Experimental study on the application of red mud to controlled low strength material made of excavated soil

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Abstract. To improve the resource utilization of solid waste, excavation abandoned soil and red mud, a by-product of alumina industry, were introduced into the preparation of controlled low strength material (CLSM). By carrying out the flowability test, bleeding test and compressive strength test, the relationship between properties of CLSM mixture and the amount of red mud was analysed. The experiment results indicate that the flowability and bleeding rate of the mixture decrease with the increase of red mud content. When the red mud content is less than 20%, the mixture shows good flowability. The addition of red mud can accelerate the completion time of bleeding and play a positive role in the bleeding stability of the mixture. When the red mud content is 10%, the strength of the mixture reaches the maximum, while the strength of the mixture with other contents decreases with the increase of red mud content. For the CLSM made of excavated soil, red mud has a good application prospect in terms of bleeding stability and strength.

1. Introduction
To solve the situation that the backfill compaction degree does not meet the engineering requirement, North American countries have adopted a fluid backfill material in pipe trench engineering since the 1990s. This material is defined as a controlled low-strength material by the American Concrete Institute (ACI) (Controlled low strength material, CLSM) [1]. Compared with traditional fillers that require layered compaction, CLSM is easy to mix and backfill because of its self-leveling characteristics, and it can flow into parts that are difficult to reach with traditional materials. At the same time, the use of CLSM can achieve the purpose of saving resources, shortening the construction period and controlling the strength of the structure, reducing the difficulty of excavation for future maintenance work. Conventional CLSM mainly consists of cementing material, aggregate, admixture and water. Compared with cement mortar, CLSM is very similar in composition, but it does not have high requirements for raw materials. Related research has used construction waste [2], slag [3], red mud [4-5], phosphogypsum [6] and other wastes to prepare CLSM mixtures, and satisfactory results have also been achieved in this area. Wang et al. tried to produce CLSM by partially replacing aggregate with alum sludge [7]. Xiao et al. successfully made CLSM based on the pozzolanic reaction between waste glass powder and hydrated lime [8]. Mahamaya et al. developed a new type of CLSM using ferrochrome slag as the base material with cement and fly ash as binding material [9]. In recent years, in order to solve the environmental pollution and resource waste problems caused by excavated soil waste, relevant scholars have begun to introduce spoiled soil into the preparation of fluidized
materials. In addition to self-compacting properties, the new fillers also show certain advantages in bearing capacity [10].

In the aluminum smelting industry, about 2 tons of red mud are discharged for every 1 ton of alumina produced, making red mud grow at a rate of 120 million tons per year globally. The red mud contains not only a large amount of SiO$_2$, Al$_2$O$_3$, and Fe$_2$O$_3$, but also a large amount of calcium silicate. The author applied red mud in the fluidization treatment of silt in the early stage, and obtained satisfactory test results [11]. Therefore, in order to improve the resource utilization rate of industrial solid waste, this paper replaces part of cement with red mud and applies it to the fluidization treatment of excavated soil. Through flowability test, compressive strength and bleeding test, the effect of red mud on the performance indicators of mixture is discussed.

2. Raw materials and test method

2.1. Raw materials

The test soil was taken from the excavation soil in the Jinan East Station area. Standard screening test was conducted on soil samples, and the particle size distribution was shown in Table 1, in which particles with particle size less than 0.075 mm accounted for 98.3% of the total weight of soil samples. The liquid limit $\omega_L=46.28\%$, plastic limit $\omega_P=24.66\%$, and plasticity index $I_p=21.62$ were obtained through the limit water content test. The soil sample is low liquid limit clay. Portland cement (P.O 42.5) was used in the test with a specific surface area of 1.3 m$^2$/g. The red mud is taken from the red mud storage yard of the Weiqiao Group in Binzhou City, with a specific surface area of 13.6 m$^2$/g. The test water is clean tap water. The main chemical components of raw materials are shown in Table 2.

2.2. Test program

The mixture must have good flowability, which is a necessary condition for the flowability filler to have self-leveling function. Therefore, the water-solid ratio and the cement-water ratio should be determined based on the flowability index in the design of the mix ratio scheme, where the water-solid ratio (W/S) is the ratio of the mass of water and solid materials, and the cement-water ratio (C/W) is the ratio of the mass of cement and water.

