Experimental Performance of Filling Material with Modified Red Mud for Roadbed

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Abstract. Cement-modified red mud as roadbed filler was investigated through tests, including compaction, California Bearing Ratio (CBR), modulus of resilience (E0), unconfined compressive strength (UCS), and scanning electron microscopy. Optimum moisture content (ω0), maximum dry density(ρ_{dmax}), CBR, modulus of resilience, UCS, and microscopic characteristics of red mud were analyzed in different modified states. An optimal cement admixture for red mud modification was proposed. Results showed that (1) adding cement significantly improved CBR and modulus of resilience, (2) cement-modified red mud exhibited faster initial strength formation, with 7-day UCS over 65% of 28-day UCS, (3) water stability and frost resistance improved significantly with 4% and 6% cement dosing, (4) recommended cement admixture was 1.1% without adverse conditions, but not less than 6% with water immersion. Modified red mud is unsuitable for seasonal frozen regions. The recommended blending and leaching concentration met regulatory requirements, meeting technical, environmental, and economic goals for roadbed filler in highway construction.

Key words: red mud; roadbed; filling material; industrial solid waste; CBR; UCS; SEM

1. Introduction

Bayer red mud is the most discharged highly polluting industrial solid waste generated during the smelting of alumina[1-3]. For every 1 t of alumina produced, 1.1–1.8 t of red mud will be discharged. China's alumina production capacity accounts for 50.2% worldwide, and its share is still expanding; it discharges about 69.18 million tons of red mud annually[4,5], and a rough estimate of red mud accumulation in China indicates that it has reached 1.3 billion tons. Red mud particles are fine, uniform, and poorly graded. They exhibit poor water stability and are strong pollutants, and thus, they cannot be directly applied to engineering. At this stage, the method for dealing with red mud is primarily based on stockpiling in open air, which not only occupies a large portion of land, but also causes environmental problems, such as soil alkalization and surface water and groundwater pollution. In 2022, the "Opinions of the State Council on Supporting Guizhou to Break New Ground in the Development of Western China in the New Era" (Guo Fa [2022] No. 2) indicated "the implementation of phosphorus, manganese, red mud, coal gangue pollution special treatment, to promote phosphogypsum, manganese slag, and other harmless resource utilization technology research and engineering application demonstration." As China's focus on environmental protection increases, red mud has gradually become a bottleneck that limits the development of the alumina industry. The hazards of stockpiled red mud are becoming increasingly prominent, and research on resourceful and harmless red mud utilization is imminent. To promote the utilization of red mud, experts and scholars have been working together to solve the problem of red mud resource utilization.

In wastewater treatment, although red mud can remove harmful elements, such as cadmium, lead, zinc, and phosphorus, from wastewater[6-9], harmful components, such as radionuclides, contained in these elements are also dissolved in wastewater. Consequently, other processes are necessary for the secondary treatment of wastewater, and secondary treatment eventually requires occupying a landfill area. Hence, the amount of red mud is extremely limited. In waste gas treatment, using red mud to treat waste gas has outstanding environmental and economic benefits[10-12]. However, red mud in its natural state easily cakes, and thus, it should be dried and ground finely before it can be used. Ground red mud particles are extremely fine and easily cause pipe blockage.

