Experimental Study on Kaolinite Weathering Sand as Cement Mortar Accelerating Agent

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In this study, the weathered sand from kaolinite mine in Yushan County, Jiangxi Province, China, was tested and analyzed in laboratory. XRD results show that montmorillonite is the main mineral composition of kaolinite weathered sand, and the content of montmorillonite is 35%. XRF test results show that the content of aluminum in weathered kaolinite sand is 9.8%. In order to explore the material properties of kaolinite weathered sand as cement mortar accelerating agent, the study compared the quick setting effect of kaolinite weathered sand with an accelerating agent and did the parallel test of 7-day strength of M10 grade mixed mortar. The results show that the 7-day unconfined compressive strength of kaolinite weathered sand fine sand mixed mortar test block is higher than that of accelerating mortar mixed mortar test block when the content of kaolinite weathered fine sand is equal to that of the accelerating agent. However, the 7-day unconfined compressive strength of mortar decreases when the content of fine-grained kaolinite weathered sand increases and the content of cement decreases, indicating that fine-grained kaolinite weathered sand cannot completely replace cement as cement mortar, and the proportion of fine-grained kaolinite weathered sand should be considered according to the strength grade of mixed mortar.

1. Introduction

There are abundant kaolinite mineral resources in Yushan County of Jiangxi Province. At present, block stone has been efficiently developed and utilized, but the mining and utilization of its weathered products is less, and the weathered products are mostly accumulated in the mine residue, as shown in Figure 1, which often causes resource waste. In order to better excavate and utilize this kind of rock and soil mass, this study carried out indoor physical and mechanical tests on the weathered sand soil of kaolinite mine in this area, revealed its geotechnical engineering characteristics and material properties as mortar accelerating agent, and explored the way of resource utilization of this kind of rock and soil mass.

Kaolinite is rich in montmorillonite. Montmorillonite is a kind of inorganic ultra-high molecular weight silicate polymer with natural nanostructure, which has strong properties of water absorption, expansion, cementation, dispersion, thixotropy, and cation exchange, and has been widely used in petroleum, chemical industry, building materials, mining, agriculture, environmental protection, and other fields [1–8]. Kaolinite, as an additive, plays a good role in improving peat sedimentation and shear strength [9–11]. Kaolinite content plays an important role in the rheological properties and strength development of limestone calcined clay cements [12]. Kaolin and metakaolin as supplementary cementing materials can reduce the pressure of cement consumption and improve the performance of concrete [13–17].
Bentonite is mainly composed of montmorillonite and has been used as seepage wall material in civil and hydraulic engineering [18–21]. As a concrete admixture, bentonite can improve the strength, permeability, and thermal conductivity of concrete [22, 23]. Bentonite as a cement additive can reduce the emission of polluting gases [24]. As a mortar additive, bentonite can enhance the strength, durability, and permeability of cement mortar and resist steel corrosion [25–28]. As an asphalt additive, bentonite improves the fatigue life, indirect tensile strength, and binder of asphalt mixture [29, 30]. In addition, the application of bentonite in drinking water and paper industry has also achieved some research results [31, 32].

Based on the development and utilization of montmorillonite as additive, this study puts forward the idea of using weathered sand as a cement mortar accelerating agent and carries out relevant tests to verify it.

2. Physical Properties of the Samples

2.1. Natural Moisture Content. Weathered sand samples were collected from Yushan County, Jiangxi Province, packed into sealed bags, sealed with paraffin, and then transported to the laboratory for relevant research. The natural moisture content of weathered sand is tested by the drying method according to the regulations of Standard for Geotechnical Test Methods (GB/T 50123-1999) [33]. The samples were placed in an oven at 105°C and dried for more than 6 hours until the mass was constant. The natural moisture content of kaolinite weathered sand was 22.1%.

2.2. Particle Gradation. According to the screening method in Standard for Geotechnical Test Methods (GB/T 50123-1999) [33], the grain analysis test of dry weathered sand was carried out, and the grading curve of weathered sand was obtained, as shown in Figure 2. According to the regulations on the naming of soil samples in Code for Geotechnical Engineering Investigation (GB50021-2001) [34], the weathered sand with a particle size greater than 0.25 mm and a particle mass greater than 50% can be judged as medium sand.

At the same time, the grading curve shows that the particle size distribution of weathered sand is concentrated, and the mass proportion of fine particles (soil particles with particle size less than 0.075 mm) is 23.7%. Grading indexes are given in Table 1, and weathered sand can be judged as bad grading.

