Workability and mechanical property of low grade pumping concrete modified by recycled coarse aggregate

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Abstract. In recent years, the construction industry has entered a stage of rapid development in China with more and more construction waste, which has a great negative impact on natural resources and environment. These building wastes can be processed into recycled aggregate by sorting, crushing and processing. This kind of technology can realize the recycling of construction waste [1]. In order to promote the research and application of recycled aggregate concrete, this paper probes into the effect of recycled coarse aggregate (RCA) on the performance of pump concrete. By using the orthogonal test to studied the impact of the amount of fly ash, replacement of RCA and change of sand rate on the mechanical properties of C30 recycled pump concrete (RPC). By adjusting water consumption to ensure RPC pump requirements. The pump concrete prepared by natural coarse aggregate (NCA) was treated as a control group, which was called natural pump concrete (NPC). The experimental results show that the best proportion of RPC, fly ash content, recycled aggregate content, sand rate respectively are 40wt%, 50wt% and 45wt%.

1. Introduction

RCA are processed by waste of built (structure) concrete, mortar, stone and brick, in a diameter greater than 4.75mm particles. Concrete pumping technology rapid development, has become an important technical means of building construction, widely used in all kinds of construction projects. It is of great significance to prepare RPC with RCA instead of NCA. Scholars at home and abroad have carried out extensive research on the preparation of various types of concrete with recycled aggregate, and continuously improve the recycling rate of construction waste.

Zhang Yanqing [2] found that the higher of cycled aggregate strength, the better the recycled concrete strength. Akbarnezhad A et al. [3] studied the content of recycled aggregate mortar and the effect of attached mortar quality on the compressive strength of recycled concrete. The results show that the compressive strength of recycled concrete approximately decreases linearly with the increase of the paste content, the better the quality of the attached mortar, the higher the compressive strength of the recycled concrete.

2. Raw Materials

2.1. Coarse Aggregates

The RCA used for the experiment is a continuous grading of 5~25mm, from the Dongguan construction waste treatment plant. The NCA used for testing is a continuous grading of 4.75~25mm particle size, which is taken from the concrete mixing station of Shenzhen port. The particle grading of two coarse aggregate are shown in figure 1.
Figure 1. Particle size distribution of two coarse aggregate

Through figure 2, the analysis of the composition of RCA, it can be seen that the main components include the waste old natural aggregates, waste cement and tile blocks, respectively accounting for 78.8wt%, 18.5wt% and 2.7wt% respectively. There are also a few impurities, which mainly include scrap metal, waste glass, tile, waste plastic and small stick, etc. accounting for 0.02wt% of the total components. Compared with NCA, the RCA composition is more complex.

Figure 2. Analysis results of recycled aggregate composition

Table 1. Physical properties of NCA and RCA

| Coarse aggregate | Loose packing density /kg/m³ | Compact packing density /kg/m³ | Apparent density /kg/m³ | Water absorption/% | Crushing value/% | Needle plate content/% | Sediment percentage/% | Void fraction/% | Solidity |
|------------------|----------------------------|-------------------------------|------------------------|-------------------|------------------|----------------------|----------------------|-------------|---------|
| NCA              | 1461                       | 1548                          | 2645                   | 0.5               | 11               | 5                    | 1.60                 | 44          | 0.39    |
| RCA              | 1294                       | 1389                          | 2601                   | 2.1               | 16               | 6                    | 1.22                 | 50          | 6.20    |

There are big difference between the basic properties of RCA and NCA when the particle size distribution is basically the same. Compared with NCA, the RCA composition is complex. Some of the crushed stone surfaces are covered with waste water slurry, rough and multi-edge. After secondary processing, the number of internal microcracks increases. You can see from the table 1 that it has low
accumulation density and apparent density, high water absorption, crushing index, porosity and needle chip content.

2.2. Fine Aggregates
The fine aggregate of the test is natural river sand, which is taken from the concrete mixing station of Shenzhen port. According to industry standard JGJ 52-2006 to test the grain size distribution of river sand, the results showed that the river sand fineness modulus is 2.7, belong to medium sand II area.

