Study on factors influencing the performance of reactive powder concrete

Xikang Yan¹, Jiapeng Wen¹

¹School of Civil and Transportation Engineering, Hebei University of Technology, Tianjin 300401, China
tjsyxk@126.com, 1035713148@qq.com

Abstract. Reactive powder concrete (RPC) is a new type of ultra-high performance concrete (UHPC). There are many related factors that affect the mechanical properties of RPC. This paper researches on the effect of curing temperature and steel fiber type on the material strength. The research results show that within a certain range, the strength of RPC increases with the increase of curing temperature, and the maximum strength can be obtained when the curing temperature is 90°C. In the actual project, the best curing temperature is 75°C. And the study has shown that blending fine steel fibers can optimize its mechanical properties.

1. Introduction

Reactive powder concrete (RPC) is a new type of cement-based material with ultra-high strength, high toughness and super durability. Its mechanical properties are much better than ordinary concrete. The use of RPC instead of ordinary concrete for construction in the field of civil engineering has very good application prospects. A large number of experimental studies [1-7] have been conducted at home and abroad on the mix ratio of RPC, etc.

Currently in China, the application of RPC is still in its infancy, and a large number of projects in China are still constructed with ordinary concrete (such as C30, C40 and C50). In addition, due to the complex composition of RPC, it is greatly affected by the performance of raw materials in various regions, and there is no uniform ratio to restrict its large-scale promotion and application. In this paper, the influence of curing temperature and steel fiber type on the ratio of RPC is studied for RPC suitable for prefabricated pavement panels, which provides a reference for RPC application in pavement engineering.

2. Test Overview

2.1 Raw Materials

Cement: It adopts 42.5# ordinary Portland cement produced by a domestic factory. Cement fineness is 3400cm²/g; standard consistency water consumption is 27%; loss on ignition is 0.5%; gypsum content is 3.0%; initial setting time is 2h 40min; final setting time is 3h 40min. The mineral composition of cement is shown in Table 1.

Table 1. Clinker mineral composition of 42.5# cement

| Mineral | C₂S | C₂S | C₃A | C₄AF | f-CaO | f-MgO |
|---------|-----|-----|-----|------|------|------|

1. Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

Published under licence by IOP Publishing Ltd
Steel fiber: It adopts fine round surface copper-plated steel fiber and coarse thread carbon steel fiber produced by a domestic company, with diameters of 0.22mm and 0.35mm, and a length of 12-15mm.

Fine aggregate: fine quartz sand with a particle size range of 0-1.25mm is divided into extra fine sand, fine sand, medium sand, etc. according to the thickness. The measured apparent density and bulk density of quartz sand with different thickness are shown in Table 2.

| Particle Classification/mm | Apparent Density/g/cm³ | Bulk Density/g/cm³ |
|---------------------------|-------------------------|--------------------|
| Extra Fine                | 2.620                   | 1.500              |
| 0.16-0.315                | 2.634                   | 1.440              |
| 0.315-0.625               | 2.627                   | 1.428              |

Special additive for RPC: It is formulated with active minerals such as active SiO₂ and trace elements. The characteristic state is off-white fine powder, and the density is 2.18g/cm³.

High-performance water-reducing agent: a new type of non-naphthalene-based high-performance water-reducing agent produced by a domestic plant, a dark purple transparent liquid, with a water reduction rate of 31%.

2.2 Test Block Production Preparation Process

2.2.1 Test Block Production. The materials are weighed according to the mixing ratio, and the fine aggregate, steel fiber, cement, special additives and other materials are poured into the mixer in a certain order. After the aggregate and steel fiber are fully contacted and reach a macroscopic uniform distribution, add water Stir with water reducer for more than 3min. The slump of the mixed concrete mixture was measured, and the concrete test piece was vibrated and formed on a high-frequency vibrating table. After the forming, it was immediately sent to the curing room, and the mold was removed after 1d. Then put the specimens into curing boxes of different temperatures for curing, and the heating rate should not exceed 15℃ per hour. After reaching the curing temperature, continue curing for 72h. The cured specimens are moved to the standard curing room (20±2℃, humidity more than 90%) curing to the age required for performance measurement.