2.3. Limit Moisture Content. The limit water content of the fine grain group (particle size less than 0.075 mm) in kaolinite weathered sand can be used to determine the type of the fine grain group (silt or clay) and the name of weathered sand. According to the Standards for Geotechnical Test Methods (GB/T 50123-1999) [33], dry sand samples and take fine grain groups with particle size less than 0.075 mm to conduct the limit moisture content test. The results show that \( w_L \) and \( w_P \) of the fine grain group are 44.9% and 26.1%, respectively. According to the following formulas, the plastic index \( I_P \) and liquid index \( I_L \) of fine-grained weathered sand are 18.8 and −0.21, respectively.

\[
I_P = w_L - w_P, \quad (1)
\]

\[
I_L = \frac{w - w_P}{I_P}. \quad (2)
\]

According to Figure 3, the fine grain group of weathered sand is classified. As the IP of the fine grain group is \( I_P \geq 0.73(w_L - 20) \), \( I_P \geq 10 \), and \( w_L < 50% \), it can be judged that the fine grain group of weathered sand is low liquid limit...
Therefore, weathered sand is named clay sand (SC).

2.4. Specific Gravity (G_s). Particle specific gravity is the ratio of the mass of weathered sand baked to constant value at 105–110°C to the mass of pure water with the same volume at 4°C. According to the Standards for Geotechnical Test Methods (GB/T 50123-1999) [33], the weathered sand was ground to the fine mineral powder with a particle size less than 0.075 mm before the test, and then, the particle specific gravity test was carried out under the condition of sand bath. The results show that the specific gravity of weathered sand is 2.66.

3. Microstructure Analysis

The weathered sand was observed by the scanning electron microscope of state Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences. The scanning electron microscope was Quanta250 produced by FEI Company of America, mainly used for mineral, rock, metal, ceramic, biological, and other samples as well as a variety of solid materials for indoor observation and analysis. Before the test, the weathered sand of kaolinite was dried and then sifted with 0.075 mm aperture, and the sifted fine grain group was tested. The scanning images and test results are shown in Figure 4.

Scanning electron microscopy (SEM) images show that the surface of weathered sand particles has obvious edges and angles, with many uneven protrusions and flocculation. The contact between particles is point contact and surface contact is less. The distribution of particles is loose, the number of pores is large and most of them are small pores, and the direction of the distribution of soil particles tends to be irregular, and the overall structure is lamellar.

4. Mineral and Element Composition

The composition analysis tests of weathered sand include X-ray diffraction mineral composition analysis (XRD) and X-ray fluorescence spectrometry (XRF), which are used to detect mineral composition and element content, respectively.

4.1. Mineral Composition. The D8 advance X-ray diffractometer of State Key Laboratory of Geomechanics and Geotechnical Engineering was used to analyze the mineral composition of weathered sand. In the experiment, the sample placed in the center of the spectrometer (goniometer) is irradiated with X-ray, and the intensity of X-ray is detected and recorded to obtain the X-ray diffraction spectrum. Qualitative analysis, lattice constant determination, and stress analysis can be carried out by using computer to analyze the relationship between peak position and strength.

Before the test, the weathered sand was dried and ground. Samples of the weathered sand with a particle size less than 0.075 mm were sent to carry out XRD tests to analyze the mineral composition of the weathered sand. The test results are shown in Figure 5.

The results show that the main mineral composition of weathered sand is montmorillonite. As montmorillonite has a unique laminate crystal structure, it has the ability to expand when exposed to water and can form a gel containing a large amount of water network structure, which can
increase its volume by 10–30 times after absorbing water [35]. It is also confirmed that when this kind of weathered sand is directly mixed with river sand as plaster mortar, it is easy to crack in high humidity environment.

4.2. Element Composition. The elemental determination of weathered sand was carried out by means of the XRF test (X-ray fluorescence spectrometry), and the test results were expressed in the form of elemental oxides. After calculation and transformation, the contents of main elements in weathered sand are obtained, as given in Table 2. The content of Fe and Al in weathered sand is 8.7% and 9.8%, which is consistent with the high content of montmorillonite in weathered sand. As the main mineral composition of weathered sand is montmorillonite, the chemical composition of montmorillonite is mainly SiO$_2$, Al$_2$O$_3$, H$_2$O, Fe$_2$O$_3$, and MgO. Fe$_2$O$_3$ makes weathered sand reddish brown, and high content of aluminum makes it possible to become aluminothermic quick setting material.

