Research on influences of fly ash content on mechanical properties of shotcrete

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Abstract. Shotcrete technology is a key technology of the New Austrian tunnelling method. Owing to advantages of simple and quick process of construction and strong adaptability, it is an indispensable means of modern tunnel construction. Mixing shotcrete with appropriate amount fly ash not only can reduce the generation of cracks and compensate the shrinkage, but also can improve the shotcrete peace ability and reduce the cost of project construction. Through a given number of tests, we study on the influences of fly ash content on the mechanical properties of shotcrete, i.e., tensile, compressive, flexural strength. The results of experiments show that: the strength indexes of shotcrete decrease gradually with the increase mixing content of fly ash. When the fly ash content is more than 28%, the concrete strength has serious loss. For ordinary shotcrete, it is suggested that the optimum dosage of fly ash should be about 9%.

1. Introduction
Shotcrete technology has become more and more widely used in civil engineering such as tunnel engineering and underground engineering, and has become an indispensable means of supporting system. Although the technology that mixing shotcrete with fly ash has not been used in civil engineering for a long time, many experts and scholars have done a lot of research, and it is now widely used. In 1999, Zhang studied the effect of silica fume and fly ash on the basic properties of shotcrete with polypropylene fiber [1]. Yang did many laboratory experiments on shotcrete with fly ash [2]. Studies show that a certain amount of fly ash can reduce the initial setting time of cement in shotcrete. Meanwhile, there is a negative correlation between adding content of fly ash and early strength of shotcrete, and it can cause corresponding loss to the later strength of shotcrete [3]. Xu studied the effect of fly ash in coal roadway support [4], and found the proper amount of fly ash can improve the durability of shotcrete. At present, although shotcrete with fly ash is widely used and some progress has been made in related research, there are still many problems. The research on the influence of adding content of fly ash on the mechanical properties of shotcrete and its mechanism is rarely studied at home and abroad [5], it is still in a blank stage. With the large-scale field engineering application, the research on the influence of fly ash on the mechanical properties of shotcrete is urgent important [6-7]. The scientific and reasonable adding amount of fly ash is directly related to the quality performance of shotcrete, which directly affects the quality of construction and construction safety [8].

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2. Specimens production

The standard test specimens are made and maintained according to the requirements of laboratory tests for concrete. HW-60 type concrete mixer and platform vibrator are used to make specimens. The cement is ordinary Portland cement with minimum strength of 30 MPa. The sand is medium sand with fineness modulus of 2.64 and clay content less than 0.9%. Since the sand ratio has a great influence on the mechanical properties of the shotcrete, the sand ratio in this test is 45%. The aggregate is crushed stone with a diameter of 5 ~ 10mm. Water is clean tap water. In the process of making specimens, I grade fly ash with smaller fineness is used, and its chemical composition is shown in Table 1.

| Chemical composition (%) | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | SO₃ |
|--------------------------|------|-------|-------|-----|-----|-----|
|                          | 56.5 | 34.3  | 3.8   | 2.1 | 0.8 | 0.5 |

The mixture ratio of each concrete material per cubic meter concrete is shown in Table 2, and the unit of measurement is quality. In addition, the sand ratio is 45% and the water binder ratio is 0.48.

| Design mix proportion of concrete | Cement | Sand | Stone | Water |
|----------------------------------|--------|------|-------|-------|
|                                 | 440    | 800  | 1000  | 220   |

In the experiment design, the mechanical properties of concrete including compressive strength, tensile strength and flexural strength are studied with adding content of fly ash as a variable. Eight groups of experiments are designed. The adding amount of fly ash is 0%, 10%, 15%, 20%, 25%, 30%, 35%, and 40% respectively.

3. Results

3.1. Analysis of compressive strength test

The standard cube specimen of 150mm * 150mm * 150mm is used to carry out the test of compressive strength. Loading speed is continuous and the value is 0.5MPa/s. The adding content of fly ash is 0%, 10%, 15%, 20%, 25%, 30%, 35%, and 40% respectively. The specimens are divided into 8 groups, each containing 3 specimens. The total number of specimens are 24. The average 28d strength of the three specimens is taken as the test result.

| Test results of compressive strength of 8 group specimens | Adding content of fly ash (%) | Compressive strength (MPa) |
|---------------------------------------------------------|------------------------------|---------------------------|
|                                                         | 0                            | 40.3                      |
|                                                         | 10                           | 37.8                      |
|                                                         | 15                           | 36.9                      |
|                                                         | 20                           | 33.9                      |
|                                                         | 25                           | 32.2                      |
|                                                         | 30                           | 31.1                      |
|                                                         | 35                           | 27.7                      |
|                                                         | 40                           | 24.8                      |

The compressive strength test results of 8 group specimens are shown in Table 3, and the relationship between compressive strength of shotcrete and fly ash content is shown in Figure 1. Results show that with the increase adding content of fly ash, the compressive strength of shotcrete decreases gradually. When the dosage is about 28%, the compressive strength decreases obviously. While when the dosage
is less than 15%, the compressive strength decreases slowly. Therefore, when using fly ash instead of cement to configure shotcrete, the adding amount of fly ash should not be more than 15%, which can not only save cost, but also keep the shotcrete with high strength.

