Study on the effect of fineness and dosage of fly ash on mechanical properties of concrete

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Abstract: Ultrafine fly ash concrete is one of the main directions for the development of concrete materials in the future. In order to study the mechanical properties of ultra-fine fly ash concrete, the compressive strength, splitting tensile strength and flexural strength of concrete under different ages and different ultra-fine fly ash particle sizes and dosages were tested. (1) The slump of concrete mix under different fly ash particle size increases with the increase of ultrafine fly ash content, but the rate of increase decreases gradually. Under the same fly ash content, the smaller the particle size of ultrafine fly ash particles, the greater the slump of the corresponding fly ash concrete, and it has the exponential relationship between the particle size and the particle size of fly ash. (2) The smaller the particle size of ultra-fine fly ash, the larger the optimum dosage in concrete. When the particle size of ultrafine fly ash is less than 5μm, the optimal dosage of ultrafine fly ash in concrete is 30% to ensure 60d compressive strength. (3) When the concrete curing age is 60d, the splitting tensile strength and flexural strength of ultra-fine fly ash concrete under different particle sizes increase first and then decrease with the increase of ultrafine fly ash content. The law of variation is that the split tensile strength and flexural strength of fly ash concrete are the highest when the content of ultrafine fly ash is 20%-30%.

1. Preface:
As an important part of the sustainable development strategy of energy, fly ash has been widely used in cement and concrete industry due to its certain form effect, volcanic ash effect and micro-aggregate effect [1-2]. However, the slow hydration rate of fly ash easily leads to problems such as low early strength and large drying shrinkage of concrete after incorporation of fly ash [3-4], which brings new challenges to the safety of concrete structures.

In order to reduce the adverse effects of fly ash and give full play to the active effect of fly ash, many scholars have found that grinding fly ash is an effective method after research [5]. Cong Shumin [6] studied the effect of ground fly ash and raw ash in high strength concrete through comparative experiments, and found that ground fly ash concrete has good cohesion and good working performance. Chen Chen [7] studied the variation rule of the compressive strength and splitting strength of ultra-fine fly ash concrete under the conditions of different dosage and ratio. LiHui [8] studied the influence of fly ash with different dosage and different average particle size on the working and mechanical properties of high-strength concrete, and the results showed that the ultrafine grinding can significantly enhance the compressive strength of concrete in the early and latest ages. Yao Wei jing [9] pointed out through orthogonal experimental study that under the reasonable dosage of ultra-fine fly ash, it could not only meet the strength requirements of concrete, but also effectively improve work ability and save cement.

The above research results have provided many valuable opinions for promoting the application and
development of ultra-fine fly ash in concrete. However, these research results are relatively one-sided and cannot fully reflect the influence of ultra-fine fly ash on the mechanical properties of concrete under different conditions. Therefore, this paper studies the compressive strength, splitting tensile strength and bending strength of concrete at different ages and with different particle sizes and dosage of ultrafine fly ash, which is expected to provide theoretical data foundation support for the further application of ultrafine fly ash concrete.

2. Experimental design

2.1. Test materials

(1) Cement: ordinary Portland cement P·O 42.5 produced by Yaobo Special Cement Group Co., Ltd.; Ultra-fine fly ash

(2): to Wuhan JingLong chemical co., LTD. Provide 1 grade fly ash as raw material, on the basis of this device is made of superfine powder grinding of grinding, the average particle size were 12.2 mu m, 7.6 mu m and 3.4 um, three kinds of ultra fine fly ash for the convenience of written records, the three kinds of ultra fine fly ash by particle size is too big to small UFA1, UFA2 and UFA3 said;

3) Stone: the use of Xi’an local continuous grading gravel, particle size of 5-20mm;

(4) Sand: select the local medium sand in Xi’an, the particle size is 0.5-5mm

(5) Water reducer: polycarboxylic acid water reducer, the dosage of cement and fly ash of the total mass of 0.8%;

(6) Water: daily tap water.