5. Cement Mortar Strength Test

In view of the high content of aluminum element in weathered sand, the commercial accelerating agent is made of aluminum oxide clinker (that is, bauxite, soda ash, and quicklime fired in proportion to the clinker) by grinding. The cement mortar test will explore the performance of fine-grained weathered sand as a cement mortar accelerating agent.

Before the test, the weathered sand was baked to dry, and the fine particle group with particle size less than 0.075 mm was selected as building plaster to mix and build mortar sand, used to study the quick setting performance of the weathered sand fine particle group as building plaster. In the test, samples were prepared according to the proportion of M10 grade mixed mortar according to the specification for design of masonry mortar mix (JGJT98-2011) [36]. Conch P32.5 cement was used and river sand was standard medium sand. Four groups of parallel tests were conducted, and six cubic mortar samples were poured in each group, as shown in Figure 6. The sample size was 70.7 mm × 70.7 mm × 70.7 mm. The type and content of ash paste in each group were different: the type of ash paste in the first group was conch P32.5 cement; the second group of ash paste type is produced from the Anhuim market concrete accelerating agent, accelerating agent accounted for 16% of glue; the third group of ash paste was the fine group of weathered sand with particlesize less than 0.075 mm, which accounted for 16% of the glue ratio; and the fourth group was the fine group of weathered sand with particle size less than 0.075 mm, which accounted for 8% of the glue ratio. The composition of each group of mortar is given in Table 3.

According to the cement mortar strength test method (GB/T 17671-1999) [37], the unconfined compressive strength test was carried out on the standard sample of cement mortar after 7 days of curing. The strength test was carried out by the digital-controlled electrohydraulic servo testing machine RMT-150C mechanical test system developed by the State Key Laboratory of Geomechanics and Geotechnical Engineering. The displacement control
method was used in the test, and the loading rate was 0.002 mm/s. The strength test results are shown in Figure 7.

The unconfined compressive strength of all groups meets the design strength of M10 mixed mortar. Compared with the tests of groups 1, 2, and 3, the results show that the rapid setting effect of concrete with the accelerating agent and weathered sand fine particle group is significantly improved, and the compressive strength is basically unchanged, indicating that the weathered sand fine particle group can be used as plaster to build M10 mixed mortar. The weathered sand fine grain group can improve the early strength of cement mortar, its effect is better than commercial concrete accelerator, and the unconfined compressive strength is 7.5% higher than that of mortar mixed with the accelerator. Compared with the tests of groups 3 and 4, the 7-day unconfined compressive strength of mortar decreases when the content of fine-grained kaolinite weathered sand is increased and the content of cement is decreased, indicating that fine-grained kaolinite weathered sand cannot completely replace cement as cement mortar, and the proportion of fine-grained kaolinite weathered sand should be considered according to the strength grade of mixed mortar.

6. Conclusions

The main purpose of this study is to study the effect of kaolinite weathered sand as cement mortar accelerating agent, adding different proportions of weathered sand and accelerating agent and comparing their rapid setting effect and unconfined compressive strength. The test results show that weathered sand can be used as the accelerating agent of cement mortar. According to the test, the following conclusions can be drawn.

The kaolinite weathered sand is a kind of clay sand composed of montmorillonite and feldspar as the main minerals, and the content of montmorillonite is 35%. The content of fine groups in weathered sand is 23.7%, which is

| Group | Material proportion (g) |
|-------|------------------------|
| 1     | Cement 125, Standard 525, Water 85 |
| 2     | Cement 105, Standard 525, Accelerator 20, Water 85 |
| 3     | Cement 105, Standard 525, Sandy soil 20, Water 85 |
| 4     | Cement 115, Standard 525, Sandy soil 10, Water 85 |

Table 2: Main component element of sandy soil (%).

| Si    | Al  | Fe  | Mn  | Ca  | Mg  | Na  |
|-------|-----|-----|-----|-----|-----|-----|
| 23.00 | 9.80| 8.65| 3.48| 2.72| 2.12| 1.87|

Figure 6: Cement mortar samples.

Figure 7: Statistics of 7-day compressive strength of each group.
convenient for industrial screening and purification of montmorillonite.

The fine grain group in weathered sand can be used as an accelerating agent to add into cement mortar, which can improve the early strength of mortar; the effect is better than the commercial accelerating agent, but cannot completely replace cement as mortar.

Data Availability

All the experimental data have been shown in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] C. Du, G. Zhou, H. Wang, X. Chen, and J. Zhou, “Depth profiling of clay-xanthan complexes using step-scan mid-infrared photoacoustic spectroscopy,” Journal of Soils and Sediments, vol. 10, no. 5, pp. 855–862, 2010.

