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To cite this article: Jurui Wang *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **300** 022017

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Study on durability of ultra high performances concrete with aeolian sand

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Abstract. Compared with ordinary concrete and high strength concrete, ultra-high performance concrete has more excellent mechanical properties and durability. It has great social and economic benefits to prepare ultra-high performance aeolian sand concrete using aeolian sand as aggregate. It is of great significance to study the durability of ultra-high performance aeolian sand concrete. The mechanical properties and durability of ultra-high performance concrete are analyzed and compared by optimizing mix ratio and optimizing mix ratio. The test results show that the compressive strength of ultra-high performance aeolian sand concrete loses obviously after 300 freeze-thaw cycles. However, the splitting tensile strength is not affected by the number of freeze-thaw cycles; the strength of ultra-high performance aeolian sand concrete is not affected by sulfate immersion; with the increase of the number of dry-wet cycle-sulfate erosion coupling cycles, the compressive strength and splitting tensile strength of ultra-high performance aeolian sand concrete decrease rapidly at first, then increase gradually, and then decrease rapidly.

Keyword: Ultra High Performances Concrete; Aeolian sand; Durability

1. Introduction

Aiming at the durability study of super-high wind-blown sand concrete, the aeolian sand concrete is firstly analyzed, whose sand-laden flow will destroy the concrete material in the building, affect the functional use of the building, and the service life of the building, also reflected in the decline of the concrete durability [1]. Secondly, the existing concrete materials have low abrasion resistance, short service life, easy to crack, and low bond strength in use [2]. Finally, in order to solve these problems, it is necessary to study and use ultra-high-performance concrete. In practical application, this kind of super-high performance aeolian sand concrete has high abrasion resistance, high mechanical properties and durability. This kind of cement-based composite material has good application in bridges and roads. Therefore, the durability of concrete is analyzed mainly from its specific characteristics [3,4].

In the special environment, the durability study of concrete is an important work, which directly affects the quality of later construction. From the global use of concrete, due to insufficient durability of concrete, a large number of problems arise, affecting the application effect of engineering and design. This phenomenon leads to the waste of resources, and the maintenance cost caused by the durability of



concrete structure is seriously beyond the budget scope of the project cost [5]. The adverse impact of durability will promote the reconstruction of the project and increase the project expenditure [6]. The service life of concrete in harsh environment in China is relatively short, which cannot exceed 20 years on average. According to statistics, more than half of the concrete structures in China need to be appraised and strengthened, such as those in coastal areas, cold and windy sandy all the year round, which seriously affect the durability of concrete [7].

According to the unique geological characteristics of China, in the durability analysis of concrete, it is necessary to adopt ultra-high-performance aeolian sand concrete, which is often used in harsh conditions. For example, the concentration of soluble salt in desert sand is about 0.14-1.32%, and the pH value is between 8.4-9.6. The reason why the environment is alkaline is that the proportion of chloride and carbonate is high [8]. In northern cities of China, concrete structures in desert often encounter wind erosion, salt invasion, freeze-thaw, dry-wet alternation due to environmental impact. In order to ensure that concrete structures can have high durability in complex environment, it is necessary to use ultra-high-performance aeolian sand concrete to improve the resistance to the environment and ensure the durability of materials.

2. Materials

2.1. Materials and mixture proportion

The raw materials used in this study include cement, silica fume(SF), FA, GGBS, aeolian sand, quartz sand, quartz powder, SAP, steel fibres, superplasticizers and tap water.

Cement: P.II52.5 cement produced by Jiangnan-xiaoyetian Cement Co., Ltd, and its chemical composition is presented in Table 1.

Silica fume: Silica fume provided by Gansu Sanyuan Silicon Material Co., Ltd. The density is 2.2/cm³, the activity index is 105%~130%, and the water requirement ratio is 116~122%, and its chemical composition is presented in Table 1.

Slag: The slag powder used in this experiment is from Chongqing Haihuang Building Materials Technology Co., Ltd, and its chemical composition is shown in Table 1.

