The application of waste fly ash and construction-waste in cement filling material in goaf

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Abstract. As the process of urbanization accelerated, resulting in a large number of abandoned fly ash and construction waste, which have occupied the farmland and polluted the environment. In this paper, a large number of construction waste and abandoned fly ash are mixed into the filling material in goaf, the best formula of the filling material containing a large amount of abandoned fly ash and construction waste is obtained, and the performance of the filling material is analyzed. The experimental results show that the cost of filling material is very low while the performance is very good, which have a good prospect in goaf.

1. Introduction

Coal mining which have brought huge pressure to the environment and the prominent environmental problem is subsidence and underground water loss. The filling mining is an effective approach for coal mine marching toward “harmless” and “safe” production. However, the main reason why it cannot be popularized in a large area is that the cost of filling material is too high. There is about 650 million m² newly built building every year in China, and the construction waste arising from the construction of newly built building in a year is about 40 million tons. The construction waste arising from the dismantling of old building is about 40 million tons in a year. The combination of them reaches a huge quantity [1-3]. The survey showed that for every 10,000 construction waste, about 0.067 km² of land is required. However, the supply of fly ash produced by the plant in the remote area is larger than the demand, which resulted in a large quantity of fly ashes wasted in the open, all about of which brought huge pressure to the environment. The survey showed that fly ash contained a variety of heavy metals, compounds and other toxic substances, which will pollute air, water and soil, endanger human health, and aggravate secondary geological disasters. If the construction waste and fly ash is mixed with filling material after recovery processing and reaches the performance requirement of filling material, which will solve not only the environmental pollution from construction waste, but also the problem that the cost of filling material is too high. Thus, this paper obtains the best formula of construction waste-fly ash based cementing filling material through orthogonal experiment, and analyzes the mechanical property of filling material.
2. **Raw material and its composition relationship**

The filling aggregate is the crushed construction waste–recycled aggregate (brick, glass, tile and concrete are get from 1 m³ construction waste as filling aggregate), which is shown in figure 1. The cement is Swan brand 32.5 complex Portland cement manufactured by Tatai Group Harbin Cement Co., Ltd, which properties are that the content of sulfur trioxide was 2.45, the content of magnesium oxide was 2.11%, the burning loss was 4.27, the initial setting time was 172 hours, the final setting time was 231 hours. The fly ash is abandoned fly ash from Harbin Power Plant, the main chemical composition of waste fly ash and physical properties, which is shown in table 1. The mixing water is tap water, and the additives are sodium chloride and anhydrous sodium carbonate (the mass ratio is 1:3). The raw material composition relationship is shown in figure 2.

![Construction waste after crushed](image1)

**Table 1.** Chemical composition and physical properties of cribble fly ash.

|          | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | K₂O | Na₂O | SO₃ | Loss | Total | Fineness (m²/kg) | Density (kg/m³) |
|----------|------|-------|-------|-----|-----|-----|------|-----|------|-------|-----------------|-----------------|
| Coarse fly ash | 37.2 | 24.5  | 8.4   | 8.3 | 1.6 | 1.2 | 1.6  | 12.2| 2.7  | 97.7  | 119.0           | 2.2             |

![The composition of filling raw material](image2)

**Table 2.** Levels and factors of the orthogonal test.

| Levels | A/g  | B    | C    | D    |
|--------|------|------|------|------|
| 1      | 1600 | 0.40 | 0.70 | 7/3  |
| 2      | 1300 | 0.45 | 0.75 | 6/3  |
| 3      | 1000 | 0.50 | 0.80 | 5/3  |
3. Experimental scheme and result analysis

3.1. Orthogonal experiment factor level
This paper takes construction waste (A), mortar-aggregate ratio (B), water-binder ratio (C) and Fly ash-Cement ratio (D) as the experimental factor. Each factor has three levels, the orthogonal experiment factor levels are shown in Table 2.

3.2. Preparation of filling material
According to experiment scheme, which is shown in Table 3, nine groups of different proportions of raw materials for experiment are weighed using electronic scales. The bottom of 7.07 cm×7.07 cm×7.07 cm trigeminy trial mould is plugged with a wooden plug to prevent the slurry discharging. Then, pour the weighed water, fly ash, cement and additives to the forced stirrer and stir them for 5 min, pour the weighed construction waste to the stirrer and stir them for 10 min and finally make them into filling slurry. Next, we pour the prepared filling slurry to the compression-resistant trial mould, and vibrate them using handheld slab vibrator so as to shape up. After that, we float the top surface using the scraper, cover the surface with a block of plastic cloth, and put the trial mould in a standard curing box for curing.