[2] S. M. Koh and J. B. Dixon, “Preparation and application of organo-minerals as sorbents of phenol, benzene and toluene,” Applied Clay Science, vol. 18, no. 3-4, pp. 111–122, 2001.

[3] F. Chivrac, E. Pollet, and L. Avérous, “Progress in nano-biocomposites based on polysaccharides and nanoclay,” Materials Science and Engineering: R: Reports, vol. 67, no. 1, pp. 1–17, 2009.

[4] Y. Yao, B. Gao, J. Fang et al., “Characterization and environmental applications of clay-biochar composites,” Chemical Engineering Journal, vol. 242, pp. 136–143, 2014.

[5] C. H. Hu, L. Y. Gu, Z. S. Luan, J. Song, and K. Zhu, “Effects of montmorillonite–zinc oxide hybrid on performance, diarrhea, intestinal permeability and morphology of weaning pigs,” Animal Feed Science and Technology, vol. 177, no. 1-2, pp. 108–115, 2012.

[6] D. Saxena and G. Stotzky, “Insecticidal toxin from Bacillus thuringiensis is released from roots of transgenic Bt corn in vitro and in situ,” FEMS Microbiology Ecology, vol. 33, no. 1, pp. 35–39, 2000.

[7] H. He, Y. Ma, J. Zhu, P. Yuan, and Y. Qing, “Organoclay prepared from montmorillonites with different cation exchange capacity and surfactant configuration,” Applied Clay Science, vol. 48, no. 1-2, pp. 67–72, 2010.

[8] P. Lv, C. Liu, and Z. Rao, “Review on clay mineral-based form-stable phase change materials: Preparation, characterization and applications,” Renewable and Sustainable Energy Reviews, vol. 68, pp. 707–726, 2017.

[9] S. Kazemian, A. Prasad, B. B. K. Huat, J. B. Bazaz, F. N. A. A. Aziz, and T. A. M. Ali, “Influence of cement - Sodium silicate grout admixed with Calcium chloride and kaolinite on Sapric peat/Saprogeniniu ˛ Durpiu ˛ Poveikis Cemento Ir Natrio Silikato Skiedinio Su Kalcio Chloridu Bei Kaolinitu Savybėms,” Journal of Civil Engineering and Management, vol. 17, no. 3, pp. 309–318, 2011.

[10] S. Kazemian, A. Prasad, B. B. K. Huat, T. A. Mohammad, and F. N. A. A. Aziz, “Stabilization of tropical peat by chemical grout,” Journal of the Chinese Institute of Engineers, vol. 36, no. 1, pp. 114–128, 2013.

[11] S. Kazemian, “Effect of different binders on settlement of fibrous peat,” Soil Mechanics and Foundation Engineering, vol. 52, no. 1, pp. 9–14, 2015.

[12] K. Scrivener, F. Avet, H. Maraghechi et al., “Impacting factors and properties of limestone calcined clay cements (LC3),” Green Materials, vol. 7, no. 1, pp. 3–14, 2018.

[13] S. C. Taylor-Lange, E. L. Lamon, K. A. Riding, and M. C. G. Juenger, “Calcined kaolinite-bentonite clay blends as supplementary cementitious materials,” Applied Clay Science, vol. 108, pp. 84–93, 2015.

[14] R. P. Borg, A. M. M. Hamed, R. Edreis, and A. M. Mansor, “Characterization of Libyan metakaolin and its effects on the mechanical properties of mortar,” IOP Conference Series: Materials Science and Engineering, vol. 442, no. 1, Article ID 012005, 2018.

[15] A. Mitrovic, M. Komljenevic, and B. Ilic, “Research of possibilities for use domestic kaolin clays for production of metakaolin,” Chemical Industry, vol. 63, no. 2, pp. 107–113, 2009.

[16] R. Hamzaoui, O. Bouchenafa, O. B. Maauoa, and S. Guesasma, “Introduction of milled kaolinite obtained by mechnasynthesis to cement mixture for the production of mortar: study of mechanical performance of modified mortar,” Powder Technology, vol. 355, pp. 340–348, 2019.

[17] Y. Fan, S. Zhang, S. Kawashima, and S. P. Shah, “Influence of kaolinite clay on the chloride diffusion property of cement-based materials,” Cement and Concrete Composites, vol. 45, pp. 117–124, 2014.

