Experimental study on mixing proportion of reactive powder pavement concrete

XiKang Yan¹, Ming Zhou¹
¹School of Civil and Transportation Engineering, Hebei University of Technology, Tian Jin 300401, China
tjsyxk@126.com, 2543119810@qq.com

Abstract: Experimental study is carried out on mixing proportion of reactive powder pavement concrete. Writer studied influence of concrete admixtures such as silica fume, metakaolin and RPC special mineral filler. Studies have shown that: Silica fume can improve compressive strength of RPC. When metakaolin is used to replace some silica fume, compressive strength will decrease, but workability of concrete mixture will improve obviously. Thus, metakaolin should be add up according to specific situation. Special mineral filler can obviously improve construction performance of concrete mixture, reduce viscosity and increase slump without affecting compressive strength. Therefore, it should be add up firstly. At the same time, RPC100, which is suitable for road surface engineering, was successfully prepared, and its mixing proportion and related mechanical properties were obtained.

1. Introduction

RPC(Reactive Powder Concrete) is a kind of ultra-high performance concrete with high strength, high toughness and low porosity developed by Bouygues in 1993.¹,² At present, a lot of research progress has been made on RPC in foreign countries, but the research and application of RPC are still in the initial stage in China, and its design, construction and acceptance specifications lack. There is still no unified standard for the mixing proportion.³

The traditional pavement surface is common cement concrete pavement surface, but its strength is low. When there is vehicle load or aircraft load for a long time, it is easier to cause fatigue damage and other problems. If RPC technology is applied to the pavement surface, these problems can be solved effectively. For example, the runway D expansion project of Tokyo international airport in Japan adopted 6900 prestressed RPC pavement surface as airstrip, and the project is the largest amount of RPC all over the world.⁴

At present, researchers mainly focus on the research of RPC microscopic composition and its own mixing proportion at home and abroad,⁵,⁶ and there are few literature reports on mixing proportion of reactive powder pavement concrete. Therefore, writer carried out an experimental study on mixing proportion of reactive powder pavement concrete, and studied influence of metakaolin, silica fume and special mineral filler on RPC mixing proportion, in order to provide technical reference for its engineering application.

2. Test condition

2.1. Raw materials
Fig 1 shows specimen making process. Cement is 42.5 type ordinary Portland cement, and it is produced by a cement factory in Beijing. Its fineness is 3400cm²/g. Its initial setting time is 2 hours 40 minutes, and final setting time is 3 hours 40 minutes. Its water consumption for standard consistency is 27%, and ignition loss is 0.5%. Table 1 shows mineral composition of cement. Table 2 shows main mechanical properties of cement.

Table 1. Mineral composition of cement.

| Mineral | C₃S | C₂S | C₃A | C₄AF | f-Cao | f-Mgo |
|---------|-----|-----|-----|------|-------|-------|
| Content (%) | 60.5 | 18.1 | 7.4 | 8.9 | 0.9 | 1.8 |

Table 2. Main mechanical properties of cement.

| Indicators | Compressive Strength | Tensile strength |
|------------|----------------------|-----------------|
| Age        | 3d 28d               | 3d 28d          |
| Given value (MPa) | 27 55 | 5.5 9.0 |
| Measured value (MPa) | 46.2 69.2 | 5.17 9.62 |

Silicon fume is produced by an alloy factory in Hebei province. Its density is 2.1g/cm³, and its specific surface area is 20m²/g. Metakaolin is produced in Yangquan of Shanxi province, and its particle size range is 0.16~1.25mm. Steel fiber is made of copper plated steel fiber with thin round surface and it is produced in Hebei province. Its diameter is 0.22mm, and length is 12~15mm. Special mineral filler is made of a variety of active minerals, which is prepared by combination test of activity and calculation of optimal particle size distribution, and main chemical composition is SiO₂ and trace elements. Its characteristic state is gray white fine powder and density is 2.18g/cm³.

Water reducing agent is a new non-naphthalene series high performance water reducing agent and it is produced by a concrete admixture factory in China. It is dark purple transparent liquid. Its water reducing rate is 31%, and there is no slump loss in 1 hour.

