Study on Preparation and Performance of Fly Ash Used in Clay Fluidized Backfill Materials

Xianghui Kong*, Xiaohua Yu and Yanna Zhao
Jinan Rail Transit Group Co., Ltd., 5 Jiefang East St., Jinan, China
Email: kongxh@sdjzu.edu.cn

Abstract. The problem of insufficient compaction of traditional fillers is difficult to solve in the backfilling project. It is a new solution to prepare backfill materials with self-leveling and self-compacting properties by using excavated clay, cement and water as raw materials. Adding fly ash to the backfill materials to replace part of the cement can effectively improve the utilization of industrial waste. Through a series of laboratory tests, the fluidity, bleeding and compressive strength of the mixture were studied respectively, and the influence of fly ash content on the performance of the mixture was preliminarily grasped. The test results show that the increase of fly ash content can reduce the fluidity of the mixture. Compared with the strength of the mixture without fly ash, when the amount of fly ash replacing cement is less than 10%, the strength of the mixture increases, and when the amount of fly ash replacing cement is more than 15%, the strength of the mixture decreases.

Keywords. Backfill materials; clay; fly ash; fluidity; compressive strength.

1. Introduction
The continuous development of the city has led to a sharp expansion of its space demand. In order to solve the problem of limited urban space resources, underground space can be used as the main carrier of urban infrastructure. The development of underground space mainly includes urban underground passages, urban subways and tunnels, commercial facilities and comprehensive disaster prevention construction. In most of the emerging cities, the workload of new construction, reconstruction and maintenance of pipelines is relatively large, resulting in frequent excavation of urban roads. Traditional excavation backfill projects usually use sand or gravel material with good compaction performance, and then mechanically compacted to achieve the specified compaction and strength of the backfill. However, due to the relatively small construction operation space in the excavation area, there is a dead angle at the interface with the structure. When the compaction quality of the backfill cannot be guaranteed, non-coordinated and discontinuous deformation will occur between the backfill site and the original area, resulting in uneven settlement or fracture. Therefore, road damage and other adverse conditions often appear, jeopardizing the driving environment, and if the second maintenance is carried out, the cost of construction will rise [1].

In order to effectively solve the problem of insufficient compaction in the backfilling project, the backfill materials need to have the characteristics of self-leveling and self-compacting. The American Concrete Association (ACI) defines this material as a Controlled Low Strength Material (CLSM), also known as a fluid backfill material [2]. Conventional CLSM consists primarily of binder (cement), aggregate (sand), water, and additives. In terms of the constituent materials, CLSM is similar to general cement concrete or cement mortar, but the technical requirements of the material for raw materials are far less strict than concrete or mortar. Many industrial wastes that cannot be used by
Concrete or mortar can become the raw materials of CLSM. Relevant scholars at home and abroad have introduced wastes into the preparation of backfill materials such as construction waste, bottom ash, slag, sludge, coal gangue, red mud and foam particles [3-9].

Fly ash is the main solid waste discharged from coal-fired power plants. The main oxide composition of fly ash in thermal power plants in China is: SiO$_2$, Al$_2$O$_3$, FeO, Fe$_2$O$_3$, CaO, TiO$_2$ and so on. Fly ash is an artificial pozzolanic mixture material with little or no hydraulic gelling properties, but when it is present in powder form, it can be used at room temperature, especially under hydrothermal treatment (steam curing). Calcium hydroxide or other alkaline earth metal hydroxide chemically reacts to form a compound having hydraulic gelling properties, which is a material that increases strength and durability. For example, adding fly ash to concrete not only saves cement and fine aggregate, but reduces water consumption, and improves the workability of concrete mixture.

2. Raw Materials and Test Methods

2.1. Raw Material

The raw materials used to prepare the fluidized backfill material include: excavated clay, cement, fly ash and water.

2.1.1. Excavated Clay. The clay is selected from the excavation soil in a certain area of Jinan, as shown in figure 1. It is a kind of soil with little sand, sticky, good plasticity, and water does not easily pass through. The general clay is formed by the weathering of silicate minerals on the surface of the earth, which is generally plasticity, bonding and thixotropic properties. In this study, the selected clay was subjected to a standard screening test. The particles with a particle size greater than 0.075 were recorded (table 1). The plastic index, liquid limit and plastic limit of the clay were 21.61, 46.276 and 24.659.