Figure 1. Relationship between compressive strength of shotcrete and fly ash content.

3.2. Analysis of split tensile test
The standard cube specimen of 150mm * 150mm * 150mm is also used to carry out the split tensile test. Loading speed is continuous and the value is 0.06MPa/s. The adding content of fly ash is also 0%, 10%, 15%, 20%, 25%, 30%, 35%, 40% respectively. The specimens are also divided into 8 groups, each containing 3 specimens. The total number of specimens are 24. The average 28d strength of the three specimens is taken as the test result.

Table 4. Split tensile test results of 8 group specimens

| Adding content of fly ash (%) | Tensile strength (MPa) |
|------------------------------|------------------------|
| 0                            | 3.78                   |
| 10                           | 4.00                   |
| 15                           | 3.55                   |
| 20                           | 3.69                   |
| 25                           | 3.52                   |
| 30                           | 3.43                   |
| 35                           | 3.33                   |
| 40                           | 3.15                   |

The split tensile test results of 8 group specimens are shown in Table 4, and the relationship between tensile strength of shotcrete and fly ash content is shown in Figure 2. Results show that the change law of tensile strength of shotcrete is similar to that of compressive strength. Both of them show a downward trend with the increase of fly ash content. When the adding content of fly ash is 10% and 20%, the loss of tensile strength is 2.4% and 9.3% respectively. Due to the smooth surface of fly ash particles, the cohesive force of fly ash and other substances in concrete is weak. When the dosage is less than 10%, the influence of fly ash on the tensile strength of shotcrete is relatively small. When the dosage is more than 10%, the tensile strength of shotcrete reduces significantly, leading to bad construction quality of shotcrete and may affect the safety of engineering construction in serious cases.
3.3. Analysis of flexural strength test
The standard specimen of 100mm * 100mm * 400mm is used to carry out the flexural strength test. Loading speed is continuous and the value is 0.06mm/s. The adding content of fly ash is also 0%, 10%, 15%, 20%, 25%, 30%, 35%, 40% respectively. The specimens are also divided into 8 groups, each containing 3 specimens. The total number of specimens are 24. The average 28d strength of the three specimens is taken as the test result.

Table 5. Flexural strength test results of 8 group specimens

| Adding content of fly ash (%) | Flexural strength (MPa) |
|------------------------------|-------------------------|
| 0                            | 5.0                     |
| 10                           | 4.9                     |
| 15                           | 4.7                     |
| 20                           | 4.6                     |
| 25                           | 4.4                     |
| 30                           | 4.3                     |
| 35                           | 3.7                     |
| 40                           | 3.1                     |

Figure 3. Relationship between flexural strength of shotcrete and fly ash content
The flexural strength test results of 8 group specimens are shown in Table 5, and the relationship between flexural strength of shotcrete and fly ash content is shown in Figure 3. Results show that with the increase adding content of fly ash, the flexural strength of shotcrete shows a downward trend, which is similar to the results of compressive strength test and split tensile test. When the dosage is less than 30%, the flexural strength of concrete decreases slowly, when the dosage is higher than 30%, the flexural strength decreases almost linearly and the loss reaches 50%. This indicates that the influence adding content of fly ash on the flexural strength of shotcrete is not very obvious when the adding content of fly ash is less than 30%. Therefore, in order to ensure engineering safety, the adding amount of fly ash should not exceed 30%.

4. Conclusion
In this paper, with the fly ash as a variable a large number of tests have been carried out to analyze the influence of fly ash to mechanical properties of shotcrete. The main conclusions are that:

(1) Under the 28day standard curing condition, the compressive strength, tensile strength and flexural strength of shotcrete are negatively correlated with fly ash content, that is, the higher the fly ash content is, the greater the loss of the mechanical strength is.

(2) For compressive strength, the adding content of fly ash instead of cement should not exceed 15% in actual engineering construction.

(3) For splitting tensile strength, the influence adding content of fly ash on tensile strength is obvious. When the fly ash content exceeds 10%, the tensile strength reduces obviously and the loss is larger. Therefore, the adding content of fly ash instead of cement should not exceed 10%.

(4) For the flexural strength, the influence of fly ash on the flexural strength is not obvious within 30% of the content. Therefore, the adding content of fly ash instead of cement should not exceed 30%.

(5) In a word, it is suggested that the adding content of fly ash instead of cement should not exceed 9% in the engineering operation. Otherwise, the strength loss of sprayed concrete is more serious and it cannot guarantee the structure safety.

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