Bauxite typically contains iron, titanium, gallium, and scandium, which are basically enriched in red mud during alumina production. The extraction of valuable metals from red mud is another means of recycling red mud. Experts and scholars have extracted valuable components from red mud, such as iron, titanium, aluminum, scandium, and other rare earth metals[13-16]. Although the extraction of valuable fractions from red mud is theoretically, technically, and programmatically achievable, extraction and recovery processes exhibit bottlenecks, such as complex processes, costly equipment requirements, or high overall costs, and thus, they are still unable to achieve industrialization. After refining trace valuable metals, red mud can still be stored only in piles, which cannot realize the requirements of reduction, harmlessness, and scale utilization of red mud. To realize the resource utilization of red mud, the key lies in the combination of technology, economy, and environmental protection. Considering its chemical composition and physical properties, red mud can be used as a raw material or admixture in the production of building materials. This application not only has a simple process, but it also involves a large amount of slag, which can considerably improve the comprehensive utilization rate of red mud. Therefore, scholars have used red mud as a raw material in cement production[17] and brickmaking raw material[18]. Red mud is also used as a modification material for silt[19], loess[20], pitch, and road construction materials. For example, cement, lime, and composite materials have been used as modifiers for road construction materials. Yang, Weigang et al.[21] used modified red mud as roadbed filler and found that the composite- modified red mud-filled roadbed exhibited better bearing capacity and water stability compared with using cement and lime. On the basis of indoor and field tests, Cheng Yu et al.[22] determined that using a cementitious curing agent with red mud can significantly improve its road performance. The indicators were better than the specification requirements, but the practical value of the cementitious curing agent was debatable because of its high admixture requirement and cost. Tan Hua.[23] reported that the leaching amount of harmful substances and radionuclide content of red mud from the Guangxi Pingguo Aluminum Company met the requirements of relevant norms and did not belong to hazardous solid waste. All of the road use indexes of this red mud satisfied the general requirements of norms. By adding different proportions of cement, fly ash, and silica fume with red mud from an aluminum mine in Luoyang as raw material, Wang Xiao et al.[24] prepared ordinary pavement cement using red mud treated with alkali washing method. By adding red mud to the cement, the content of C4AF in the base cement was increased, resulting in a 28-day flexural strength and compressive strength of 8.45 MPa and 53.2 MPa, respectively, thereby improving the performance of the base cement for pavement.In order to further study the radioactivity of the modified red mud, Wang Xiao et al.[25] mixed red mud, limestone, sandstone, and fly ash in certain proportions to obtain red mud-based cement. The red mud-based cement was then placed in a high-temperature electric furnace and maintained at 1400 ℃ for 30 minutes to obtain red mud-based clinker. The red mud-based clinker was subjected to radiological testing, and it was found that the emitted radiation levels were within the recommended safety limits of China's national standard GB6566-2010.Kushwaha et al.[26] conducted a study on the impact of different soil enzyme contents on the stability of red mud. The study found that adding soil enzymes can reduce the optimum moisture content of red mud and increase its maximum dry density. The optimal ratio of soil enzymes was found to be 4%, resulting in a significant improvement in CBR (California Bearing Ratio) and USC (Unconfined Compressive Strength), which increased by 580.9% and 578% respectively.

From existing research and practice results, problems still exist in the utilization of red mud resources, such as low slag use amount, high cost, and failure to promote large-scale applications. However, the amount of roadbed fill needed in municipal roads, highways, and other projects is large, and the requirements for roadbed fill are considerably more lenient compared with those for the preparation of concrete. In the development of red mud-based roadbed filler, the major physical and mechanical indicators examined are microscopic characteristics, bearing capacity, water stability, UCS, modulus of resilience, dynamic deformation modulus, deflection value, bending and tensile strengths, durability, and fatigue performance. The major chemical indicators are pH and leaching of harmful substances and radionuclide content. Cement, as the most common modifier, exhibits the advantages of low cost, easy access, and good modification effect. In this regard, the current study proposes the use of common cement-modified red mud as roadbed filler. Road performance tests, such as compaction test, California bearing ratio (CBR) test, and UCS test, are conducted to investigate the index problems of cement-modified red mud used as roadbed filler and help in the resource utilization of industrial solid waste.

2. Materials

The test materials used in this research were obtained from a red mud dump in Qingzhen City, Guizhou Province. The research found that the chemical composition of red mud from different origins differed significantly[27] The data in Table 1 show that the liquid and plastic limits of Qingzhen red mud are high, its plasticity index is moderate (14.17), and its natural water content (36.50%) is higher than its plastic limit. In the site, red mud under natural storage conditions exhibits a hard plastic state, low strength, and large compression. Its hydration activity is largely determined by the content of two oxides: CaO and SiO2. As indicated in Table 2, Qingzhen red mud contains 49.75% of the total mass of CaO and SiO2, the percentage of Luoyang red mud reaches 66.23%, and the percentage of Zibo red mud is only 23.27%. In addition, the contents of other chemical components, such as Fe2O3, Al2O3, and Na2O, also vary considerably. That is, the chemical components and physical indexes of red mud are not the same in each production area due to differences in head grade, production industry, production equipment, and other factors. Therefore, the modification scheme should be adapted to local conditions.

The cement used in the test was Conch brand 42.5# ordinary Portland cement produced by Guizhou Conch Panjiang Cement Co. The major chemical components and performance indicators are provided in Tables 3 and 4, respectively.