Table 3. Programs and results of orthogonal test.

| Experiment number | Factors | σ_c/MPa |
|-------------------|---------|---------|
|                   | A       | B       | C       | D       | 3 days | 7 days | 28 days |
| 1                 | 1(1600 g) | 1(0.40) | 1(0.70) | 1(7/3) | 1.90 | 3.66 | 5.34 |
| 2                 | 1(1600 g) | 2(0.45) | 2(0.75) | 2(6/3) | 1.49 | 3.32 | 4.46 |
| 3                 | 1(1600 g) | 3(0.50) | 3(0.80) | 3(5/3) | 1.03 | 2.95 | 3.75 |
| 4                 | 2(1300 g) | 1(0.40) | 2(0.75) | 3(5/3) | 2.05 | 3.90 | 6.73 |
| 5                 | 2(1300 g) | 2(0.45) | 3(0.80) | 1(7/3) | 1.19 | 2.60 | 3.47 |
| 6                 | 2(1300 g) | 3(0.50) | 1(0.70) | 2(6/3) | 1.49 | 3.94 | 5.82 |
| 7                 | 3(1000 g) | 1(0.40) | 3(0.80) | 2(6/3) | 1.70 | 4.01 | 4.82 |
| 8                 | 3(1000 g) | 2(0.45) | 1(0.70) | 3(5/3) | 1.87 | 5.03 | 6.46 |
| 9                 | 3(1000 g) | 3(0.50) | 2(0.75) | 1(7/3) | 1.44 | 3.27 | 4.39 |

3.3. Experimental scheme and result
The experimental scheme will be obtained according to the orthogonal experiment factor level, the filling slurry was poured into test mode and then put it in the curing box. After curing for 3 days, the test block of filling material is measured the uniaxial compressive strength with the full automatic cement press machine, and record the experimental data. After curing for 7 days and 28 days, measuring the uniaxial compressive strength one more time. The experimental scheme and result is shown in Table 3.

3.4. Range analysis
The range analysis of compressive strength is shown in Table 4. That \( \sigma_{c,3\text{days}} \), \( \sigma_{c,7\text{days}} \) and \( \sigma_{c,28\text{days}} \) in the table 4, which mean the compressive strength of the test block after curing for 3 days, 7 days and 28 days. A means construction waste, B means mortar-aggregate ratio, C means water-binder ratio, D means Fly ash-Cement ratio, I means three levels of influencing factors, \( k_i \) means the sum of compressive strength of three test blocks when the influencing factor selects ith level, \( k_i \) is the mean of \( K_i \), and R is the range of influencing factor [4-6].
According to analyzing table 3, it is known that the corresponding result of factor A at different levels indicates that the less the construction waste is, the compressive strength of test block is bigger; the mortar-aggregate ratio and water-binder ratio increase gradually, and the compressive strength of test block decreases gradually; the fly ash-cement ratio decreases gradually and the compressive strength of test block increased gradually. Thus, the optimization level combination of various factors is A:1B:2C:3D, hat is construction waste is 1000g, mortar-aggregate ratio is 0.4, water-binder ratio is 0.7 and fly ash-cement ratio is 5/3, the construction waste and fly ash account for 71.4% and 5.4% of total mass respectively.

4. Material setting time and mechanical characteristic analysis

4.1. Relationship between setting time and water-binder ratio

Since construction waste has no gelation characteristic, the setting time of material mainly directs at the binding slurry composed cementing material mixed with water. Hydration reaction happens after mixing cementing material and water. The binding slurry is solidified gradually with the progress of hydration reaction, and becomes the solid with certain strength. The time used by the slurry setting process is called setting time. The setting time includes initial setting time and final setting time. The initial setting time affects the conveyance performance of filling slurry directly. When the slurry is at the initial setting stage, it is not transported. To prevent blockage, we must ensure the initial setting time of material greater than the slurry conveyance time, so the initial setting time of binding slurry need to determine. The final setting time decides the demoulding time, so the final setting time need to determine [7-8].