According to ASTM D 6103 [12], the classification standard of flowability ($f$) is: $f<150$ mm, low flowability; 150 mm $\leq f \leq 200$ mm, conventional flow; $f>200$ mm, high flowability. Preliminary research results show that for soil-based fluid backfill materials, when 180 mm $\leq f \leq 300$ mm, the flowability of the mixture is suitable for engineering application [13-14]. On the basis of this, the basic mix ratio of the mixture was first determined through flowability test. The water-solid ratio was 0.4, 0.5, 0.6 and 0.7, and the corresponding cement-water ratio was 0.3, 0.4, 0.5, 0.6 and 0.7 for each water-solid ratio. The test results were shown in Figure 1.

| Pore diameter (mm) | Separate sieve residual soil quality (g) | Percentage of sieve residue (%) | Cumulative percentage of screening (%) | Passing rate (%) |
|-------------------|----------------------------------------|---------------------------------|----------------------------------------|-----------------|
| 2                 | 0.50                                   | 0.25                            | 0.25                                   | 99.75           |
| 0.075             | 2.90                                   | 1.45                            | 1.70                                   | 98.30           |
| Sieve bottom      | 196.60                                 | 98.30                           | 100.00                                 | -               |

| Raw materials | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | CaO | Na$_2$O | MgO | MnO | K$_2$O | TiO$_2$ |
|---------------|--------|-------------|-------------|-----|---------|-----|-----|--------|---------|
| Portland cement | 20.41  | 7.59        | 3.34        | 61.35 | 0.32    | 2.07| 0.10| 0.95   | 0.67    |
| Red mud       | 16.70  | 16.31       | 22.65       | 16.15 | 5.12    | 1.37| -   | 1.23   | 3.54    |
In this study, the mass ratio of water to solid and cement to water was 0.6, 0.5. Five combinations of different mix ratios were designed (shown in Table 3), and the proportion of red mud replacing cement was 0, 5%, 10%, 15%, 20%, represented as R-0, R-5, R-10, R-15, R-20, respectively.

![Figure 1. Flowability at different mix ratio.](image)

| Number | Proportion (%) | Red mud (g) | Cement (g) | Water (g) | Clay (g) |
|--------|---------------|-------------|------------|-----------|----------|
| R-0    | 0             | 100         | 0          | 360       | 720      | 840      |
| R-5    | 5             | 95          | 18         | 342       | 720      | 840      |
| R-10   | 10            | 90          | 36         | 324       | 720      | 840      |
| R-15   | 15            | 85          | 54         | 306       | 720      | 840      |
| R-20   | 20            | 80          | 72         | 288       | 720      | 840      |

2.3. Test method

Based on different mixing ratio, the raw materials are mixed in a mortar mixer. First, mix the mixture for 1 min without water, then add water and mix for 2 min. After mixing, let it stand for 1 min.

The flowability test is performed following the procedures of ASTM D 6103 [12]. The cylindrical mold size is φ75×150 mm. Place the cylindrical mold filled with the mixture on the glass plate, slowly lift it within a specified time, and measure the diameter of the circle formed by the mixture, which is the flowability of the mixture.

The bleeding rate was tested according to ASTM C 232 [15] with a barrel size of φ150×150 mm. Measure regularly the accumulated effluent on the mixture surface until two consecutive readings indicate no further bleeding.

In the unconfined compressive strength test, cube blocks of 70.7 mm were used, and the mixture was poured into the test mould without vibration. After 24 h, the mould was released, and the molded test blocks were put into the standard curing room for the required time. Then, the strength of the mixture at the age of 7 d, 14 d and 28 d was measured respectively.

3. Results and discussion

3.1. Flowability

The relationship between red mud content and the mixture flowability is shown in Figure 2. It can be seen that as the proportion of red mud in the mixture increases, the flowability of the mixture continues to decrease. The corresponding flowability of R-0, R-5, R-10, R-15 and R-20 are 237 mm, 218 mm, 204 mm, 196 mm and 190 mm, respectively. When the mass ratio of red mud replacing
cement increases from 0 to 20%, the flowability of the compound is reduced by 20%, but it can meet the minimum requirements for flowability [13].