2.3. Binders
In this study, cementing materials include cement, fly ash and slag powder. The cement is PO. 42.5R provided by the cement supplier. Fly ash is grade II from Mawanin Shenzhen. The slag powder is the S95-grade mineral powder provided by Xiaoyetian in Shenzhen. The physical properties of the cementing material are shown in the table 2 and table 3.

| Table 2. Physical properties of slag, fly ash and cement |
|----------------------------------------------------------|
| 7d Strength /MPa | 28d Strength /MPa | Density /g/cm³ | sieve residue percentage/% | Specific surface area/m²/kg | fluidity |
|------------------|-------------------|----------------|---------------------------|-----------------------------|---------|
| Cement           |                   |                |                           |                             |         |
| 8.73                  | 75.77              | 9.2            | 85.1                      | 2.500                       | 7.36    | -      | 260 |
| Fly ash           |                   |                |                           |                             |         |
| 3.93                  | 47.39              | 7.9            | 57.1                      | 3.030                       | 0.41    | 483    | 273 |
| Slag             |                   |                |                           |                             |         |
| 6.78                  | 51.48              | 8.0            | 93.5                      | 3.229                       | 0.57    | 343    | 248 |

3. Experimental Procedure
In the experiment, mineral admixtures are composed of fly ash and slag micropowder, replacing 53wt% of cement. The three variables are fly ash content, regeneration aggregate substitution rate and sand rate respectively. The factor level design is shown in table 3.

| Table 3. The design table of orthogonal experiment |
|-----------------------------------------------|
| FA/wt% | SP/wt% | RCA/wt% |
|-------|-------|--------|
| Level1 | 30    | 43     | 50    |
| Level2 | 35    | 45     | 75    |
| Level3 | 40    | 47     | 100   |

Note: FA represents fly ash; SR represents sand ratio; RCA represents the content of recycled coarse aggregate.
Table 4. The elaborate mixture proportions of concrete

| Mix no. | NCA /Kg/m³ | RCA /Kg/m³ | Sand /Kg/m³ | FA Kg/m³ | Slag Kg/m³ | Cement Kg/m³ | Water reducing agent/Kg/m³ | Water Kg/m³ |
|---------|-------------|-------------|-------------|----------|------------|---------------|----------------------------|-------------|
| A1      | 524.1       | 524.1       | 790.8       | 102.0    | 78.2       | 159.8         | 5.783                     | 140.0       |
| A2      | 252.9       | 758.6       | 827.6       | 102.0    | 78.2       | 159.8         | 5.783                     | 156.9       |
| A3      | 262.1       | 262.1       | 790.8       | 119.0    | 61.2       | 159.8         | 5.783                     | 166.9       |
| A4      | 0.0         | 1011.5      | 864.3       | 119.0    | 61.2       | 159.8         | 5.783                     | 161.9       |
| A5      | 487.3       | 487.3       | 864.3       | 119.0    | 61.2       | 159.8         | 5.783                     | 141.1       |
| A6      | 505.8       | 505.8       | 827.6       | 119.0    | 61.2       | 159.8         | 5.783                     | 132.1       |
| A7      | 243.7       | 731.0       | 864.3       | 119.0    | 61.2       | 159.8         | 5.783                     | 138.9       |
| A8      | 1011.5      | -           | 827.6       | 119.0    | 61.2       | 159.8         | 5.783                     | 147.6       |

The workability of premixed concrete was adjusted by controlling the amount of water. The extent of slump is in 180±20mm, and the range of extensibility is 450±30mm to ensure the pumpability of concrete. The mechanical properties of C30 RPC and normal C30 NPC were compared and analyzed.

The slump of concrete is measured according to GB 50080-2002. The concrete compressive strength test takes shape with a size of 100mm x 100mm x 100mm. The forming test block is maintained under standard curing conditions, and the curing temperature is about 20°C, and the humidity is about 95%. The compressive strength of concrete is tested according to GB 50081-2002, which tests the strength of 7d and 28d respectively. The different matching concrete is shown in table 4.

4. Results and Discussions

The workability and mechanical properties of the concrete are listed in table 5.