Table 1 Physical indicators of Bayer process red mud

Natural water content(ω)	Soil natural density(ρ)	Plastic limit	Liquid limit	Plasticity index	Free expansion(	Methylene blue
36.50%	1.89 g/cm3	35.26%	49.43%	14.17	6%	1.67

Table 2 Chemical composition of Bayer process red mud from different production areas

	CaO	SiO2	Fe2O3	Al2O3	Na2O	TiO2	MgO	SO3	K20
Qingzhen	31.12	18.63	14.42	13.72	13.35	4.83	2.8	0.91	0.22
Luoyang	40.88	25.36	11.29	7.48	3.19	1.72	2.12	—	1.04
Zibo	3.16	20.11	34.26	21.43	8.09	1.96	0.34	—	0.24

Table 3 Cement chemical composition

CaO	SiO2	Fe2O3	Al2O3	MgO	Na2O	TiO2	SO3	K20
65.41	21.82	3.58	5.06	1.56	13.35	4.83	0.91	0.22

Table 4 Major performance indicators of cement

Setting time (min)		Flexural strength (MPa)		Compressive strength (MPa)		Stability	Density(g/cm3)
Initial set	Final set	7 days	28 days	7 days	28 days	Pass	3.225
166	391	6.8	8.0	41.3	55.9		

3. Methods

3.1 Compaction Tests

The compaction test is a common method for determining the compaction characteristics of different types of soil in accordance with the Test Methods of Soils for Highway Engineering (JTG3430-2020). On the basis of the specifications for the heavy II-2 compaction test, red mud must be enclosed for 24 h before mixing it with cement . After the compaction test, the surface was scraped, and the moisture content of the sample was measured. Then, the compaction curve was drawn as shown in Fig. 1. The optimum moisture (ω_0) and maximum dry density (ρ_{dmax}) of the modified red mud with different cement contents were obtained. The results are presented in Fig. 2. The maximum point of the compaction curve characterizes the dry density of the specimen that reaches the maximum value under the optimum moisture condition.

As shown in Fig. 1, the trends of the compaction curves of raw and modified red mud (cement content: ≥6%) were more significant. A slight change in moisture content caused a large fluctuation in dry density, indicating that such modified red mud was highly absorbent. If applied to an actual project, then the inability to control moisture content accurately will lead to difficulty in controlling the compaction degree of the roadbed during construction, ultimately increasing construction difficulties.

