Effect of Fly Ash Content on Mechanical Properties of C80 High-Strength Concrete

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Abstract. The changes of compressive strength and elastic modulus of concrete specimens with water-to-water ratio of 0.25, different content of fly ash (0%, 20%, 40%) and different ages (7d, 14d, 28d, 56d, 90d, and 120d) were studied. The results show that the amount of fly ash has a great influence on the compressive strength and the elastic modulus of the high-strength concrete. The compressive strength and elastic modulus of concrete with 0%, 20% and 40% content increase with age, but the compressive strength and elastic modulus decrease with the same age.  
Keywords: High strength concrete; Fly ash; Elastic modulus; Compressive strength; Construction technology.

1. Introduction
Fly ash is industrial solid waste, which can be used as concrete admixture in building structure to promote the regeneration of resources and environmental protection. When preparing high-strength and high-performance concrete, fly ash, granulated blast furnace slag, silicon powder and other admixtures should be added. Their physical and mechanical properties (such as elastic modulus and compressive strength, etc.) change with age after pouring [1-6], and the mechanical properties are discrete. In this paper, the effect of fly ash on compressive strength and elastic modulus of C80 concrete was studied.

2. Materials and Experimental Methods

2.1. Raw Materials
Cement: P· II 42.5R cement, 28d flexural strength 9.0 MPa, compressive strength 60.4 MPa, density 3.14 g/cm³, specific surface area 350 m²/kg. Table 1 physical properties of cement. Fly ash: grade I fly ash, density 2.25 g/cm³, specific surface area 559 m²/kg, water demand 92%, fineness 5.5%, chemical composition as shown in table 2. Silica fume: 28d flexural strength 10.3 MPa, compressive strength 75.2 MPa, activity index 125%, density 2.05 g/cm³, specific surface area 20100 m²/kg. Mineral powder: 28d flexural strength 8.9 MPa, compressive strength 53.9 MPa, activity index 106%, density 2.45 g/cm³, specific surface area 455 m²/kg, water demand (103%), fineness (27.5%). Fine aggregate: coarse river sand with a fineness modulus of 3.1 and washed by circulating equipment with a mud content of 0.9 %. Coarse aggregate: 5 ~ 20mm continuous gradation, crushing index 5.6%; fine aggregate grain grade 0.08 ~ 2.0 mm, fineness modulus 2.7, mud content less than 2%, graded qualified medium sand. Admixture: JL118T, belonging to aminosul fonate, water reduction rate up to 30%. admixture: type CZ-II admixture. Sand: select coarse river sand with fineness modulus 3.1, and after washing by
circulating equipment, the mud content is 0.9%; gravel: choose Fushun production gravel, 5~20 mm continuous gradation, crushing index is 5.6%. the concrete used in the test is configured according to C80. The fly ash parameters are 0%, 20%, and 40%, respectively. the mix ratio parameters are shown in table 3.

The specimens of C80 concrete were made of 100 mm ×100 mm ×100 mm cube to meet the requirement of maximum particle size of aggregate. the compressive strength was measured up to day 7, 14, 28, 56, 90 and 120 days for each group of 3 specimens, 6 ages and 30 groups for each.

Table 1. Basic physical and mechanical properties of cement.

| 80 mm screening (%) | Normal consistency (%) | Rupture strength (MPa) | Compression strength (MPa) |
|---------------------|-------------------------|------------------------|---------------------------|
|                     |                         | 3d  | 7d  | 28d | 3d  | 7d  | 28d |
| 1.1                 | 27.5                    | 4.3 | 8.89| 20.31| 53.91|

Table 2. Chemical composition of cement and fly ash (%).

| Fly ash | CaO | SiO₂ | Al₂O₃ | Fe₂O₃ | MgO | Na₂O | K₂O | MnO | TiO₂ | P₂O₅ | SO₂ |
|---------|-----|------|-------|-------|-----|------|-----|-----|------|------|-----|
| 4.34    | 56.63 | 25.66 | 5.41  | 1.25  | 0.47 | 1.73 | 0.05 | 1.39 | 0.72 | 0.44 |
| Cement  | 36.68 | 22.40 | 6.13  | 4.32  | 0.93 | 0.21 | 0.56 | 0.13 | 0.23 | 0.05 | 0.51 |

Table 3. Concrete mix ratio (kg/m³).

| Quantity level | Water-to-adhesive ratio | Water | Cement | Fly ash | Coarse aggregate | Superplasticizer |
|----------------|-------------------------|-------|--------|---------|------------------|-----------------|
| C80            | 0                       | 140   | 540    | 0       | 1240             | 5.40            |
| C80            | 20                      | 0.25  | 140    | 432     | 110              | 1240            | 5.40            |
| C80            | 40                      | 0.25  | 140    | 325     | 217              | 1240            | 5.40            |

2.2. Test Methods
Using BT-9300S laser particle size distribution instrument, the mineral admixture and cementitious material samples were analyzed. with reference to the GB/T50081-2002 standard for testing the mechanical properties of ordinary concrete, the compressive strength of the standard concrete cube test block with 100 mm ×100 mm ×100 mm size was tested with fully automatic ARD-Auto 3000 type concrete press. Test the performance of new concrete with reference to JGJ/T 281-2012 high-strength concrete application technical specification and CECS203-2006 self-compacting concrete application technical specification.

