compressive strength of geopolymer soil is higher at early stage, and slightly decreases over time. The results provide theoretical basis for engineering application of geopolymer modified clay.

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