Table 5. The workability and mechanical property results of concrete

| Mix no. | FA/wt% | SP/wt% | RA/wt% | Slump value/mm | Extension degree/mm | Compressive strength/MPa 3d | Compressive strength/MPa 7d | Compressive strength/MPa 28d | Water -cement ratio |
|---------|--------|--------|--------|----------------|----------------------|-----------------------------|----------------------------|----------------------------|---------------------|
| A1      | 30     | 43     | 50     | 195            | 400                  | 23.5                        | 28.4                       | 41.5                      | 0.43                |
| A2      | 30     | 45     | 75     | 200            | 385                  | 20.7                        | 24.7                       | 38.4                      | 0.48                |
| A3      | 30     | 47     | 100    | 180            | 380                  | 18.0                        | 22.5                       | 35.0                      | 0.51                |
| A4      | 35     | 43     | 75     | 185            | 390                  | 23.8                        | 27.5                       | 40.6                      | 0.43                |
| A5      | 35     | 45     | 100    | 190            | 380                  | 20.3                        | 24.3                       | 36.1                      | 0.49                |
| A6      | 35     | 47     | 50     | 195            | 380                  | 22.3                        | 26.4                       | 41.7                      | 0.43                |
| A7      | 40     | 43     | 100    | 185            | 390                  | 20.7                        | 23.6                       | 36.1                      | 0.46                |
| A8      | 40     | 45     | 50     | 190            | 450                  | 25.0                        | 30.6                       | 44.1                      | 0.40                |
| A9      | 40     | 47     | 75     | 190            | 405                  | 25.7                        | 29.5                       | 45.8                      | 0.42                |
| A0      | 15     | 38     | 0      | 180            | 460                  | 19.5                        | 28.9                       | 45.4                      | 0.45                |

4.1. Concrete Mixtures

According to the results listed in table 5, the designed RPC can meet the pumping performance. The results of concrete water-cement ratio(W/C) are shown in the table 6.
Table 6. Analysis of range of water cement ratio of concrete

| Performance indicators | FA/wt% | SP/wt% | RCA/wt% |
|------------------------|--------|--------|---------|
| k1                     | 0.47   | 0.44   | 0.42    |
| k2                     | 0.45   | 0.46   | 0.44    |
| k3                     | 0.43   | 0.45   | 0.49    |
| range                  | 0.04   | 0.02   | 0.07    |

As can be seen from the table 6, with the increase of fly ash, the W/C decreases gradually; with the increase of sand ratio, the W/C increases first and then decreases; with the increase of the amount of recycled aggregate, the W/C is gradually increasing. The analysis shows that the replacement rate of RCA is the most important factor affecting the W/C of the RPC.

The reasons are as follows: (1) the surface of the RCA is rough and angular, and it is wrapped in a large amount of mortar, which increases the porosity and water absorption capacity. (2) In the process of crushing, the RCA can produce a large number of tiny cracks within it, which results in the reduction of its density and the enhancement of water absorption. (3) The composition of RCA is complex. It has more waste brick, mortaret, which leads to the more capillary lines in the RCA, so it is easy to produce capillary phenomenon. Capillarity causes the water on the aggregate surface to migrate to the interior, partly stored in the voids within the aggregate, which can not provide the workability for the concrete.

According to the table 6 can see the W/C is an important index to influence the mechanical properties of concrete, W/C is too large, the compressive strength is lower. This is because the more water, the more free water in the RPC. The free water partially evaporates, resulting in the gradual formation of unrulable and interpenetrating capillary interstice in the cement, thus reducing the strength of the RPC. Therefore, the W/C should be reduced as far as possible under the design requirements.