The influencing factor of setting time of binding slurry is water-binder ratio. Three levels of water-binder ratio 0.7, 0.75 and 0.8 are selected to prepare three groups of binding slurry and determine the setting time, the result is shown in figure 3. The initial setting time is 141, 180 and 232 minutes, and

Table 4. Range analysis of compressive strength.

| item | 3 days $\sigma_{c,3\text{days}}$/MPa | 7 days $\sigma_{c,7\text{days}}$/MPa | 28 days $\sigma_{c,28\text{days}}$/MPa |
|------|-----------------------------------|-----------------------------------|-----------------------------------|
|      | A       | B       | C       | D       | A       | B       | C       | D       | A       | B       | C       | D       |
| K_1  | 4.42    | 5.65    | 5.26    | 4.53    | 9.93    | 11.57   | 12.63   | 9.53    | 13.55   | 16.89   | 17.62   | 13.20   |
| K_2  | 4.73    | 4.55    | 4.98    | 4.68    | 10.44   | 10.95   | 10.49   | 11.27   | 16.02   | 14.39   | 15.58   | 15.10   |
| K_3  | 5.01    | 3.96    | 3.92    | 4.95    | 12.31   | 10.16   | 9.56    | 11.88   | 15.67   | 13.96   | 12.04   | 16.94   |
| k_1  | 1.47    | 1.88    | 1.75    | 1.51    | 3.31    | 3.86    | 4.21    | 3.18    | 4.52    | 5.63    | 5.87    | 4.40    |
| k_2  | 1.58    | 1.52    | 1.66    | 1.56    | 3.48    | 3.65    | 3.50    | 3.76    | 5.34    | 4.80    | 5.19    | 5.03    |
| k_3  | 1.67    | 1.32    | 1.31    | 1.65    | 4.10    | 3.39    | 3.19    | 3.99    | 5.22    | 4.65    | 4.01    | 5.65    |
| R    | 0.2     | 0.56    | 0.44    | 0.14    | 0.79    | 0.47    | 1.02    | 0.81    | 0.82    | 0.98    | 1.86    | 1.25    |
the final setting time is 205, 231 and 276 minutes. According to figure 3, it is known when the water-binder ratio is 0.7, the setting time is a minimum, and the setting time increases with the increasing of water-binder ratio. Water-binder ratio increases, the concentration of cementing material decreases, and the possibility for producing greater gelling structure in the hydration reaction of slurry becomes small, so the initial setting time and final setting time increase. According to figure 3, it is also known that the final setting time of material is within 8 hours, while the working system of coal mine is usually “three eight-hour” system. It indicates that filling and demoulding can be completed in a work shift. Therefore, the material has quick setting characteristic.

![Figure 3. Relationship between water cement ratio and setting time.](image)

4.2. Mechanical property of material

After the test block is obtained according to formula, 3 days stress-time curve of materials can be obtained according to press machine. As is shown in figure 4, that the curve can be divided into four stages: the first stage is compression stage, curve curvature increases gradually. The second stage is elastic stage, the slope of curve approximates to a constant and the load and time appear basic linear relationship. The third stage is plastic deformation stage. The curvature of curve decreases gradually and reaches the load peak. It indicates that test block behaves strong plasticity in the compressive failure process. The failure process is slow and progressive, not sudden. It is extremely beneficial to the safety of mine filling. The fourth stage is yield failure stage. The curvature of curve increases gradually, test block produces obvious crack until it is destroyed totally and loses strength, as shown in figure 5. However, the residual strength after the yield of material is high, about 70% to 90% of the ultimate strength. Thus, the filling body has good carrying ability [9-10].

![Figure 4. 3 days stress-time curve of materials.](image)
5. Conclusion
1) The results show that construction waste was 1000g, pulp bone ratio was 0.4, water-cement ratio was 0.7, powder mud ratio was 5/3, and construction waste and fly ash accounted for 1.4% and 5.4% weight of the material, which was the best formula of construction-waste and fly-ash-based cement filling material.

2) This construction-waste and fly-ash-based cement filling material is provided to have strong plastic, high residual strength and fast-setting properties.

3) This formula reduces the cost of cemented filling material effectively and digests a large quantity of construction waste and abandoned fly ash, which is conducive to protecting the environment and has a good application prospect.

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