Fly ash: Grade I FA in compliance with Chinese standard GB 1596-2005 28 was employed in this study and its chemical composition is shown in Table 1.

The particle size distributions of the cement, Silica fume agglomerations, FA, and GGBS used in this study are provided in Fig. 1.

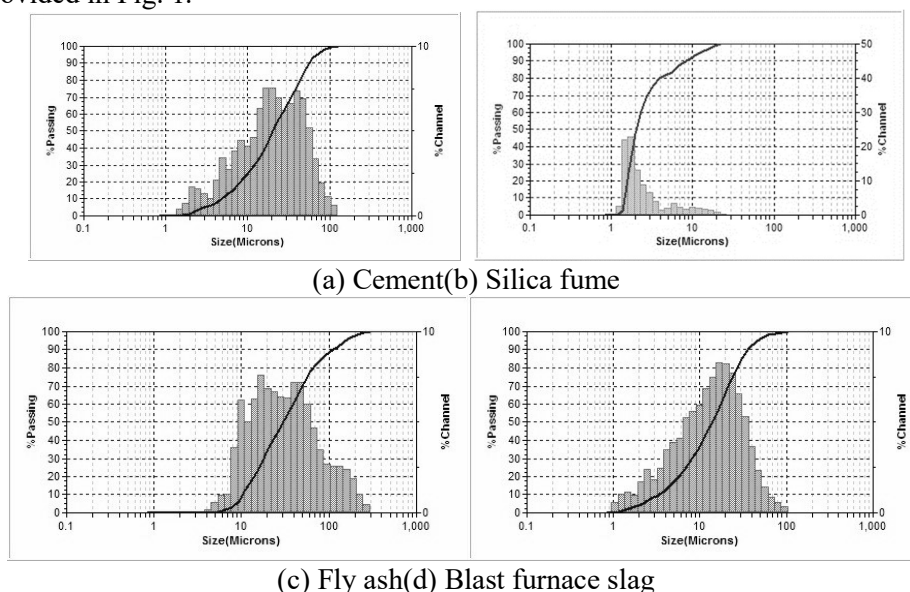


Figure 1. Particle size distribution of powder materials

Table 1. Chemical composition of experiment materials (%)

| | CaO | SiO ₂ | Al ₂ O ₃ | Fe ₂ O ₃ | MgO | Na ₂ O | MnO | K ₂ O | SO ₃ | Loss |
|--------|-------|------------------|--------------------------------|--------------------------------|------|-------------------|------|------------------|-----------------|------|
| Cement | 64.13 | 21.43 | 2.24 | 3.78 | 2.07 | 0.78 | | | 2.25 | 3.32 |
| SF | 0.52 | 94.51 | 0.61 | 0.22 | | | | | | 4.14 |
| FA | 2.4 | 47.25 | 26.34 | 12.97 | 2.26 | 0.43 | | 1.58 | 0.71 | 6.06 |
| GGBS | 45.75 | 31.4 | 12.3 | 0.79 | 5.25 | 0.42 | 0.51 | 0.37 | 2.32 | 0.89 |

Water reducer: RPC-H polycarboxylic acid water reducer produced by KZJ New Materials Group. The main performance parameters are shown in Table 2.

Table 2. Water reducing agent performance parameters

| Item | Appearance | Water reduction rate | Solid content (%) |
|---------------|---------------------|----------------------|-------------------|
| Water reducer | Light yellow liquid | >30 | 43 |

Quartz sand: Coarse, medium and fine sand provided by Guangdong Gateway New Materials Technology Co., Ltd. The main performance parameters are shown in Table 3.

Table 3. Quartz sand performance parameters

| Quartz sand species | | Coarse sand | Medium sand | Fine sand |
|------------------------------|------------------|-------------|-------------|------------|
| Density (kg/m ³) | Apparent density | 2600 | 2630 | 2670 |
| | Stacking density | 1340 | 1390 | 1420 |
| Particle size (mm) | | 1.25~0.62 | 0.63~0.315 | 0.315~0.16 |

Steel fibers: The brass-coated steel fibres, 13-mm long with a diameter of 0.2 mm, were included in the mixes. Their properties are shown in Table 4.