2.2. Specimen making

Each material was weighed according to mixing proportion. Putting fine aggregate, steel fiber, cement, special mineral filler, silica fume, metakaolin into mixer. After aggregate and steel fiber were fully contacted and evenly distributed, adding up water and water reducing agent, and keeping on them mixing fully for more than 3 minutes. Concrete mixture was measured determine slump, and then specimens were vibrated on the high-frequency vibration table. Then specimens were sent to curing room immediately after vibrated forming, and mold was removed 1 day later. Specimens were placed into curing boxes at different temperatures for curing, and heating rate was lower with 15°C per hour. After reaching the curing temperature, specimens were further cured for 72h. Then, specimens were
moved into standard curing (20±2°C, humidity above 90%) and cured to age required for the determination of performance.

2.3. Specimen size and test method
Compressive strength specimens were cube of 100×100×100mm, and flexural strength specimens were prism of 100×100×400mm. Cube compressive strength and flexural strength were tested according to the test method for mechanical properties of ordinary concrete (GB/T50081-2019). Compressive strength and flexural strength of prismatic were tested according to the test method for strength of cement colloidal sand (GB/T0506-2005).

3. Analysis of test results

3.1. Influence of metakaolin and silica fume on compressive strength
Silica fume is a kind of high activity, super fine particle admixture. It contains high content of SiO2, and it can increase strength of concrete. Metakaolin, as a new auxiliary cementing material, can improve workability of concrete. Writer studied influence when mixing metakaolin with silica fume. Table 3 shows mixing proportion and compressive strength of concrete. Fig 2 shows compressive strength curve.

| Table 3. Mixing proportion and compressive strength of concrete (kg/m³). |
|---|---|---|---|---|
| Raw materials | Age | Specimen number |
| | | R1 | R2 | R3 | R4 |
| Water/cement ratio | — | 0.19 | 0.19 | 0.19 | 0.19 |
| Cement | — | 705 | 705 | 705 | 705 |
| Silica fume | — | 176 | 132 | 230 | 172 |
| Metakaolin | — | — | 44 | — | 58 |
| Standard sand | — | 1358 | 1358 | 1358 | 1358 |
| Steel fiber | — | 200 | 200 | 200 | 200 |
| Waterreducing agent | — | 47.1 | 47.1 | 47.1 | 47.1 |
| Water | — | 176.6 | 176.6 | 176.6 | 176.6 |
| Slump (mm) | — | 100 | 130 | 180 | 220 |
| Viscosity | — | large | large | large | large |
| Compressive strength (MPa) | 3d | 128.9 | 118.0 | 132.8 | 125.7 |
| | 7d | 145.4 | 127.1 | 154.2 | 135.2 |
| | 28d | 140.8 | 124.2 | 146.3 | 128.8 |

Note: dosage of metakaolin is 25% of dosage of admixture.
Figure 2. Compressive strength curve.

It can be seen from Fig 2 that compressive strength of R1 and R3 is greater than R2 and R4. Results showed that compressive strength of concrete decreased when partial metakaolin was used to replace silica powder. At the same time, compared to R1, 3-day compressive strength of R2 decreased by 8.45%, and compared to R3, 3-day compressive strength of R4 decreased by 5.34%. Compared to R1, 28-day compressive strength of R2 decreased by 11.79%, and compared to R3, 28-day compressive strength of R4 decreased by 11.96%. Writer concluded that enhancement effect of silica fume on compressive strength is obviously greater than metakaolin. Concrete compressive strength will decrease obviously when content of metakaolin was increased. Compressive strength with only adding up silicon fume is greater than mixing silicon fume with metakaolin.

Compared to R1, slump value of R2 increased by 30% and compared to R3, slump value of R4 increased by 18%. It shows that workability of concrete will improve obviously when adding up some metakaolin. Writer thought that metakaolin is mineral admixture of highly active pozzolanic material. Its internal reaction is similar to fly ash. It can increase strength of cement slurry, increase compressive strength of concrete. However, if content of metakaolin is too high, morphology of the flake particles on the surface greatly weakens morphology distribution of the particles, resulting in uneven distribution in the cement, and it would decrease compressive strength of concrete.\[7\]

3.2. Influence of special mineral filler on working performance and compressive strength
Special mineral filler can significantly improve working performance of concrete mixture and reduce slump loss. It is made of a variety of minerals and trace elements. Table 4 shows mixing proportion and compressive strength. Fig 3 shows compressive strength curve.