[18] D. Koch, “Bentonites as a basic material for technical base liners and site encapsulation cut-off walls,” Applied Clay Science, vol. 21, no. 1-2, pp. 1–11, 2002.

[19] Z. Kledynski, P. Falacinski, A. Machowska, K. Szarek, and K. Krysiak, “Hardening Slurries with Fluidized-Bed Combustion by-products and their Potential significance in Terms of Circular Economy,” Materials, vol. 14, no. 9, p. 2104, 2021.

[20] X. Xu, X. Liu, M. Oh, and J. Park, “Swelling capacity and hydraulic conductivity of polymer-modified bentonite under saline water conditions,” Applied Sciences, vol. 8, no. 7, pp. 1025, 2018.

[21] S. L. Garvin and C. S. Hayles, “The chemical compatibility of cement-bentonite cut-off wall material,” Construction and Building Materials, vol. 13, no. 6, pp. 329–341, 1999.

[22] H. Abbaslou, A. R. Ghanizadeh, and A. T. Amlashi, “The compatibility of bentonite/sepilite plastic concrete cut-off wall material,” Construction and Building Materials, vol. 124, pp. 1165–1173, 2016.

[23] Y. Xie, J. Li, Z. Lu, J. Jiang, and Y. Niu, “Effects of bentonite slurry on air-void structure and properties of foamed concrete,” Construction and Building Materials, vol. 179, pp. 207–219, 2018.

[24] C. Andrade, A. Martinez-Serrano, M. Á Sanjuán, and J. A. Tenorio Ríos, “Reduced Carbonation, Sulfate and chloride Ingress Due to the Substitution of cement by 10% Non-Precalcined bentonite,” Materials, vol. 14, no. 5, p. 1300, 2021.

[25] Y. Hu, L. Diao, Z. Lai et al., “Effects of bentonite on pore structure and permeability of cement mortar,” Construction and Building Materials, vol. 224, pp. 276–283, 2019.
[26] M. Liu, Y. Hu, Z. Lai et al., "Influence of various bentonites on the mechanical properties and impermeability of cement mortars," *Construction and Building Materials*, vol. 241, Article ID 118015, 2020.

[27] Q. Li, Z. Jia, and Y. Zhao, "Laboratory evaluation of hydraulic conductivity and chemical compatibility of bentonite slurry for grouting walls," *Environmental Earth Sciences*, vol. 80, no. 17, pp. 1–11, 2021.

[28] V. K. Karunaratne, S. C. Paul, and B. Šavija, "Development of nano-SiO2 and bentonite-based mortars for corrosion protection of reinforcing steel," *Materials*, vol. 12, no. 16, p. 2622, 2019.

[29] H. Ziari, R. Babagoli, M. Ameri, and A. Akbari, "Evaluation of fatigue behavior of hot mix asphalt mixtures prepared by bentonite modified bitumen," *Construction and Building Materials*, vol. 68, pp. 685–691, 2014.

[30] A. Zare-Shahabadi, A. Shokuhfar, and S. Ebrahimi-Nejad, "Preparation and rheological characterization of asphalt binders reinforced with layered silicate nanoparticles," *Construction and Building Materials*, vol. 24, no. 7, pp. 1239–1244, 2010.

[31] F. Zhou, J. Li, L. Zhou, and Y. Liu, "Preparation and mechanism of a new enhanced flocculant based on bentonite for drinking water," *Advances in Materials Science and Engineering*, vol. 2015, Article ID 579513, 8 pages, 2015.

[32] H. Liang, Z. Long, S. Yang, and L. Dai, "Organic modification of bentonite and its effect on rheological properties of paper coating," *Applied Clay Science*, vol. 104, pp. 106–109, 2015.

[33] National Standard Writing Group of the People's Republic of China, "Standard for Geotechnical Test Methods GB/T 50123-1999," 1999.

[34] National standard of the People's Republic of China, "Code for Geotechnical Engineering Investigation GB50021-2001," 2002.

[35] L. J. Goldman, L. I. Greenfield, A. S. Damle, G. L. Kingsbury, C. M. Northeim, and R. S. Truesdale, *Clay Liners for Waste Management Facilities: Design, Construction and Evaluation*, Noyes Data Corporation, Park Ridge, New Jersey, United States, January 1990.

[36] Ministry of Housing and Urban-Rural Development of the People's Republic of China, "Specification for Design of Masonry Mortar Mix JGJ/T98-2011," August 2011.

[37] National standard of the People's Republic of China, "Cement Mortar Strength Test Method GB/T 17671-1999," May 1999.