Study on strength and durability of fair-faced concrete in underground station of urban rail transit

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Abstract: Concrete is still in the developing stage in China, only some design and construction units can master its construction technology. The side walls and middle columns of underground station of Changzhou Metro Line 2 are made of fair-faced concrete. In this paper, the material properties of the underground station are studied based on the project. In this paper, the working performance, compressive strength, impermeability, sulfate corrosion and carbonization resistance of fair-faced concrete are mainly studied by drawing up the base mix ratio. The research results have reference value for the future development of fair-faced concrete engineering.

1. Introduction

The strength and durability of concrete are important for concrete structures. By carefully controlled construction technology, fair-faced concrete structure takes the original poured surface after concrete pouring as the external surface, and achieves the architectural aesthetic requirements with its own good texture \textsuperscript{[1,2]}. The smooth surface and clear texture of fair-faced concrete after forming bring a feeling of returning to nature. The overall effect is natural, thick and elegant \textsuperscript{[3]}. At the same time, the steps of plastering and decoration are omitted, the cost is reduced and the time of decoration stage is saved. It is an excellent green building material. At present, the technology of fair-faced concrete is in the development stage in China, which is only a little higher than the ordinary concrete in the performance requirements. The research on fair-faced concrete is not mature, lacking theoretical basis, experimental demonstration and practical engineering verification \textsuperscript{[4,5]}. There are still many problems in the mix design and construction of fair-faced concrete, especially in the performance of fair-faced concrete. The surface quality of fair-faced concrete is required to be high, so most of the researchers and constructors improved its surface quality from the formwork, but less from the aspect of mix proportion. The formwork is very important to its surface quality, but it is also of great significance to optimize the concrete mix proportion and improve the concrete performance to meet the quality requirements of the concrete surface. In practical engineering, when the surface of fair-faced concrete is directly exposed to the external environment, its durability is particularly important, which not only affects its surface beauty, but also is very important for its corrosion resistance and structural safety. In order to improve its durability, many scholars have conducted a lot of research on its mineral admixtures and additives.

The sidewalls and middle columns of Changzhou Metro Line 2 underground station are made of C35 grade and C45 grade fair-faced concrete respectively. The fair-faced concrete structure of the
underground station needs to show its inherent feeling of clear texture, smooth surface and returning to nature, which has spiritual and sensory enjoyment for the waiting passengers, so there are certain requirements for its appearance quality. As an important part of the supporting structure, the sidewalls and middle columns of the underground engineering are generally required that the fair-faced concrete material of which to have preferable bearing capacity and durability, and to meet the requirements of modern buildings. Combing with this project, the working performance, strength and durability of the fair-faced concrete with different mix were mainly studied in this paper, which has reference value for the application of fair-faced concrete.

2. Experiment

2.1 Test materials
The raw materials used for the fair-faced concrete in Changzhou Metro Line 2 project were selected for specimen preparation to ensure the consistency of the concrete material. The selected raw materials were:

a. Cement: Yangzi P-O42.5;
b. Sand: medium sand in zone II;
c. Gravel: 5.0-25.0 two-gradation, the proportion of 5.0-16.0 gravel to 16.0-25.0 gravel is 25%: 75%;
d. High performance water reducing agent: sobote pca-i;
e. Fly ash: Changzhou Guodian Grade I;
f. Mineral powder: Grade S95;
g. Anti crack and waterproof agent: 5% admixture.

2.2 Test scheme
The mix proportion of the fair-faced concrete for the sidewalls and the middle columns of the underground station was designed according to the code [6]. By changing the content of the mineral admixture, the mix proportions of the specimens were adjusted. The details of the mix proportions are shown in Table 1 and Table 2. The workability of the fair-faced concretes with different mix proportions were tested according to the slump method in the code [7]. The compressive strengths of the concretes were tested with 150mm×150mm×150mm specimens after standard curing 28 days according to the code [8]. The disabilities were tested according to the requirements about the impermeability, the sulfate resistance and the carbonation resistance in the code [9], in which the method of step-by-step pressure was used for the impermeability test, dry and wet cycle method was used for sulfate resistance test, and fast carbonation method was used for the carbonation resistance test.