Table 4. Mixing proportion and compressive strength of concrete(kg/m³).

| Raw materials          | Age | Specimen number |
|------------------------|-----|-----------------|
|                        |     | R5              | R6              |
| Water/cement ratio     | —   | 0.19            | 0.19            |
| Cement                 | —   | 706             | 706             |
| RPC special mineral filler | —  | 204             | —               |
| Silica fume            | —   | —               | 204             |
| Standard sand          | —   | 1286            | 1286            |
| Steel fiber            | —   | 200             | 200             |
| Water reducing agent   | —   | 47.1            | 47.1            |
| Water                  | —   | 176.6           | 176.6           |
It can be seen from Fig 3 that compressive strength of R5 is greater than R6. Compared to R5, 3-day and 28-day compressive strength of R6 decreased by 0.32% and 2.61%. Compared to R6, slump value of R5 significantly increased, viscosity was smaller, and construction performance obviously improved. At the same time, 3-day and 28-day compressive strength of R5 and R6 are almost same, indicating that special mineral filler can be added up for mixing proportion design. Composition of special mineral filler is SiO₂ and trace elements, and its internal reaction is similar to silicon fume. It can react with Ca(OH)₂ and produce hydrated calcium silicate. This reaction will increase cementstone skeleton, decrease porosity and increase compressive strength of concrete. In addition, special mineral filler is grey powder with low density and can improve workability of concrete mixture.

3.3. Mixing proportion of RPC100
At present, relevant mixing proportion of RPC is still a trade secret in China. Therefore, combined with the above test results, mixing proportion of RPC100 which is suitable for pavement engineering was successfully prepared in the laboratory. Table 5 shows mixing proportion of RPC100. Table 6 shows mechanical properties of RPC100.

### Table 5. Mixing proportion of RPC100.

| Cement /kg | Special mineral filler/kg | Quartz sand/kg-coarse | Quartz sand/kg-medium | Quartz sand/kg-fine | Steel fiber /kg | Water reducing agent/kg | Water /kg |
|------------|---------------------------|------------------------|-----------------------|---------------------|-----------------|------------------------|-----------|
| 706        | 204                       | 368                    | 736                   | 191                 | 200             | 47.1                   | 176.6     |

### Table 6. Mechanical properties of RPC100.
Concrete level  Compressive strength/MPa  Tensile strength/MPa  Flexural strength/MPa
RPC100  126.6  12.66  15.7

4. Conclusion
(1) Silica fume can improve compressive strength of RPC. When metakaolin is used to replace some silica fume, compressive strength will decrease, but workability of concrete mixture will improve obviously. Thus, metakaolin should be added up according to specific situation.

(2) Special mineral filler can obviously improve construction performance of concrete mixture, reduce viscosity and increase slump without affecting compressive strength. Therefore, it should be added up firstly.

(3) According to the test results, mixing proportion and related mechanical properties of RPC100 are obtained.

Funding project: E2017202111

References
[1] Richard P, Cheyrezy M. Composition of Reactive Powder Concrete Research[J]. Cement and Concrete Research, 1995.25(7): 1501-1511
[2] Richard P, Cheyrezy M. Composition of Reactive Powder Concrete Research[J]. Cement and Concrete Research, 1995.25(11): 1501-1511
[3] Zheng Wen Zhong, Lu Xue Yuan. Research progress of reactive powder concrete[J]. Journal of Building Structures 2015(10): 44-58
[4] Musha H, Ohkuma H, Kitamura T. Innovative UFC structures in Japan[C]//International Symposium on Ultra-High Performance Fibre-Reinforced Concrete. Marseille, France: RILEM Publications, 2013: 17-26.
[5] Cheyrezym, Maretv, Frouinl. Microstructural analysis of RPC [J]. Cement and Concrete Research, 1995, 25(7): 1491-1500.
[6] Feylessoufi A, Villieras A, Michot L J. Water environment and nanostructural network in a reactive powder concrete[J]. Cement and Concrete Composites, 1996, 18(1): 23-29.
[7] Li Gang. Study on the preparation, characteristics and mechanism of new environmental protection RPC. Master's thesis of southeast university, 2001, 5.