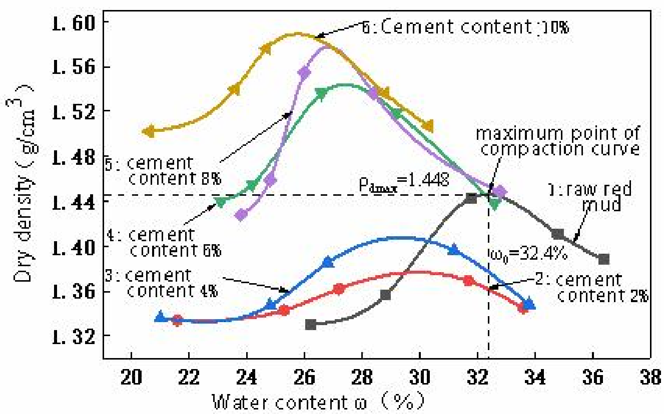

Fig. 1 Compaction curve of modified red mud with different cement contents

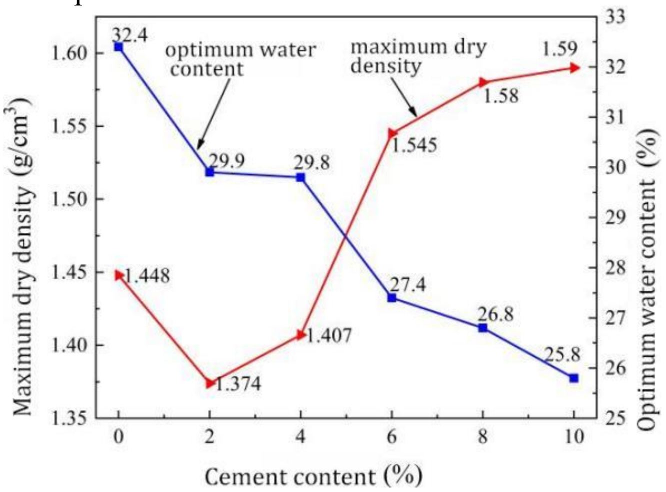

Fig. 2 ω_0 and ρ_{dmax} of red mud modified with different cement contents

When the amount of modified red mud cement was low (≤4%), the compaction curve was flat. The small floating range of moisture content exerted minimal effect on dry density. This result showed that the ratio of low-content cement (≤4%) could effectively improve the engineering properties of red mud. As depicted in Figure 2, the best moisture content of modified red mud decreased the fastest when cement content was within the range of 0% to 2%. However, when cement was within the range of 2% to 4%, optimal water content was only reduced by 0.1%, reflecting a rapid decrease in reduction rate. Then, optimal water content steadily decreased with an increase in admixture, and optimal water content was only 25.9% at 10% cement content, which was 6.5% lower than that of raw red mud. This phenomenon was attributed to the fact that the large amount of free Ca2+ generated during the hydration reaction of cement reduced the concentration of hydrophilic ions, such as Na+ and K+, in red mud via replacement, which, in turn, significantly decreased the optimal water content of the modified red mud. With an increase in cement content, the maximum dry density of the modified red mud exhibited a trend of initially decreasing and then increasing. When the content of cement reached 6%, the maximum dry density exceeded that of raw red mud primarily due to cement hydration products cementing the red mud together to form large particles of red mud calcium silicate polymer. However, voids existed between red mud calcium silicate polymer particles, decreasing the maximum dry density of the modified red mud. With a gradual increase in cement content, a large number of hydration products gradually filled the interparticle voids, and the dry density of the modified red mud gradually increased. When cement content reached 8%, the voids were filled, and thus, the maximum dry density of the modified red mud only increased by 0.01 g/cm3 when cement content reached 10%.

3.2 Cbr Tests

CBR is an index proposed by the California Department of Highways in 1942 for comparing the strength of materials. It is currently one of the most important indexes for evaluating the bearing capacity of roadbed soil under adverse conditions. CBR tests were performed in accordance with relevant test specifications (Fig. 3). After all the samples were tested, unit pressure (p) was used as the X-axis and penetration amount (l) was used as the Y-axis,. The curve was plotted by substituting the test data, as shown in Fig. 4.

Fig. 3 CBR tests

As shown in Fig. 4, the value of pressure increased slowly with an increase in penetration. After the penetration degree exceeded 4mm, pressure value no longer increased and the curve tended to be smooth. Sample bearing capacity reached the limit. At 2% cement content, the pressure value that can be withstood by the modified red mud increased sharply with an increase in penetration (OA section). When the penetration degree reached 3 mm, the value gradually decreased, and the curve tended to be smooth and reached the bearing capacity limit. At 4% cement content, the pressure value that the sample could withstand before the penetration degree reached 2.5mm (OB section) increased steadily with a high growth rate, and then decreased, but still kept growing at a high rate until penetration degree reached 5mm. That is, bearing capacity limit was not reached. This phenomenon was more evident after the cement content reached 6%, and the sample exhibited excess load capacity at this time. The greater penetration amount of 2.5mm and 5mm were defined in correspondence with the bearing ratio as the CBR value of a sample, as depicted in Fig. 5. Finally, the swelling of the sample with different cement reference amounts was measured via the water test, as shown in Fig. 6.

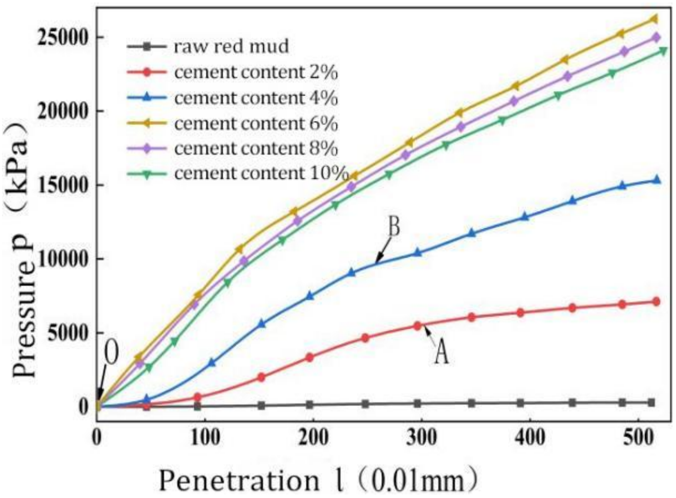

Fig. 4 p－l curves

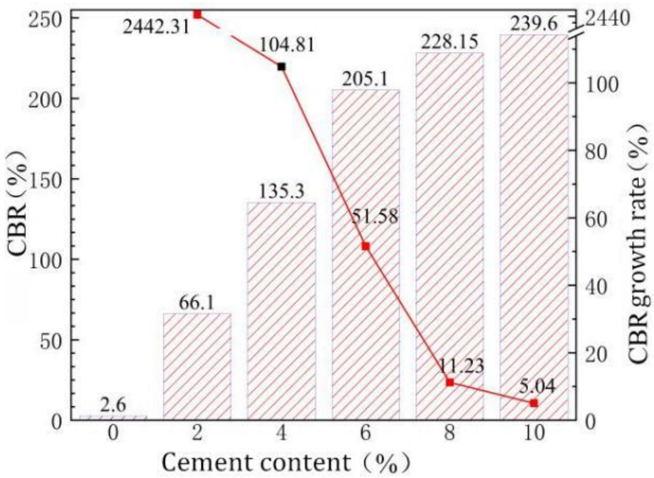

Fig. 5 CBR values of different cement contents

As shown in Fig. 5, the CBR of modified red mud increased sharply with an increase in cement content. The CBR value of modified red mud at 2% cement content increased sharply from 2.6% to 66.1%, which was 25.4 times that of raw red mud. When cement content was less than 8%, the increase in CBR value decreased with an increase in content, but still maintained growth with a large increase. The increase in CBR value dropped after cement content reached 8%, and only a small increase of 11.23% and 5.04% was observed when cement content reached 8% and 10%, respectively. Marginal benefit gradually decreased.