The RPC test pieces used for testing are divided into two types according to size and application. Among them, the test pieces used for the anti-press strength test are 100×100×100mm cubes, and the test pieces used for the anti-bending strength test are 100×100×400mm prisms.

2.2.2 Test Method. The anti-press strength and anti-bending strength of concrete shall be tested according to the standard for test methods of concrete physical and mechanical properties(GB/T 50081-2019)[8].

The loading speed of anti-press strength is 1.2MPa/s, and the loading speed of anti-bending strength is 0.1MPa/s.

The loading diagram and failure diagram of the test piece used in the anti-bending strength test are shown in Figures 1 and 2.
3. Test Results

3.1 Effect of Curing Temperature on the Strength of RPC. In order to study the effect of different curing temperatures on the RPC anti-press strength, a total of 24 test specimens in 8 groups used in the test were R1 with curing temperature of 60℃, R2 with curing temperature of 75℃, R3 with curing temperature of 80℃, and R4 with curing temperature of 90℃, to compare the anti-press strength of the specimen at 28d curing at different curing temperatures. The mixing ratio and anti-press strength of each RPC test piece are shown in Table 3, and the comparison of test result data is shown on Figure 3.

Table 3. RPC Mix Ratio and Anti-press Strength at Different Curing Temperatures

| Raw Materials          | Age/d | Test Block Number | R1  | R2  | R3  | R4  |
|-----------------------|-------|------------------|-----|-----|-----|-----|
| Water-to-binder Ratio | —     |                  | 0.19| 0.19| 0.19| 0.19|
| Cement/kg/m³          |       |                  | 706 | 706 | 706 | 706 |
| Admixture/kg/m³       | —     |                  | 204 | 204 | 204 | 204 |
| Mineral A/kg/m³       | —     |                  | 92  | 92  | 92  | 92  |
| Fine Quartz Sand/kg/m³| —     |                  | 1336| 1336| 1336| 1336|
| Crude Steel Fiber/kg/m³| —    |                  | 150 | 150 | 150 | 150 |
| High Performance Water Reducer/kg/m³ | —     |                  | 48.8| 48.8| 48.8| 48.8|
| Water/kg/m³           | —     |                  | 176.2| 176.2| 176.2| 176.2|
| Anti-press Strength/MPa| 3    |                  | 135.3| 158.4| 161.5| 163.8|
|                       | 28    |                  | 147.0| 165.4| 166.8| 172.3|

Figure 3. Comparison of Anti-press Strength of RPC of Test Blocks at Different Ages
It can be seen from Figure 3 that under the same conditions of RPC mix ratio, the anti-press strength of RPC increases with the increase of curing temperature. It can be seen that the strength of RPC is obviously different at different curing temperatures. The reason why RPC curing under high temperature conditions can obtain higher anti-press strength is that high temperature curing accelerates the volcanic ash effect of mineral powder and minerals in RPC, which is beneficial to strength growth of.

According to the existing test results, RPC can obtain the maximum anti-press strength with 90℃ hot water curing, but the difference in anti-press strength under 75-90℃ hot water curing is not obvious. When the age is 3d, the anti-press strength of R2 and R3 is about 96.7% and 98.6% of R4 respectively; when the age is 28d, the anti-press strength of R2 and R3 is about 96.0% and 96.8% of R4 respectively. In engineering applications, construction personnel need to comprehensively consider the strength requirements and maintenance difficulty of RPC. Since the RPC strength difference is very small when the curing temperature is 75-90℃, in actual engineering, 75℃ curing temperature is the best choice.