2.2. design of concrete mix proportion

Based on C30 ordinary concrete mix proportion design, in keeping the water cement ratio, coarse aggregate, fine aggregate, gelling material and water reducing agent were 0.57, total 1228 kg/m³, 662 kg/m³, 325 kg/m³ and 2.6 kg/m³, under the condition of the above three different particle size of ultrafine fly ash UFA1, UFA2, UFA3 according to different dosage (0%, 10%, 20%, 30% and 40%) to replace cement concrete specimen preparation, specific parameters are shown in table 1.

| Number | Ultrafine Fly Ash (kg/m³) | Cement (kg/m³) | Water-binder ratio | Coarse Aggregate (kg/m³) | Fine Aggregate (kg/m³) |
|--------|-----------------------------|-----------------|--------------------|--------------------------|------------------------|
| A0     | 0 (UFA1)                    | 325             | 0.57               | 1228                     | 662                    |
| A1     | 32.5 (UFA1)                 | 292.5           | 0.57               | 1228                     | 662                    |
| A2     | 65 (UFA1)                   | 260             | 0.57               | 1228                     | 662                    |
| A3     | 97.5 (UFA1)                 | 227.5           | 0.57               | 1228                     | 662                    |
| A4     | 130 (UFA1)                  | 195             | 0.57               | 1228                     | 662                    |
| B0     | 0 (UFA2)                    | 325             | 0.57               | 1228                     | 662                    |
| B1     | 32.5 (UFA2)                 | 292.5           | 0.57               | 1228                     | 662                    |
| B2     | 65 (UFA2)                   | 260             | 0.57               | 1228                     | 662                    |
| B3     | 97.5 (UFA2)                 | 227.5           | 0.57               | 1228                     | 662                    |
| B4     | 130 (UFA2)                  | 195             | 0.57               | 1228                     | 662                    |
| C0     | 0 (UFA3)                    | 325             | 0.57               | 1228                     | 662                    |
| C1     | 32.5 (UFA3)                 | 292.5           | 0.57               | 1228                     | 662                    |
| C2     | 65 (UFA3)                   | 260             | 0.57               | 1228                     | 662                    |
| C3     | 97.5 (UFA3)                 | 227.5           | 0.57               | 1228                     | 662                    |
| C4     | 130 (UFA3)                  | 195             | 0.57               | 1228                     | 662                    |

2.3. Test

The concrete specimens were prepared and cured in accordance with the Performance Test Standard for Ordinary Concrete Mixtures (GB/T 50080-2016), with curing ages of 28d and 60d, respectively. After
the curing period, the corresponding concrete specimens were tested for their compressive strength, splitting tensile strength and flexural strength according to the Standard of Test Methods for Mechanical Properties of Ordinary Concrete (GB/T50081-2002). The machine used for the test was shown in Figure 1.

3. Mechanical Performance Analysis of Ultra-fine Fly Ash Concrete

3.1. Slump

Curve of Concrete Mixture with Different Fly Ash Particle Size and Contents is shown in Fig. 2. Due to the morphology effect and micro-aggregate effect of ultrafine fly ash in concrete, the slump of concrete mixture with different particle sizes of ultrafine fly ash increases gradually with the increase of the content of ultrafine fly ash, but the rate of increase decreases gradually. Under the same dosage of ultrafine fly ash, the smaller the particle size of ultrafine fly ash is, the greater the slump of the corresponding fly ash concrete is, and it has an exponential increasing relationship with the reduction of particle size of ultrafine fly ash. This is mainly because after the fly ash is ground fine, the finer microbeads inside the fly ash microbeads will be released and form a good grading with other material particles to refine and fill the pores inside the concrete, thus improving the fluidity of the concrete mixture. As can be seen from the figure, when the content of ultra-fine fly ash with particle size less than 5μm is 40%, the slump of concrete mixture is 227mm, which increases by 13.5% compared with that of 12.2μm fly ash with the same content, and by 22.7% compared with that of non-fly ash.

![Fig.1 The experiment machine](image1)

![Fig.2 Slump change curve of ultra-fine fly ash concrete](image2)