Table 4. Steel fiber performance parameters

| Item | Performance shape | Tensile strength (MPa) | Length (mm) | Equivalent diameter (mm) | Draw ratio |
|-------------|-------------------------------------|------------------------|-------------|--------------------------|------------|
| Steel fiber | Copper-plated, golden, flat surface | 2850 | 12 | 0.18 | 66 |

Internal curing material: self-made inorganic powder.

Limestone powder: Ultrafine limestone powder with fineness of 4000 meshes and 1250 meshes, respectively.

Rubber powder: The reclaimed butadiene rubber powder produced by Beijing Mingjintai Rubber and Plastic Raw Material Factory has a fineness of 60 meshes (about 0.25mm in diameter) and an apparent density of 1080 kg/m³.

Water: tap water, in line with the national water requirements.

3. Effect of ultra-high-performance aeolian sand concrete on properties

3.1. Analysis of freeze-thaw performance

The freeze-thaw cycle test of ultra-high performance aeolian sand concrete was carried out. The properties of cube specimens after 50, 100, 150, 200, 250 and 300 freeze-thaw cycles were tested. The cube compressive strength and splitting tensile strength were tested. The results are shown in Table 5 and Table 6.

Table 5. Compressive strength results after coupled cycling

| Number of freeze-thaw cycles | Compressive strength (MPa) | Strength retention rate (%) |
|------------------------------|----------------------------|-----------------------------|
| 0 | 112.45 | 100 |
| 50 | 110.56 | 98.32 |
| 100 | 107.31 | 95.43 |
| 150 | 106.09 | 94.34 |
| 200 | 105.17 | 93.53 |
| 250 | 105.08 | 93.45 |
| 300 | 102.86 | 91.47 |

Table 5 shows that the compressive strength of super high performance aeolian sand concrete decreases gradually with the increase of freeze-thaw cycles. When the number of freeze-thaw cycles is 0-150, the compressive strength decreases rapidly; when the number of freeze-thaw cycles is 200-250, the compressive strength changes slightly; and when the number of freeze-thaw cycles is 250-300, the compressive strength decreases suddenly. After 300 freeze-thaw cycles, the compressive strength was 102.86 MPa and the strength loss rate was 8.53%.

Table 6. Compressive strength results after coupled cycling

| Number of freeze-thaw cycles | Splitting tensile strength (MPa) | Strength retention rate (%) |
|------------------------------|----------------------------------|-----------------------------|
| 0 | 13.67 | 100.00 |
| 50 | 13.60 | 99.51 |
| 100 | 13.54 | 99.05 |
| 150 | 13.46 | 98.43 |
| 200 | 13.55 | 99.12 |
| 250 | 13.46 | 98.45 |
| 300 | 13.50 | 98.75 |

Table 4.3 shows that the splitting tensile strength of ultra-high performance aeolian sand concrete has little change during 300 freeze-thaw cycles, and the maximum strength loss rate is only 1.57%. This indicates that freeze-thaw cycles have little effect on the splitting tensile strength of ultra-high performance aeolian sand concrete.

The main factors affecting freeze-thaw cycle are moisture and pore in concrete. During the freeze-thaw cycle, water molecules easily penetrate through the concrete pore into the interior of the concrete, which results in the transformation of physical state, the formation of internal stress and the destruction of its internal structure. The water in concrete mainly exists in three forms: bound water, adsorbed water and free water. The bound water is generally integrated with compounds through chemical action. The adsorbed water is physically adsorbed on other molecules or structures, and the freeze-thaw cycle has little effect on it. Free water exists in internal pore, which can migrate, exchange and change physical state, and is greatly affected by freeze-thaw cycle. However, the super-high performance aeolian sand concrete has less water cement and less internal free water, so it is not affected by freeze-thaw cycle. Moreover, the compactness of ultra-high performance aeolian sand concrete is higher and its internal porosity is less, which also shows that it is less affected by freeze-thaw cycle.