| Label | Cement | Fly ash | Mineral powder | Fine aggregate | Crack resistant agent | Coarse aggregate | Water | Additive |
|-------|--------|---------|----------------|----------------|-----------------------|-----------------|-------|----------|
|       | P.O 42.5 | Grade I | S95 | Medium sand | 16-16mm | 16-25mm | tap water | PCA-1 |
| P1    | 276     | 55      | 37  | 760         | 18.4   | 263    | 788     | 160    | 2.9     |
| P2    | 239     | 74      | 55  | 760         | 18.4   | 263    | 788     | 160    | 2.9     |
| P3    | 313     | 37      | 18  | 760         | 18.4   | 263    | 788     | 160    | 2.9     |
| P4    | 276     | 55      | 37  | 760         | 18.4   | 263    | 788     | 160    | 3.3     |
| P5    | 276     | 55      | 37  | 760         | 18.4   | 263    | 788     | 160    | 2.6     |

| Label | Cement | Fly ash | Mineral powder | Fine aggregate | Coarse aggregate | Water | Additive |
|-------|--------|---------|----------------|----------------|-----------------|-------|----------|
|       | P.O 42.5 | Grade I | S95 | Medium sand | 5-16mm | 16-25mm | tap water | PCA-1 |

The details of the mix proportions are shown in Table 1 and Table 2.
3. Results and discussion

3.1 Workability
The test results of concrete workability showed that the slump of each group of concrete is 170-180mm and the loss of concrete is 10-15mm after 1 hour. This was obtained by adjusting the dosage of admixture under a constant water binder ratio. It should be noted that the fluidity of P4 and P10 groups of concrete was good, but there was slight bleeding and bottom catching phenomenon. The cohesion, water retention and fluidity of the other groups of concrete were good, which met the requirements of construction. It could be seen that too much water reducing agent will cause bleeding of concrete and affect the working performance of concrete. Therefore, attention should be paid to the dosage of water reducing agent, during the mixing and preparation of fair-faced concrete, in order not to affect the workability of concrete.

3.2 Strength
Figure 1 shows the compressive strength of concrete with different mix proportions. The sidewall C35 grade concretes with the mix proportions P1-P5 and the middle column C45 grade concretes with the mix proportions P6-P10 all met the strength requirement for each grade. In the C35 concretes of the sidewall, the compressive strength of P2 group is the lowest, and that of P3 group is the highest, but not significantly higher than those of P1, P4 and P5 groups. In the middle column C45 grade concretes, the compressive strength of P7 group is the lowest, and that of P8 group is the highest, but not significantly higher than those of P6, P9 and P10 groups. The strengths of P3 and P8 group concrete developed well, and separately reached C35 and C45 strength grades at 7 day age.

Comparing P2 group and P7 group with the reference groups, it can be found that though the compressive strength of concrete decreased with the increase of fly ash and mineral powder, the concrete strength decreased to a small extent. This may be due to the fact that the variation of the mineral powder admixture was small, thus has little influence on the concrete strength. Some researches showed that adding a large number of mineral admixture could reduce the strength of concrete, so the amount of mineral admixture should not be too much in actual project, in order to avoid the concrete strength not meeting the requirement and affecting the structural safety.

3.3 Impermeability
Table 3 shows the impermeability pressure and grade of the concrete with each mix proportion. The sidewall C35 grade concretes with the mix proportions P1-P5 and the middle column C45 grade concretes with the mix proportions P6-P10 all met the impermeability requirement for each grade. The impermeability grades of concretes are between p15-p17, which met the requirement of the
underground station concrete impermeability. The change of mineral admixture content had no significant effect on the impermeability of concrete. In addition, the impermeability of C45 concrete was not higher than that of C35 concrete.

| Label | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 |
|-------|----|----|----|----|----|----|----|----|----|-----|
| Water pressure (MPa) | 1.7 | 1.6 | 1.6 | 1.8 | 1.7 | 1.7 | 1.6 | 1.8 | 1.6 |
| Impermeability grade | P16 | P15 | P15 | P17 | P16 | P16 | P15 | P17 | P15 |