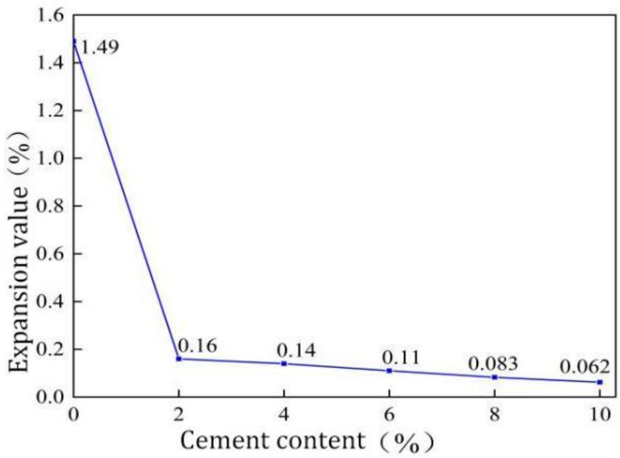

Fig. 6 Expansion of modified red mud with different cement contents

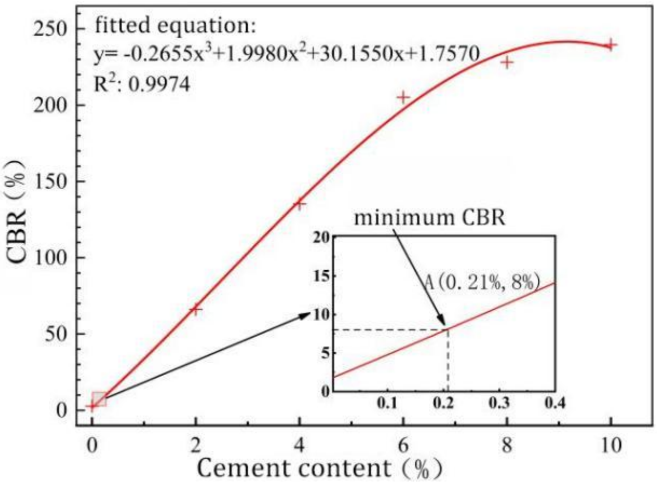

Fig. 7 Fitting curve of cement content and CBR value

As indicated in Fig. 6, the expansion rate of the raw red mud was 1.49% after soaking in water, while that of the modified red mud was 0.16% when cement content was 2%, i.e., only 10.74% that of the raw red mud. When cement content reached 4%, the expansion rate was less than 0.15%, i.e., no expansion occurred, indicating that the admixture of cement could effectively improve the anti-expansion of red mud. With cement content as the independent variable and CBR value as the dependent variable, test date should be fitted by using cubic spline interpolation. The fitted curve of cement content versus CBR value was plotted in Fig. 7.

As depicted in this figure, the slope of the fitted curve was maintained at around 30 when cement content was lower than 6%, and growth was maintained at a higher rate. The growth rate of the slope slowed down when cement content was over 6%, and the slope of the curve was only 2.462 when doping amount was 10%. The curve tended to be smooth. The Specifications for Design of Highway Substructure (JTG D30-2015) require minimum CBR values for roadbed fill on highways and primary roadbeds. The CBR value of the modified red mud was 8% at 0.21% cement content. Considering the limited data for fitting calculations, some errors will occur. Under the condition of ensuring safety, CBR was set in accordance with a safety factor of 1.3, and 10.4% was considered. Thus, the recommended cement content was 0.28%.

3.3 Modulus Of Resilience Tests

The modulus of resilience (E0) is the most direct indicator of the overall bearing performance of a roadbed. It is used to characterize the ability of a material to resist vertical deformation. This ability is related to the performance of the overlying structural layer under the action of traffic load. The modulus of resilience test was conducted in accordance with the Test Methods of Soils for Highway Engineering (JTG 3430-2020) (Fig. 8). The modulus of resilience of the modified red mud with different cement contents was calculated. The test results are presented in Fig. 9.