3.2. Compressive strength

Fig. 3 shows the change curve of the compressive strength of ultra-fine fly ash concrete with the particle size and dosage of ultra-fine fly ash at different ages. As can be seen from the figure, the smaller the particle size of fly ash is, the more obvious the form effect, micro-aggregate effect and volcanic ash activity effect of fly ash are, and the more significant the improvement effect of it on the compressive
strength of concrete is. When the age of ultrafine fly ash concrete is 28d, due to the short curing time, the activity effect of ultrafine fly ash has not been effectively played. Therefore, the greater the content of ultrafine fly ash, the greater the range of compression strength reduction of ultrafine fly ash concrete, especially when the content of ultrafine fly ash is greater than 20%. With the decrease of the particle size of ultra-fine fly ash, the compressive strength of fly ash concrete increases gradually and the rate of increase is faster and faster under the same dosage condition. When the particle size of ultrafine fly ash is less than 5μm, the 28d compressive strength of concrete with the content of ultrafine fly ash less than 20% begins to exceed that of plain concrete. Superfine fly ash concrete age of 60 d, active effect of ultrafine fly ash has been effectively play, at that time, dosage of 20% superfine fly ash concrete under compressive strength of concrete are more than plain concrete, while more than 30% content of concrete for superfine fly ash replacing cement quantity too much, lead to parcel between aggregate of cement slurry is reduced, the compressive strength could be lower than plain concrete. In addition, because of the superfine fly ash particle size is smaller, the activity of ultrafine fly ash effect more significantly, leading to the lower the particle size of fly ash in concrete, the optimal dosage, the greater the when superfine fly ash particle size less than 5 microns, superfine fly ash in concrete, the optimal dosage of 30%, at this point, even if the superfine fly ash mortar was 40%, the concrete compressive strength is more than 60 d plain concrete.

3.3. Splitting tensile strength

Curve of variation of splitting tensile strength of ultra-fine fly ash concrete with particle size and dosage of ultra-fine fly ash at different ages is shown in Fig. 4. Because the activity effects of ultrafine fly ash with different particle sizes are not consistent, when the curing period of concrete is 28 days, the splitting tensile strength of the concrete with the particle size of ultrafine fly ash less than 5μm increases first and then decreases with the increase of the content of ultrafine fly ash. However, the splitting tensile strength of concrete with ultra-fine fly ash particle size greater than 5μm decreases first, then increases and then decreases. When concrete curing age is 60 d, due to the active effect of ultrafine fly ash has made full play, and the smaller the particle size, the stronger the superfine fly ash activity, therefore, under the different particle sizes of ultrafine fly ash concrete splitting tensile strength increases with the superfine fly ash dosage first increases then decreases, the change rule of the superfine fly ash content is 20% - 30%, the highest tensile splitting strength of fly ash concrete, about 103% of the plain concrete - 107%.
3.4. Flexural strength

Flexural strength of ultra-fine fly ash concrete with particle size and dosage of ultra-fine fly ash at different ages is shown in Fig. 4. It can be seen that the variation of the flexural strength of concrete with the particle size and dosage of ultra-fine fly ash is consistent with the splitting tensile strength, but the variation range is relatively large. When the age of concrete is 28d, the flexural strength of concrete is the highest when the content of ultra-fine fly ash is 20%. When the concrete age is 60 days, the flexural strength of concrete is the highest when the content of ultra-fine fly ash is 20%-30%, and the smaller the particle size of ultrafine fly ash is, the maximum optimal content of ultrafine fly ash concrete is.

4. Main conclusions

(1) The slump of concrete mixture with different fly ash particle size increases gradually with the increase of the dosage of ultrafine fly ash, but the rate of increase decreases gradually. Under the same fly ash content condition, the smaller the particle size of ultrafine fly ash is, the greater the slump of the corresponding fly ash concrete is, and it has an exponential increasing relationship with the reduction of fly ash particle size.

(2) When the age of ultrafine fly ash concrete is 28d, the greater the content of ultrafine fly ash, the greater the range of compression strength reduction of ultrafine fly ash concrete, especially when the content of ultrafine fly ash is greater than 20%; however, when the particle size of ultrafine fly ash is less than 5μm, the 28d compressive strength of concrete with the content of ultrafine fly ash less than
20% is higher than that of plain concrete.

3) The smaller the particle size of ultrafine fly ash is, the more significant its activity effect is, so the greater the optimal mixing amount of ultrafine fly ash in concrete is. When the particle size of ultrafine fly ash is less than 5μm, the optimal dosage of ultrafine fly ash in concrete is 30% in order to improve the 60d compressive strength.

4) When the curing age of concrete is 60 days, the splitting tensile strength and bending strength of ultrafine fly ash concrete with different particle sizes both increase first and then decrease with the increase of the content of ultrafine fly ash. When the content of ultrafine fly ash is 20%-30%, the splitting tensile strength and bending strength of fly ash concrete are the highest.

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