4.2. Mechanical Property of Concrete

Table 7. Compressive strength analysis of recycled pump concrete [MPa].

| Age  | FA/wt% | SP/wt% | RCA/wt% |
|------|--------|--------|---------|
| 7d   | k1     | 25.2   | 26.5    | 28.5    |
|      | k2     | 26.1   | 26.6    | 27.2    |
|      | k3     | 27.9   | 26.1    | 25.8    |
|      | range  | 2.7    | 0.4     | 2.6     |
|      | Optimal solution | A3 | B2 | C1 |
|      | k1     | 38.3   | 39.4    | 42.4    |
|      | k2     | 39.4   | 39.5    | 41.6    |
|      | k3     | 42.0   | 40.8    | 35.7    |
|      | range  | 3.7    | 1.4     | 6.7     |
|      | Optimal solution | A3 | B3 | C1 |

Table 5 lists the results of compressive strength of RPC in each group. A8 concrete has the best workability, its early 7d compressive strength are higher than A0, and the compressive strength of 28d is only lower than that of A0 concrete 1.7MPa. All concrete block 28d compressive strength results meet strength design standard according to JGJ 55-2011 C30. The standard value of the designed concrete compressive strength is 34.5 MPa.

The concrete compressive strength analysis is shown in table 7. The main factors affecting the compressive strength are the content of fly ash and the replacement rate of RCA. The effect of RCA replacement rate on the compressive strength of 28d reached 6.7. In comparison, the effect of sand rate on compressive strength of concrete is small. When the sand rate is 43wt%, the workability of RPC is
poor, which is not conducive to meet the pump requirement of concrete. Therefore, from the 7d compressive strength point of view, the best experimental ratio is 40% of fly ash content, 45% of sand rate, 50wt% of recycled aggregate content, namely A3B2C1; From the point of view of 28d compressive strength, the best experimental ratio is 40wt% of fly ash, 47wt% of sand, 50wt% of recycled aggregate, that is A3B3C1.

The strength of RPC increases with the increase of fly ash content. The main reasons include: (1) The morphological effect of fly ash reduces water consumption and reduces the W/C. Its filling effect reduces the proportion of harmful holes in RPC. The two interact with each other to enhance the density and strength of RPC. (2) The secondary hydration reaction of fly ash and Ca(OH)\textsubscript{2} produced during the hydration process of cement clinker. The weak zone produced by the existence of Ca(OH)\textsubscript{2} is reduced, and the capillary gap is filled, therefore, the compactness of the RPC is improved. (3) Remixing slag and fly ash in RPC can make the activity of both complement and stimulate each other, thus improving the strength of RPC.

The strength of RPC decreases with the increase of the replacement rate of RCA. The main reasons include: (1) The composition of the RCA is too complex, and the interface between the RCA and the new water mud is diverse and heterogeneous. Including the interface area of the old and new cement mortars; the interface area formed by old aggregate and new cement mortars; an interface area formed by old aggregate and old cement mortars. These interface areas are weak. When pressed, the stress concentration can be generated, and the strength of the RPC is reduced. (2) The higher the replacement rate of RCA, the higher old adhered mortars content. According to the research, the compressive strength of the recycled concrete decreases linearly with the increase of the content of old adhered mortars. (3) The accumulation density and apparent density of recycled aggregates are low, the water absorption rate, crushing index and needle chip content are high, which has adverse effects on the strength of the regenerated pump concrete [4].

The effect of sand rate on the RPC's 7d, 28d compressive strength is small, and there is no obvious change rule. Therefore, it can be said that the sand rate has no great influence on the compressive strength of RPC. When sand ratio is appropriate, not only fill the gap of gravel, the sand aggregate but also can guarantee a certain thickness between the mortar layer, reduced the sliding resistance of coarse aggregate, in the end, the fresh concrete has good liquidity [5]. The effect of sand rate on the workability of RPC is significant.

5. Conclusion
(1) Compared with other factors, the replacement of RCA has a great influence on RPC W/C and strength. The RCA are complex. The water absorption rate, crushing index and robustness are higher than NCA, which is not conducive to the development of concrete strength.

(2) The water consumption is adjusted to meet the pumping capacity of the RPC, and all the 28d compressive strength of the RPC can satisfy the compressive strength of its design. The experiment shows that in the C30 RPC, the RCA can partially or completely replace the NCA. The optimum blending ratio is: 40wt% of fly ash content, 45wt% sand rate and 50wt% recycled aggregate.

(3) To improve the replacement ratio of RCA in the C30 RPC will inevitably reduce the strength and workability of RPC. In practical application, the method of regulating fly ash content and sand rate can be used to solve this problem.

References
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