Effect of Fly Ash Content in Shotcrete on Mechanical Properties

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Abstract. As one of the key technologies of NATM (New Austrian Tunnel Method) construction, shotcrete has advantages such as simple, fast and adaptable technology, and becomes an indispensable modern construction method in tunnel construction. Adding some fly ash into shotcrete can reduce cracks, compensate shrinkage and improve workability. In this paper, raw materials are selected for mix design, and the mechanical properties of shotcrete with different fly ash content are experimentally studied. The test results show that the 28d compressive, flexural and tensile properties of sprayed concrete shotcrete gradually decrease with the increase of fly ash content. In order to avoid too much strength reduction and ensure structural safety, the fly ash ought to be controlled within a certain amount in the actual construction process.

Keywords. Shotcrete; fly ash content; mechanical properties; optimum content.

1. Introduction
Shotcrete technology began in the United States in the 20th century and has been developed for more than 100 years. With the progress of society, shotcrete technology began to develop rapidly, and has been widely used in tunnel and underground culvert engineering, slope and foundation pit engineering, structural reinforcement engineering. Shotcrete technology has become an essential support means. Fly ash has been widely used in shotcrete [1-2]. Cao Jian found that with the development of age, the mechanical performance of fly ash concrete shows an increasing trend, and the increasing trend is more and more obvious with the higher fly ash content [3]. Hou et al. [4] and Cui et al. [5] have proved that under the same curing conditions of fly ash concrete, the strength of early age concrete decreases with the more fly ash, while the strength of longer age concrete increases. Through the experimental analysis of ultra-fine fly ash (UFA) concrete, Zhang et al. [6] studied the relevancy between the short-term and long-term strength and the content of fly ash. Wang et al. [7] did a lot of research on the mechanical strength of superfine fly-ash concrete. Dai [8] studied the association between compressive strength and fly ash. Chen [9] pointed out that the concrete strength and the content of fly ash are in reverse ratio. Li et al. [10] pointed out that the smaller the amount, the better of the fly ash, the higher strength of concrete, and the better the mechanical properties of concrete.

2. Laboratory Tests on Shotcrete’s Mechanical Properties

2.1. Standard Specimen
The standard specimen for tests were all made and maintained according to requirements in the new testing standard [11] by HW-60 single horizontal shaft forced concrete mixer and vibration table. The
strength grade of the concrete configured by the specimen was C30, and an ordinary Portland cement with the strength grade of P.O42.5 was used. The physical standards and chemical compositions of the cement were all up to the related national standard on experiment specification. Medium sand with fineness modulus 2.59 and sediment percentage lower than 0.9% was used. And the sand rate of 45% was chosen in this research. Gravel with particle size of 5-10mm was used. And clear running water was used. During the production process of the specimen, the fly ash with small fineness of I-grade was applied and its specific chemical composition can be checked in table 1.

**Table 1.** Main components of fly ash (%).

| Component | SiO₂ | Fe₂O₃ | MgO  | Al₂O₃ | CaO  | SO₃ |
|-----------|------|-------|------|-------|------|-----|
| Content (%)| 55.4 | 4.3   | 0.9  | 33.5  | 2.9  | 0.5 |

We designed the reference concrete mix proportion, which as shown in table 2.

**Table 2.** Concrete composition.

| Component | Cement | Sand | Gravel | Water |
|-----------|--------|------|--------|-------|
| Content (%)| 446    | 713  | 1083   | 240   |

In this test, the flexural, tensile and compressive strength of concrete are studied. Eight groups of tests were designed. In total 24 pieces of specimens were used, each group with three of them.

2.2. *Analysis of Test Results*

2.2.1. *Compressive Test.* Standard cubic specimen with size of 150mm×150mm×150mm was used for compressive strength test. Loading speed was set to 0.5MPa/s continuously and smoothly.

Analyzing the data shown in table 3, the relationship is shown in figure 1.

**Table 3.** Compressive test data.

| Content (%) | Compressive strength (MPa) |
|-------------|-----------------------------|
| 0           | 48.2                        |
| 5           | 46.2                        |
| 10          | 45.3                        |
| 15          | 43.8                        |
| 20          | 37.1                        |
| 25          | 32.6                        |
| 30          | 31.8                        |
| 35          | 29.5                        |
Figure 1. Compressive strength with varying fly ash content.

As we can see, the fly ash content is 10%, 15%, 20%, the strength data decreases by 6.0%, 9.1% and 23%. The compressive strength decreases slowly under the circumstances of the content less than 15%. Therefore, in the operation, the proportion of fly ash should not be greater than 15%.

2.3. Splitting Tensile Test
The size of the specimen used in the test was the same with the ones in the compressive strength test. The test data are list in table 4.

Table 4. Splitting tensile test data.

| Content (%) | Tensile strength (MPa) |
|-------------|------------------------|
| 0           | 3.89                   |
| 5           | 3.81                   |
| 10          | 3.75                   |
| 15          | 3.69                   |
| 20          | 3.31                   |
| 25          | 3.09                   |
| 30          | 2.96                   |
| 35          | 2.78                   |
From figure 2, the fly ash content is 10%, 15%, 20%, the tensile strength decreases by 3.6%, 5.1% and 14.9%. When the proportion of fly ash is greater than 15%, the tensile strength decreased sharply and the strength loss was far more serious, which might not only affect the quality of the shotcrete work but also in more severe cases affect the safety of the construction.

2.4. Flexural Test
The size of the specimen used in the test was 100mm×100mm×400mm. And the loading speed was set to 0.6MPa/s continuously and smoothly. The test result data are shown in table 5.

| Content (%) | Flexural strength (MPa) |
|-------------|-------------------------|
| 0           | 5.1                     |
| 5           | 4.8                     |
| 10          | 4.6                     |
| 15          | 4.5                     |
| 20          | 4.3                     |
| 25          | 4.0                     |
| 30          | 3.1                     |
| 35          | 2.5                     |
Figure 3 shows that the flexural strength of shotcrete decreases with the more fly ash. When the proportion is higher than 25%, the flexural strength decreases obviously. To guarantee the safety of structures, the fly ash content fewer than 25% is preferred.

3. Conclusions
By taking the fly ash content as variable, this paper studied and analyzed the shotcrete’s tensile strength, compressive strength and flexural strength after a large amount of tests. The results are as follows:

(1) In general, the 28d flexural, compressive and splitting strength gradually decrease with the more fly ash.

(2) For the first two strengths, when the content is less than 15%, the reduction range is small, and when it exceeds 15%, the reduction range of strength becomes larger.

(3) For the flexural strength, the reduction range is small when the content is less than 25%, and becomes larger when the content exceeds 25%.

(4) Combined with the change of concrete strength, to guarantee the structural safety, the proportion of fly ash is no more than 15%. Otherwise, the strength loss will be too serious for a safe construction structure.

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