3.2. Sulphate Resistant Immersion

Ultra-high performance aeolian sand concrete specimens were immersed in 5% Na₂SO₄ solution. After 1d, 3d, 7d, 14d, 21d and 28d, the specimens were taken out and their compressive strength and splitting tensile strength were tested, as shown in figs. 4.11 and 4.12. It can be seen from the figure that the compressive strength of super high performance aeolian sand concrete increases gradually with the prolongation of soaking time before 7 days, reaching the maximum value of 118.37 MPa on 7 days. This is because the super-high performance concrete is relatively dense, Na₂SO₄ solution will not enter

the concrete at the initial stage of immersion, and can not affect its performance. However, the continued hydration of unfinished cement in the concrete makes the compressive strength increase slightly, up to 5%. With the prolongation of soaking time, the compressive strength of concrete decreases gradually. This is because Na_2SO_4 enters into concrete through pore and reacts with hydration products $\text{Ca}(\text{OH})_2$ and ettringite, as shown in Formula (1), (2), to form gypsum with expansive effect, destroy ettringite, cause internal structural damage and affect its overall performance. The splitting tensile strength of ultra-high performance aeolian sand concrete is less affected by soaking time, and the maximum change value is 4%.

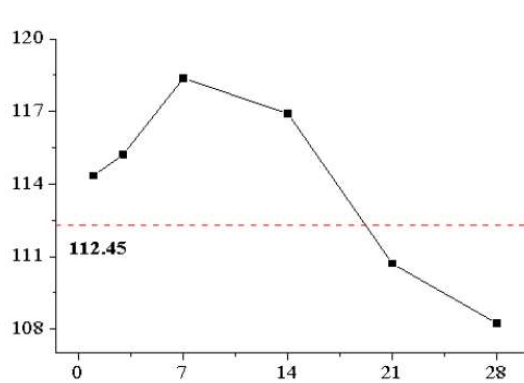
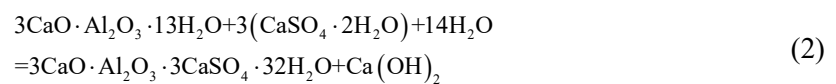
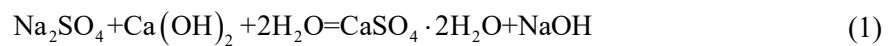


Figure 2. Test results of compressive strength under sulphate immersion

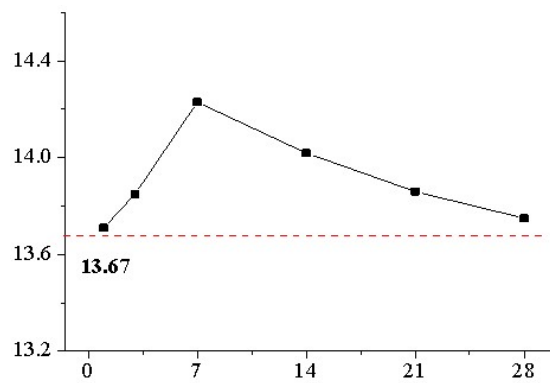
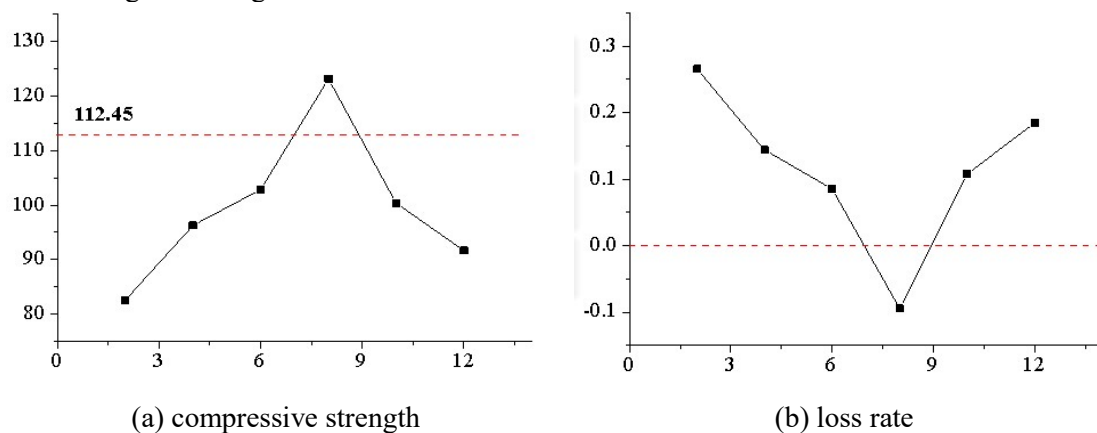