![Figure 1. Clay.](image)

| Pore size (mm) | Separate sieve residual soil quality (g) | Percentage of sieve residue (%) | Cumulative percentage of screening (%) | Passing rate (%) |
|---------------|----------------------------------------|-------------------------------|---------------------------------------|-----------------|
| 2             | 0.5                                    | 0.25                          | 0.25                                  | 99.75           |
| 0.075         | 2.9                                    | 1.45                          | 1.7                                   | 98.3            |
| Sieve bottom  | 196.6                                  | 98.3                          | 100                                   | -               |

2.1.2. Cement, Fly Ash and Water. The cement used in the test was P.O 42.5 ordinary Portland cement produced by Shandong Donghua Cement Co., Ltd., and its specific surface area was 0.34 m$^2$/g. The fly ash used in this test was Class F grade II which was from a coal-fired power plant. The test water is tap water.
2.2. Experimental Program
The test scheme includes working performance test and mechanical performance test. The working performance test mainly discusses the influence of the amount of clay and fly ash on the fluidity and bleeding rate of the backfill material, and finds the optimal amount of clay and fly ash. The mechanical performance test discusses the relationship between compressive strength and mix proportion. Under the conditions of W/S=0.5 (W/S, mass ratio of water to solid materials) and C/W=0.6 (C/W, mass ratio of cement to water), six groups of different mix proportion were designed, as shown in table 2. F-0, F-5, F-10, F-15, F-20, F-25 indicate that the proportion of fly ash instead of replacement cement is 0, 5%, 10%, 15%, 20%, 25%, respectively.

| No. | Fly ash to cement (%) | Fly ash (g) | Cement (g) | Water (g) | Clay (g) |
|-----|-----------------------|-------------|------------|-----------|----------|
| F-0 | 0                     | 100         | 0          | 330       | 550      | 770      |
| F-5 | 5                     | 95          | 16.5       | 313.5     | 550      | 770      |
| F-10| 10                    | 90          | 33         | 297       | 550      | 770      |
| F-15| 15                    | 85          | 49.5       | 280.2     | 550      | 770      |
| F-20| 20                    | 80          | 66         | 264       | 550      | 770      |
| F-25| 25                    | 75          | 82.5       | 247.6     | 550      | 770      |

2.3. Test Method

2.3.1. Mixture Mixing. The clay was first dried in an oven to a constant weight, then the dried clay was sieved (4.75 mm) to remove large pieces. According to the design mix proportion, the mixture was mixed with a cement mortar mixer, and the first mixing amount was preferably 1/3 of the total volume of the container. Firstly, the dry mixture was stirred for 60s without adding water to ensure uniform distribution. Secondly, water was added, and the mixture was mixed for 60s at a low speed, then for 30s at a high speed, and then stood for 60s at last.

2.3.2. Specimen Preparation. The mixture was filled into the test mold at one time, and the test specimen was molded by casting without vibration, covered with a plastic film on the test specimen. After scraping and plastering for 24h before the final setting of the mixture, the specimen was demoulded. After molding, the specimen was put into a thermostat with a temperature of 20±2°C and relative humidity of more than 95% until the required age.

2.3.3. Fluidity Test. The fluidity was measured in accordance with the procedure of ASTM D 6103 (Test Method for Flow Consistency of Controlled Low Strength Material) [10]. The standard stipulates that the plastic cylindrical mold with the upper and lower openings is placed on the glass plate, the plastic cylinder is filled with the fresh backfill material slurry, and then the plastic bucket is slowly lifted within 5s to allow the slurry to spread freely on the plane. When the slurry stops flowing, the diameter of the formed round pancake slurry is measured in two orthogonal directions. The average of its diameter is defined as the fluidity of the material. Figure 2 shows the tools and processes required for the fluidity test.

2.3.4. Bleeding Rate Test. The bleeding rate test was carried out in accordance with the procedures of ASTM C 232[11]. φ150x150 mm cylindrical mold was filled with a fresh mixture and covered with a plastic film to prevent evaporation. The amount of water discharged from the surface area of the mixture was recorded until two consecutive readings showed no further bleeding. Within 60min, absorb water once every 30min, record the water absorption; 60~120min stage, absorb water once
every 60min, record the water absorption; after 120h, absorb water once (according to the actual bleeding situation, the interval can be adjusted). The rate of bleeding is expressed as a percentage of the volume of the secreted water as a percentage of the initial volume of the mixture. The fluidized backfill material is considered to be stable when the bleeding rate of 2h is less than 5% by volume. Figure 3 shows the container and process used in the bleeding rate test.

![Figure 2. Fluidity test.](image)

![Figure 3. Bleeding rate test.](image)

![Figure 4. Compressive strength test.](image)

2.3.5. *Unconfined Compressive Strength Test*. The strength of the mixture at 7d, 14d and 28d was measured using a compression tester, and the loading rate was 1 mm/min. Figure 4 shows the press used for the unconfined compressive strength test.