As shown in Fig. 9, the modulus of resilience of the raw red mud was only 11.72MPa. When cement content was 2%, the modulus of resilience rose to 125.87MPa. This result indicates that cement can effectively increase the compressive modulus of resilience of red mud and improve its engineering properties. However, the growth rate of the modulus of resilience of the modified red mud decreased significantly after cement content reached 4.0%. When cement content increased from 8.0% to 10%, the increase in modulus of resilience was only 4.4%, indicating that the effect of increasing cement content on improving modulus of resilience was insignificant. This finding is consistent with the CBR test result. When cement content is regarded as the independent variable and modulus of resilience is regarded as the dependent variable, the test date should be fitted using quadratic spline interpolation. The fitted curves of cement content and modulus of resilience are plotted in Fig. 10.

Fig. 8 Test diagram of resilient modulus

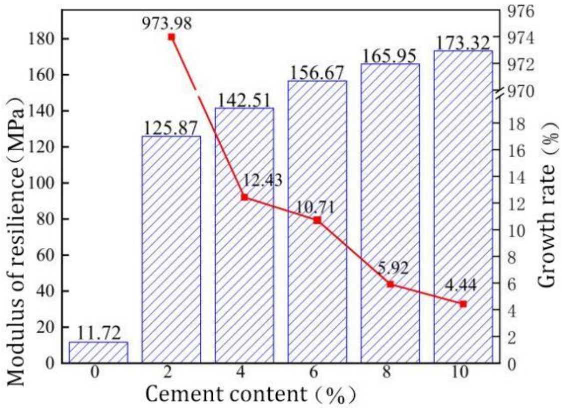

Fig. 9 Modulus of resilience of modified red mud with different cement contents

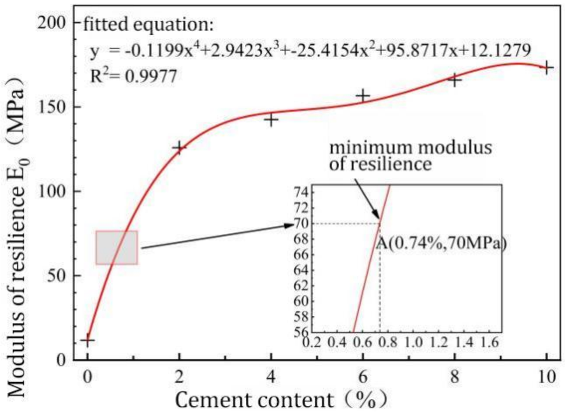

Fig. 10 Fitting curve of cement content and modulus of resilience

From Fig. 10, the modulus of resilience of the modified red mud reached 70MPa when cement content was 0.74%, meeting the minimum requirements of the Specifications for Design of Highway Asphalt Pavement (JTG D50-2017) for the modulus of resilience of the top surface of a very heavy traffic road base. The modulus of resilience was set at a safety factor of 1.3 due to the existence of errors in the fitting parameters, and the value of 91MPa was selected. Thus, the recommended cement content was 1.11%.

3.4 Ucs Tests

UCS is one of the most important indicators for evaluating the mechanical properties of roadbed filler. It reflects a material's destruction-resisting ability under the action of a vertical load, and it can visually reflect the strength characteristics of a material. The specimens were prepared in accordance with the relevant specifications, and specimen size was Class I (50 mm×50 mm). The UCS tests were conducted at different ages (7 days and 28 days) under the influence of adverse conditions, such as water immersion and the freeze–thaw cycle (Fig. 11). The experimental results are presented in Fig. 12. As shown in this figure, the use of cement as a modifier can rapidly enhance the UCS of red mud, and the 7th day compressive strength reached more than 65% that of the 28th day. With an increase in cement content, the 7th day and 28th day UCS of the modified red mud increased to different degrees. The highest increase was at 2% admixture, which increased by 119.9% relative to the raw red mud. Then, strength decreased to less than 15% with an increase in cement admixture. This finding was consistent with the results of the modulus of resilience and CBR tests. At the same curing time, the strength of the immersed and froze–thawed specimens compared with the non-immersed specimens presented several residual rates, which are characterized as the ratio of strength under the immersed and froze–thawed conditions to the corresponding strength under conventional conditions. Therefore, the residual rate of the strength of the modified red mud with different cement admixtures under immersed and froze-thawed conditions was plotted as shown in Fig. 13.