3.2. Bleeding
When the mixture is standing still, the large solid particles in it begin to sink, and the free water floats to the surface, forming a bleeding phenomenon. The bleeding rate is used characterization was performed, where the bleeding rate is the ratio of the volume of bleeding water to the initial volume of the mixture.

Figure 3 shows how the bleeding rate of the mixture changes over time. It can be seen from Figure 2 that the bleeding rate of all the mixtures increases with time, and the bleeding rate of the control mixture (R-0) is the largest. After replacing part of the cement with red mud, as the amount of red mud increases, the bleeding rate of the mixture shows a decreasing trend. The control mixture had very little bleeding after 180 minutes, and bleeding was basically completed. Replace part of the cement with red mud. When the amount of red mud exceeds 10%, the bleeding completion time of the mixture is 120 minutes. The test results show that adding red mud can reduce the bleeding rate of the mixture and speed up the bleeding completion time.

Figure 2. Effect of red mud content on flowability.

![Figure 2](image)

Figure 3. The change of bleeding rate with time.

![Figure 3](image)

Figure 4. The bleeding rate of the mixture at 2h.

![Figure 4](image)

Previous studies have shown that if the bleeding rate of the mixture within 2 h is less than 5%, the fluidized backfill material is considered stable [16]. Figure 4 shows the bleeding rate of different types of mixtures at 2 h. The bleeding rate of the control mixture at 2 h is 5.84%, which does not meet the stability requirements. When red mud is used to replace cement, the bleeding rates of R-5, R-10, R-15,
and R-20 are 4.95%, 4.28%, 3.90% and 3.46%, respectively. It can be seen that when the mass ratio of red mud to replace cement is greater than 5%, the mixture can meet the stability requirements.

3.3. Strength characteristics

Figure 5 shows the relationship between the compressive strength of the mixture and the curing time. As the time increases, the compressive strength gradually increases. The strength of the control mixture (R-0) at 14 d and 28 d was 1.24 times and 1.80 times the strength of the 7 d time, the average strength of the red mud mixture at 14 d and 28 d was 1.31 and 1.92 times the strength of the corresponding 7 d. When red mud is used to replace cement, under the same time, the strength value of R-10 mixture exceeds the strength of the control mixture (R-0), while the strength of the red mud mixture under other admixtures is lower than that of the control mixture of.

The compressive strength of the mixture with different red mud content is shown in Figure 6 at 28 days. The compressive strengths of R-5, R-10, R-15, and R-20 are respectively 96%, 122%, 93% and 89% of the compressive strength of the control group (R-0, 4.5 MPa). It shows that when red mud is used to replace 10% of cement, the compressive strength of the prepared mixture is the largest. This may be due to the presence of more alkaline substances such as Na₂O and CaO in the red mud. The alkaline environment formed at an appropriate amount can further stimulate the hydration of the cement. At the same time, the mineral composition of red mud contains a large part of calcium silicate, and these factors may promote the increase of the strength of the mixture.

4. Conclusions

In this paper, excavated soil is used to produce controlled low-strength material, and industrial solid waste red mud is introduced into the mixture to replace part of cement. The effect of red mud content on the performance of CLSM mixture was studied by analyzing the working and mechanical properties of the mixture.

Due to the large specific surface area of red mud, with the increase of red mud content, the water absorption of the mixture will increase, so the fluidity of the mixture is continuously reduced. From the point of view of meeting the minimum requirement of fluidity (180 mm), the mixture shows good fluidity under the condition that the red mud content is no more than 20%.

When the red mud substitute cement content is less than 5%, the bleeding rate of the mixture within 2 hours does not meet the stability standard. With the increase of red mud content, the bleeding rate of the mixture decreases continuously, and the addition of red mud can also accelerate the completion time of bleeding, which plays a positive role in the stability of the mixture.

The alkaline environment brought by red mud can stimulate the hydration of cement under appropriate conditions. When the red mud substitute cement content is 10%, the strength of the
mixture is the largest, which is higher than that of the control mixture. However, the strength of the mixture under other conditions decreases with the increase of red mud content.

Acknowledgments
The authors would like to acknowledge the support from the China Postdoctoral Science Foundation funded Project [Project No. 2019M652302]. Meanwhile, great appreciation goes to the editorial board and the reviewers of this paper.

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