Figure 3. Test results of splitting tensile strength under sulphate soaking

Dry-wet cycling-sulfate erosion coupling test was carried out on ultra-high performance aeolian sand concrete. The performance of the specimens after two, four, six, eight, ten and twelve cycles is tested, as shown in Fig. 4 and Fig.5.



(a) compressive strength

(b) loss rate

Figure 4. Effect of erosion times on compressive strength

It can be seen from the figure that the compressive strength and splitting tensile strength of ultra-high performance aeolian sand concrete first increase with the increase of cycle number, reach the maximum value at 8 cycles, and then decrease with the increase of cycle number. The maximum loss of compressive strength is 36.45%, and the maximum loss of splitting tensile strength is 26.58%. Although both compressive strength and splitting tensile strength have undergone performance improvement, after 12 cycles, they are lower than the pre-test strength.

3.3. The drying shrinkage

The drying shrinkage is caused by the evaporation of free water in concrete. For high performance concrete with low water-cement ratio, drying shrinkage is generally lower. At the same time, the drying shrinkage of ultra-high performance aeolian sand concrete and reactive powder concrete was tested. The drying shrinkage was calculated by reading the change of specimen length with percentile meter. The drying shrinkage values of two kinds of concrete for 1, 3, 7, 14, 21, 28, 56 and 70 days are recorded, as shown in Fig. 5. From the analysis of the figure, the drying shrinkage values of the two kinds of concrete in different time periods are not very different. The main reason is that the water-binder ratio of the two kinds of concrete is the same, and the number of water molecules evaporating is basically the same. The drying shrinkage of ultra-high performance aeolian sand concrete and reactive powder concrete is 503 and 514 microns/m respectively after 70 days, the difference between them is only 2.2%. The total shrinkage values of the two types of concrete are shown in Fig. 4.10. The total shrinkage of ultra-high performance aeolian sand concrete and reactive powder concrete is 106.6 and 1302 microns/m respectively.

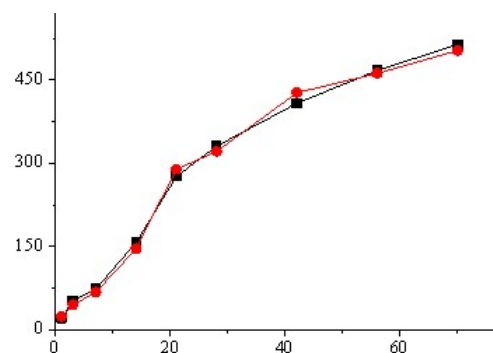


Figure 5. Drying shrinkage

4. Study on erosion and abrasion resistance of ultra-high aeolian sand concrete

4.1. Test scheme and mix ratio

Based on the results of orthogonal test, the mix ratio of benchmark ultra-high-performance concrete is compared with the mechanical properties and abrasion resistance of ordinary concrete, high strength concrete, and industrial samples produced by Guangdong Gateway Company, as shown in the table below.