Fig.11 UCS test diagram

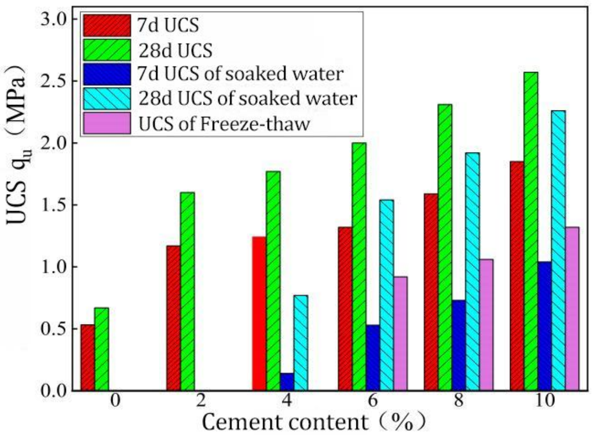

Fig.12 UCS of the modified red mud with different cement content

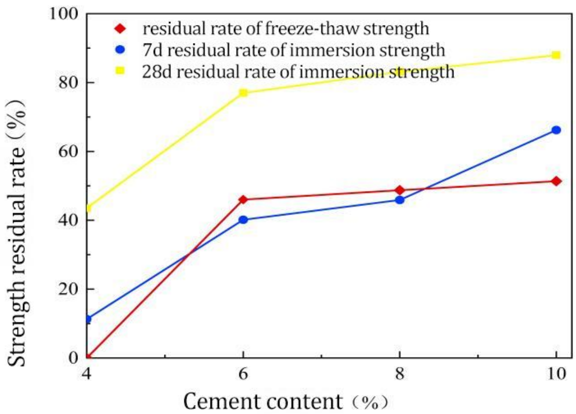

Fig.13 Residual rate of immersion and freezing-thwaing strength

Fig.14 Honeycomb sample after freezing and thawing

As shown in Fig. 13, the 7th day and 28th day specimens were damaged by soaking water when cement content was lower than 4% due to the low water stability of red mud. The strength residual rate of the modified red mud after soaking gradually increased with an increase in cement content after content exceeded 4%. The residual rate of the 7th day soaking strength was 11.29% when cement content was 4% and 66.22% when cement content was 10%. However, the residual 28th day immersion strength of the modified red mud with 6% cement content reached 77%, which was considerably higher than the residual 7th day immersion strength of 10% cement content (40.16%). This finding indicated that the water stability of the cement-modified red mud depended more on the curing time of the specimens than on cement content. The modified red mud specimens presented an alveolate structure after the freeze–thaw test (Fig. 14). When the cement admixture was less than 6%, the specimen was destroyed directly after soaking. When the cement admixture reached 6%, the froze–thawed specimen developed strength, but strength residual rate was only 46%. With an increase in cement admixture, strength residual rate slightly improved. When cement admixture was 10%, strength residual rate was 51.36%, which was only 5.36% higher than that of the cement admixture of 6%. This result showed that freezing–thawing damaged the specimens considerably, and the improvement effect was limited after increasing cement content. Therefore, using cement-modified red mud as roadbed fill is not recommended in frozen regions due to the freezing of capillary water in a low-temperature environment, causing the expansion a specimen's inner pore structure. When multiple pores penetrate, a cavity will be formed, resulting in a honeycomb-shaped specimen after freezing and thawing. Therefore, overall structural density decreased while strength dropped sharply.

3.5 Microscopic Features

The modified red mud with 6% cement admixture was taken and crushed after 28 days of curing. Representative specimens were selected to observe microscopic characteristics by using a scanning electron microscope. The results are presented in Fig. 15.