3.4 Sulfate resistance

Figure 2 shows the appearance of P8 concrete specimen after 90 cycles of sulfate drying and wetting. The results show that under the action of sulfate drying and wetting cycles, cracks appeared on the concrete surface, even with aggregate peeling off. Table 4 shows the corrosion resistance coefficients of compressive strength of the concretes with different mix proportions after 90 cycles of sulfate drying and wetting. The results show that although the compressive strength of each group of concrete decreased to different degrees, the corrosion resistance coefficients of compressive strength of the other group concretes are higher than 80% except for P3 and P8 concrete specimens. Through the analysis on P1-P3 group concretes and P6-P8 group concretes, it is found that mineral admixtures can improve the sulfate resistance of concrete, which may be due to the combination reaction of mineral admixtures and sulfate ions, so as to improve the corrosion resistance.

| Label | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 |
|-------|----|----|----|----|----|----|----|----|----|-----|
| Corrosion resistance coefficient of compressive strength (%) | 83.09 | 87.54 | 77.24 | 85.45 | 91.25 | 82.49 | 97.61 | 74.90 | 87.48 | 98.04 |

3.5 Carbonation resistance

Table 5 shows the carbonation depth of the concrete specimens with different mix proportions. The results show that the carbonation resistance of C45 concrete is stronger than that of C35 concrete. That is, the higher the strength, the stronger the carbonation resistance. Figure 3-Figure 5 are concrete specimens with different carbonation times. The results show that the carbonation of concrete is deeper with the increase of carbonation time. The carbonation resistance of concrete can be improved by adding some mineral admixtures.
Table 5. Carbonation depth of different mix proportion concrete (mm)

| Carbonation time | Label of specimen | P1 | P2 | P3 | P4 | P5 |
|------------------|-------------------|----|----|----|----|----|
| 7d               |                   | 4.4| 5.5| 4.3| 5.3| 4.2|
| 14d              |                   | 10.4| 10.7| 13.1| 8.3| 5.2|
| 28d              |                   | 12.8| 12.2| 14.4| 9.3| 8.1|

| Carbonation time | Label of specimen | P6 | P7 | P8 | P9 | P10 |
|------------------|-------------------|----|----|----|----|-----|
| 7d               |                   | 0  | 0  | 0  | 0  | 0   |
| 14d              |                   | 0  | 0  | 0  | 0  | 0   |
| 28d              |                   | 0  | 0  | 0  | 0  | 0   |

Figure 3. P1 Concrete specimens with different carbonation times

Figure 4. P3 Concrete specimens with different carbonation times

Figure 5. Concrete specimens with different mix proportion with 28d carbonation time

4. Conclusions
Based on the study of the working performance, compressive strength, impermeability, sulfate corrosion resistance and carbonation resistance of the fair-faced concrete materials used in the
sidewalls and middle columns of the underground station of Changzhou Metro Line 2, the following conclusions can be drawn from the above results:

a. In the C35 concretes for the sidewalls and C45 concretes for the middle columns with the mix proportions in this paper, except for P4 and P10 groups of concrete, the cohesion, water retention and fluidity of the other groups of concrete are good, which meets the construction performance requirements.

b. The mix proportion of each group of concrete meets the strength requirements, and the amount of mineral admixture should not be too much, otherwise the strength will be reduced.

c. The impermeability grades of C35 concrete for the sidewall and C45 concrete for the middle column are between p15-p17, and are greater than p15, which meets the impermeability requirements. Except for P3 and P8 concrete specimens, the corrosion resistance coefficients of compressive strength of the other groups of concrete specimens after 90 cycles of sulfate drying and wetting are higher than 80%. The higher the strength, the stronger the carbonation resistance. Moreover, with the extension of carbonation time, the deeper the concrete carbonates. Adding a proper amount of mineral admixture can improve the sulfate resistance and carbonation resistance of concrete.

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