3. Test Results and Discussion

3.1. Fluidity

Figure 5 shows the effect of fly ash content on the fluidity of the mixture. It can be seen that as the percentage of fly ash replacing cement increases, the fluidity of the backfill material decreases. In general, the fluidity of the mixture suitable for fluidized backfill is between 170mm and 210mm [12]. The fluidity corresponding to F-0, F-5, F-10, F-15, F-20, and F-25 is 230mm, 210mm, 180mm, 176mm, 170mm, 166mm, respectively. The quality of cement replaced by fly ash increased from 0 to 25%, and the fluidity of the mixture decreased by 27.8%. The addition of fly ash can reduce the fluidity because the unburned carbon particles of fly ash are loose and porous, which can absorb water and easily form a skeleton structure in the mixture. Fly ash itself has no gel properties, but in the presence of water, the oxides can chemically react with calcium hydroxide or other alkaline earth metal oxides to form hydrogel-forming compounds that increase strength and durability.

3.2. Bleeding

During the casting process and the curing stage, the solid large particulate material in the mixture moves downward under the action of gravity. As the large particles sink, the water and air in the backfill material float, resulting in a change in strength and a decrease in the filling volume. The application scenario of clay fluidized backfill material is the backfill of pipe trench. The bleeding of
the mixture will cause the change of the pipeline position and affect the backfilling quality. Because the fluidity of the fluidized backfill material is higher, the higher fluidity is accompanied by a higher water-solid ratio, so the bleeding rate should be higher than other cement mixtures. However, in this study, the main mixture has clay in addition to cement and water. The clay accounts for one quarter or more of the total mass of the mixture. Due to the special physical and chemical properties of the clay, it is presumed that the bleeding rate of the mixture will be small. The bleeding rate test was carried out in accordance with the procedure of ASTM C 232, and the bleeding rate is expressed as a percentage of the volume of the secreted water as a percentage of the initial volume of the mixture. The fluidized backfill material is considered to be stable when the bleeding rate of 2h is less than 5% of the initial volume. The results of the bleeding rate test are shown in table 3.

![Figure 5. Effect of fly ash content on fluidity.](image)

**Table 3. Results of bleeding rate test.**

| No. | Water-solid ratio | Cement-water ratio | Cumulative bleeding at different times (ml) |
|-----|-------------------|-------------------|--------------------------------------------|
|     |                   |                   | 30min | 60min | 120min | 12h  |
| F-5 |                   |                   | 0.10  | 0.20  | 0.25   | 0.25 |
| F-10| 0.5               |                   | 0.30  | 0.40  | 0.40   | 0.40 |
| F-15| 0.5               | 0.6               | 0.25  | 0.35  | 0.35   | 0.35 |
| F-20|                   |                   | 0.20  | 0.3   | 0.30   | 0.30 |
| F-25|                   |                   | 0.18  | 0.27  | 0.27   | 0.27 |

According to the formula of bleeding rate, the bleeding rate of all the test pieces is below 0.1%, so the bleeding rate of all test samples meets the requirements of the specification.

3.3. **Strength Characteristics**

The unconfined compressive strength of the different types of mixtures is shown in figure 6. The strength of mixture without fly ash is 24% and 73% of 28d strength (3MPa) on 7d and 14d respectively. Under the fly ash content of all levels, the average strength of the mixture on 7d, 14d is about 41%, 69% of that on 28d. Figure 7 shows the effect of fly ash content on the compressive strength of the mixture on 28d. Compared with the strength of the mixture without the addition of fly ash, when the quality of fly ash substitute for cement is 20% and 25%, the strength of the mixture is lower than the comparison value, while when the amount of fly ash substitute is 5% and 10%, the strength of the mixture is greater than this value.
Figure 6. Unconfined compressive strength of the mixture.

Figure 7. Effect of fly ash content on compressive strength (28d).

4. Conclusions
In this paper, clay and fly ash were introduced into the preparation of fluidized backfill materials. The fluidity, bleeding and compressive strength of the mixture were studied by relevant tests.

1. Mix proportion is the key factor affecting the performance of the mixture, among which the water-solid ratio plays a leading role. In this study, water-solid ratio of 0.5 and cement-water ratio of 0.6 were selected by performing a fluidity test.

2. The percentage of cement occupied by fly ash increases, the fluidity of clay fluidized backfill material decreases. The fly ash content is in the range of not more than 5%, the mixture exhibits good fluidity higher than 200 mm.

3. The amount of fly ash has basically no effect on the bleeding rate.

4. Compared with the strength of the mixture without fly ash, when the amount of fly ash substitute for cement is 20% and 25%, the strength of the mixture is lower than the comparison value, while when the amount of fly ash substitute is 5% and 10%, the strength of the mixture is greater than this value.

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