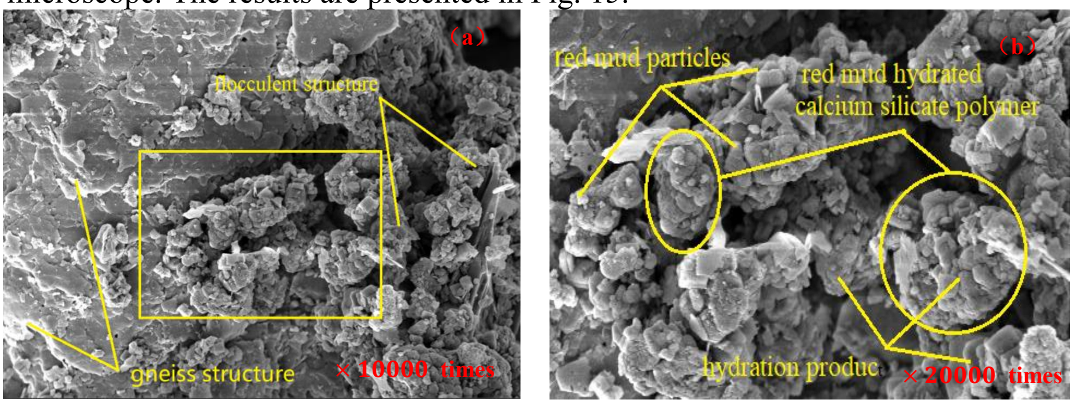

Fig.15 Microscopic morphology of solidified red mud

As shown in Fig. 15(a), the surface of the modified red mud was uneven under 10,000× scanning electron microscopy (SEM). The main body was gneiss-like, with a dense structure. The edges were partially raised and accompanied by cavities and fissures. Area b was selected for enlargement, as shown in Figure 15(b). At 20,000× SEM, the flocculent structure at the bulge in the previous text was largely formed by the aggregation of multiple large particles. The reason for this phenomenon is as follows: after mixing into cement, cement hydration occurred, and the hydration products firstly bonded a large number of red mud particles together to form red mud hydrated calcium silicate polymer. Then, a large number of polymers combined into a whole. However, a red mud curing body still existed inside a large number of voids and holes. However, the main structure of the curing body was dense, and the hydration product exhibited extremely high strength. Hence, the strength of the modified red mud cured body was considerably enhanced after mixing with cement.

3.6 Environmental Impact Of Modified Red Mud

Modified red mud with a cement admixture of 2% was used as the object of study, and water samples were prepared for detecting various hazard ingredients in red mud in accordance with the Identification standards for hazardous wastes-Identification for extraction toxicity (GB5085.3-2007). The test results are provided in Table 5.

Table 5 Toxic leaching results of modified red mud

Test project	Pb	Cd	T–Cr	As	V	Cr^{6+}	Fluoride
Hazardous waste limit (mg/L)	≤5	≤1	≤15	≤5	≤—	≤5	≤100
Raw red mud (mg/L)	1.10	1.10	12.69	0.0037	20.34	＜0.002	0.16
Cement 2% (mg/L)	0.31	0.24	8.52	0.0016	12.65	0.002	0.2

As indicated in Table 5, the leaching concentration of cadmium in the raw red mud was 1.1 mg/L, which was greater than the specification limit value of 1.0 mg/L. Therefore, red mud was classified as hazardous solid waste and could not be directly applied to roadbed filling. When the cement mixture of the modified red mud was 2%, it could effectively cure lead and arsenic in red mud. The solidification rate could reach more than 56%, but the curing effect on total chromium and vanadium was extremely limited. Curing rate did not exceed 50%. For example, the curing rate of total chromium was only 32.86%. However, the leaching concentrations of all harmful substances of the modified red mud were lower than the specification limit. Hence, the modified red mud was classified as a general solid waste that met the environmental protection technical index of filling road base. This result is attributed to the fact that although the strength of cement-modified red mud is forming and developing, the colloidal structure formed by hydration and the gel structure formed by alkali excitation combine to form a network-like junction. Some heavy metal ions are sequestered inside the gel via the encapsulation effect. In addition to the aforementioned encapsulation and sequestration in ionic form, the alkaline environment can also induce Cr3+ and Cd2+ to generate Cr(OH)3 and Cd(OH)2, and Pb2+ and dissolved silicon phase to generate Pb3SiO5, which is encapsulated and sequestered in the gel as a solid precipitate. Moreover, harmful ions, such as As, Sr, Cs, and Mo, are combined with hydrates through chemical bonding. They enter the polymer network and play a role in electrovalent balance. They are sequestered via chemical bonding combination, inhibiting the leaching of toxic and harmful substances from red mud.

4. Conclusions

Cement-modified red mud can be used as roadbed filler. Cement can effectively improve the CBR value, modulus of resilience, and other road indicators. When cement dosing is 2%, the modified red mud CBR value and modulus of resilience can reach 66.1% and 125.87 MPa, respectively, which are considerably better than the specification requirements.

A lower cement admixture (≤4%) can effectively reduce the sensitivity of red mud dry density to moisture content, improving its engineering performance and reducing construction difficulty.

When freezing–thawing and water immersion are not considered, the best dose of cement is recommended as 1.1%. When water immersion is considered, the dose should not be less than 6%. The freezing resistance of cement-modified red mud is ineffective, and it is not recommended to be used as roadbed filler in seasonal frozen regions.

The strength formation mechanism of the cement-modified red mud is as follows: cement hydration products and red mud particles form red mud and hydrated calcium silicate polymer. The polymer is linked and filled by hydration products to improve overall compactness, increasing the strength of the modified red mud.

The admixture of cement can effectively stabilize and solidify harmful metal ions and nonmetallic compounds in red mud. When the admixture of cement is 2%, the leaching concentration of harmful substances is reduced to below the limit value of hazardous waste, meeting the environmental protection technical index of filled roadbed.

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