Table 7. Ultra-high-performance concrete preferably mix ratio (kg/m³)

| No. | Cement | Fly ash | Slag | Silica fume | Quartz sand | Water | Steel fiber | Water reducer |
|-----|--------|---------|------|-------------|-------------|-------|-------------|---------------|
| Y1 | 887 | 59 | 118 | 118 | 1538 | 59 | 79 | 118 |
| Y2 | 828 | 59 | 118 | 177 | 1538 | 59 | 79 | 118 |
| Y3 | 828 | 59 | 118 | 177 | 1538 | 97 | 79 | 470 |
| Y4 | 828 | 59 | 118 | 177 | 1538 | 97 | 157 | 470 |

Durability studies the relationship between abrasion resistance and mechanical properties of concrete of different grades. The compressive strength properties of ordinary concrete and high strength concrete with different strength grades are shown in Figure 1.

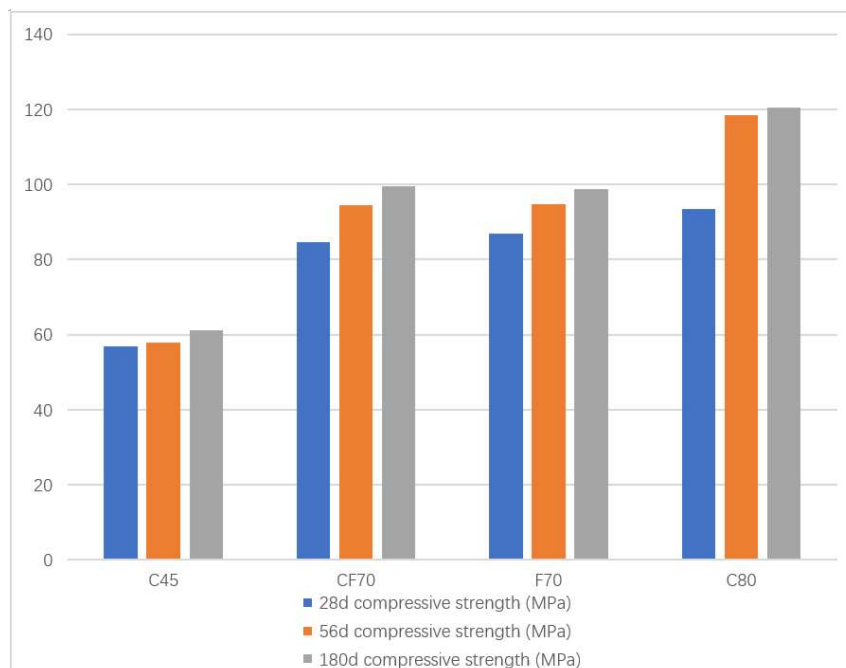


Figure 6. Compressive strength of ordinary concrete and high-strength concrete

Under the condition of low pressure test, the abrasion resistance of ultra-high-performance concrete is 3 times that of C45 concrete, 2 times that of C70 and CF70 concrete, and 1.5 times that of C80 concrete. Under the condition of high pressure test, the abrasion resistance of ultra-high-performance concrete is about 2 times that of C45 concrete, 1.5 times that of C70 and CF70 concrete, and 1.3 times that of C80 concrete.

5. Conclusion

(1) After 300 freeze-thaw cycles, the compressive strength of ultra-high performance aeolian sand concrete is 102.86 MPa, and the strength loss rate is 8.53%. However, the splitting tensile strength is not affected by the number of freeze-thaw cycles, and the maximum strength loss rate is only 1.57%.

(2) Ultra-high performance aeolian sand concrete is not affected by sulfate immersion. Within 28 days of immersion, the change value of concrete compressive strength is 5%, and the change value of splitting tensile strength is 4%.

(3) The compressive strength and splitting tensile strength of super-high performance aeolian sand concrete decrease rapidly at first, then increase gradually, and then decrease rapidly with the increase of the number of wet-dry cycle-sulfate erosion coupling cycles.

(4) The anti-abrasion strength increases with the increase of compressive strength. But the ultra-high-performance concrete mixed with rubber powder shows the opposite regularity. Its compressive strength decreases with the increase of rubber powder, but its abrasive strength is improved.

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