3.2 Effect of Steel Fiber Type on RPC Strength

In order to study the effect of steel fiber types on the anti-press strength of RPC, this study used 8 groups of 24 thin steel fiber and thick steel fiber specimens with the same content for the test, the thin steel fiber specimen number is R5, the thin steel fiber test part number is R6. The steel fiber content of the two groups of test pieces is 200kN/m³, and the curing temperature is 60 ℃. The RPC coordination used is shown in Table 4, the test results are shown in Table 5, and the strength comparison drawn from the test results is shown in Figure 4.

| Test Block Number | Water-to-Binder Ratio | Cement (kg/m³) | Mineral Powder (kg/m³) | Fine Quartz Sand (kg/m³) | Fine Steel Fiber (kg/m³) | Crude Steel Fiber (kg/m³) | High Performance Water Reducer | Water (kg/m³) |
|-------------------|-----------------------|----------------|------------------------|-------------------------|--------------------------|---------------------------|--------------------------------|---------------|
| R5                | 0.19                  | 706            | 204                    | 1386                    | 200                      | —                         | 48.8                           | 176.2         |
| R6                | 0.19                  | 706            | 204                    | 1386                    | —                        | 200                       | 48.8                           | 176.2         |

| Test Block Number | Anti-press Strength/MPa | Anti-bending Strength/MPa |
|-------------------|-------------------------|--------------------------|
|                   | 3d  | 28d  | 3d   | 28d  |
| R5                | 159.5 | 168.3 | 18.2 | 20.1 |
| R6                | 148.8 | 153.5 | 18.1 | 19.6 |
Figure 4. Comparison of Strength of Different Steel Fiber Test Blocks

It can be seen from Figure 5 that the anti-press strength of the thin steel fiber specimen is greater than that of the coarse steel fiber specimen, the anti-press strength is 7.2% greater under 3d curing, and 9.6% greater under 28d curing. The anti-bending strength of the two test blocks is not much different. During the test, it was found that the test block R5 remained intact when it was destroyed, and could still be maintained for a period of time after cracking. The test block R6 was severely damaged locally, and once cracked, it quickly reached its ultimate strength. Observation of the fracture surface of the test piece shows that the fiber content of the R5 concrete fracture surface is very small and the distribution is extremely uneven; on the contrary, the fiber distribution on the R6 concrete fracture surface is dense and uniform; at the same time, it can also be observed Many thick steel fibers were broken, and the thin steel fibers in the test block R6 were almost not broken. Comprehensive test results and observations can be obtained that blending thin steel fibers can ensure better mechanical properties of RPC.

4. Conclusion

Through the above systematic research on the influence of maintenance temperature and steel fiber type on RPC strength, the following conclusions can be obtained:

(1) At the same age, the strength of RPC increases with the increase of curing temperature; in engineering construction, the curing temperature should be 75 ℃;

(2) Incorporating thin steel fibers into RPC can improve its mechanical properties more than coarse steel fibers.

Funding project: E2017202111

References

[1] Meiyan Hang, Yukun Zhou. Experimental research on reactive powder concrete (RPC180)[J]. Bulletin of the Chinese Ceramic Society, 2017(10): 55-60.

[2] Jialiang Kou, Yunhao Liu, Haobo Zhang. Experimental study on mechanical properties and durability of reactive powder concrete[J]. Building Structure, 2018(02) :48-54.

[3] Wenzhong Zheng, Li Li. Preparation of reactive powder concrete and calculation method of its mix ratio[J]. Journal of Hunan University(Natural Sciences), 2009(02): 13-17.

[4] Guoliang Zhan, Dong Lin, Yunze Shen. Research on the effect of curing system on the strength of reactive powder concrete[J]. Building Science, 2016(05): 96-100.

[5] Ahmad S, Zubair A, Maslehuddin M. Effect of key mixture parameters on flow and mechanical properties of reactive powder concrete[J]. Construction and Building Materials, 2015 (99) :73-81.
[6] Xinxing Li, Caiqian Yang, Quan Zhou. Research on Strength and Fluidity of Reactive Powder Concrete Based on Orthogonal Test[J]. Bulletin of the Chinese Ceramic Society, 2019(04) :1201-1210.

[7] TAYABJI S, YE D, BUCH N. Design considerations for jointed precast concrete pavement systems[C]//Transportation Research Board Meeting, 2012.

[8] GB/T 50081-2019, Standard for test methods of concrete physical and mechanical properties[S]. Beijing: China Architecture & Building Press, 2019.