3. Experimental Results and Analysis

3.1. Effect of Fly Ash on Compressive Strength of Concrete
Figure 1 is the relationship between compressive strength and fly ash addition, and figure 2 is the relationship between compressive strength and age. It can be seen from the diagram that the compressive strength of concrete with 0%, 20% and 40% of the amount of concrete is increasing with the age, but the compressive strength decreases with the increase of the amount of concrete at the same age.
Figure 1. Relationship between compressive strength and fly ash addition.

From figure 2, it can be seen that before 28 days, the compressive strength of concrete with 0% dosage, 20% content and 40% amount of fly ash increases rapidly with the age, and the rate of concrete compressive strength increases slowly after 28 days of age, and the compressive strength of concrete decreases with the increase of the amount of concrete.

The strength of high strength concrete with fly ash is mainly affected by the strength of the cement paste and the characteristics of the interface transition zone between the paste and aggregate. With the increase of time, the cement is constantly hydrated, the paste is gradually hardened and the strength increases, so the strength is more sensitive to the age.

Table 4. Variation of mean compressive strength of high strength concrete.

| Quantity | Rupture strength (MPa) |
|----------|------------------------|
|          | 7d  | 14d  | 28d  | 56d  | 90d  | 120d |
| 0%       | 0.884 | 0.908 | 1   | 1.037 | 1.152 | 1.209 |
| 20%      | 0.889 | 0.918 | 1   | 1.083 | 1.187 | 1.215 |
| 40%      | 0.746 | 0.899 | 1   | 1.124 | 1.231 | 1.304 |

According to the standard, the compressive strength of concrete in 28 days of age is compared, and it can be seen from Table 4 that the ratio of compressive strength of 7 days and 14 days of age to 28 days of compressive strength of fly ash is the largest and the ratio of 40% of concrete content is the smallest when the age exceeds 28 days. The time-varying rule of C80 fly ash concrete strength under standard curing conditions, it is found that the fly ash content has a great influence on the change of cube compressive strength value of high strength concrete with time.
3.2. Effect of Fly Ash on Elastic Modulus of Concrete

The test results of elastic modulus of high strength concrete with different fly ash doped at different ages are shown in figure 3, and the elastic modulus of high strength concrete with fly ash in each age is shown in figure 4 below. From figure 3, figure 4, it can be seen that the elastic modulus of high-strength concrete with 0% content, 20% content and 40% amount of fly ash increases slowly with the age. The elastic modulus of high strength concrete with fly ash is mainly determined by the elastic modulus of aggregate and the volume fraction of aggregate, while the elastic modulus of slurry has little effect on the elastic modulus of concrete.

Figure 3. Relationship between elastic modulus and fly ash addition.

Figure 4. Relationship between elastic modulus and age.

Table 5. Elastic modulus versus age ratio.

| Quantity | Rupture strength (MPa) |
|----------|------------------------|
|          | 7d  | 14d | 28d | 56d | 90d | 120d |
| 0%       | 0.894 | 0.907 | 1   | 1.055 | 1.113 | 1.215 |
| 20%      | 0.878 | 0.885 | 1   | 1.022 | 1.137 | 1.226 |
| 40%      | 0.946 | 0.982 | 1   | 1.008 | 1.192 | 1.246 |

Referring to the standard, the elastic modulus of concrete at 28 days old is compared with the elastic modulus of concrete at different ages, and the ratio of elastic modulus of concrete at each age to 28 days old is calculated. It can be seen from Table 5 that the ratio of elastic modulus of 7 days and 14 days of age to elastic modulus of 28 days is the largest, and the ratio of 20% is the smallest. The time-varying rule of elastic modulus of C80 fly ash concrete under standard curing conditions. The results show that
the average elastic modulus of high strength concrete has a great influence on the change of elastic modulus with time.

4. Conclusion

The variation law of compressive strength and elastic modulus was statistically analyzed by the test of concrete specimens after 7d, 14d, 28d, 56d, 90d, 120d age after multiple groups of 0%, 20% and 40% fly ash. The results show that the content of fly ash has a great influence on the change of compressive strength and elastic modulus of high strength concrete. The compressive strength and elastic modulus of concrete with 0%, 20% and 40% of the amount of concrete are both increasing with the age, but the compressive strength and elastic modulus decrease with the increase of the amount of concrete at the same age.

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