Research on Mix Design and Impermeability Test of Fully Recycled Concrete Based on Building Materials

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Abstract. Reclaimed concrete may successfully accomplish concrete recycling, cut down on resource waste, and advance environmental and green development. This work studies the impermeability performance of totally recycled coarse aggregate concrete by designing the mix ratio using the coarse aggregate found in construction waste as the research point. The findings indicate that the seepage performance of recycled concrete will be influenced by the fly ash concentration, water ash ratio, and water reduction agent. The impermeability performance of reclaimed concrete decreases when the water cement ratio rises, but only to a limited extent. The best impermeability results from reclaimed concrete when the water reduction agent content is 0.5%; the best impermeability results from fly ash when it is 10%; and the greatest impermeability results from reclaimed concrete when it is not added.

Keywords: construction waste; recycled concrete; mix ratio design; impermeability.

1 Introduction

Relaimed concrete is the abandoned concrete block after crushing, cleaning, grading after a certain proportion and the graded mixed part or all instead of the natural aggregate (mainly coarse aggregate) and then add cement and water with the new concrete[1-4]. Studying recycled concrete can help to solve the problem of treating waste concrete and reduce environmental pollution and resource consumption. Compared with ordinary concrete, the performance and durability of reclaimed concrete have been significantly improved, which broadens its application scope. Tangchirapat[5]It is found that the water-cement ratio is unchanged, the permeability coefficient of 28d and 90d of general concrete is lower than that of reclaimed concrete, and the impermeability coefficient of reclaimed concrete is positively correlated with the substitution rate of recycled aggregate and the particle size of aggregate, among which the greater the substitution rate, the higher the impermeability coefficient. And Zaharieva et al[6]The surface permeability, air permeability and water permeability of reclaimed concrete are compared with natural concrete. The study shows that the water permeability of reclaimed concrete is 2 times higher than that of natural concrete. Hu Yaowen[7]Through the experiment, the influence of the replacement rate and water cement ratio on the

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impermeability of recycled concrete is explored. When the replacement rate and water cement ratio are low, the water absorption coefficient is correspondingly low, and the impermeability of recycled concrete is ideal. Zhang Li li[8]Through the comparison experiment of natural concrete and reclaimed concrete, the influence of strength, water-cement ratio and sand ratio on the impermeability of reclaimed concrete is explored.

Scholars at home and abroad have analyzed and studied the impermeability of reclaimed concrete through water cement ratio, replacement ratio, natural concrete and reclaimed concrete, and achieved some results. But the research direction is not limited to this, the mix ratio, the use of mineral admixture, water-reducing agent content will affect the permeability of concrete. Through reasonable material selection and process control, the concrete with low permeability can be prepared, thus improving the durability and safety of the concrete structure.

2 Selection of raw materials

2.1 The coarse aggregate

In the test, the recycled aggregate comes from the waste concrete fragments, and its strength grade is measured as C25-C40 by the digital display rebound instrument. After crushing by the compression test machine, then crushing into a small particle size by manual crushing and screening out by the sieve machine. Finally, the continuous granular recycled coarse aggregate is obtained. The apparent density was 2490 (kg/m^3), A packing density of 1210 (kg/m^3), The moisture content is 3.45%, the water absorption rate is 7.70%, the regenerated aggregate and natural aggregate are generally dry, the surface of the regenerated aggregate presents many cracks and edges, and its surface characteristics are similar to the gravel[9].

2.2 Standard sand

SiO_2 of standard sand used in the test 98%, wet content 0.2% and composition of natural round silica sand, and its particle distribution is shown in Table 1.

Table 1. Particle distribution of ISO reference sand.

Square hole sieve hole size / (mm)	2.00	1.60	1.00	0.50	0.16	0.08
Cumulative screening /%	0	7±5	33±5	67±5	87±5	99±5

2.3 Cement

The cement grade used in the test is marked as P. O 42.5. See Table 2 to meet the quality index requirements of GB175-2007 standard.

Table 2. Cement performance indicators

The amount of gypsum mixed (%)	The grinding aid(%)	The mixture content (%)	specific area (%)	loss on ignition (%)	Chloride ion concentration of (%)	MgO (%)	SO_3 (%)	Primary setting time (min)	Primary setting time (min)
8.0	0.04	13	350	3.50	0.042	3.5	2.6	208	292

2.4 With an admixture

Concrete admixture is a substance added in order to improve the performance of newly mixed or hardened concrete. Adxxture has become the fifth important component of the preparation of concrete except cement, sand, stone and water, and its cost is low, has obvious effect, and has significant technical and economic benefits[10].

2.5 Fly ash

Fly ash is a kind of mineral admixture, which is composed of glass crystals and a small amount of unburned carbon particles, which contains the active ingredients to be active SiO_2, Al_2O_3Under the influence of water, it can react with alkaline substances or salts, and the compounds formed have cemelling characteristics and are stable. Fly ash is generally used as the raw material of concrete, and its composition, structure and performance are the important technical parameters related to fly ash concrete[11].

3 Test protocol design

3.1 Test mix ratio

The design concrete strength in this test is C30, the slump range of the designed mixture is within 35~50mm, and the ordinary Portland cement with strength grade is 42.5MPa. The coarse aggregate was continuously graded with a particle size between 4.75 and 20 mm.

The mix ratio is calculated according to the General Composite Mix Design Specification (JGJ 55-2011):

(1) Preparation strength: fcu,t=fcu,k+1.645=30+1.645×5=38.225MPa.

(2) Water-glue ratio:$\frac{W}{B} = \frac{\alpha_a f_b}{f_{cu,0}} = \frac{0.53\times42.5\times1.16}{38.225+0.53\times0.2\times49.3} = 0.60$.

among$f_b = \gamma_f\gamma_s f_{ce} = \gamma_f\gamma_s\gamma_c f_{ce.g} = 1.0 \times 1.0 \times 1.16 \times 42.5 = 49.3$.

(3) Water consumption: the slump of the designed mixture is 35~50mm, the maximum particle size of gravel is 20mm, and the water consumption per cubic meter of concrete is $m_{w0} = 195$kg.

(4) Cement dosage: no mineral admixture is added in this test, so the amount of concrete cement per cubic meter of cement material is $m_{c0} = m_{b0} = \frac{m_{w0}}{W/B} = \frac{195}{0.6} = 325kg$.

(5) Sand rate: the water-cement ratio in this test is 0.6, the maximum particle size of gravel is 20mm, the sand rate of standard inspection β_s is 35%~40%, and the sand rate selected in this test β_s is 40%.

(6) The dosage of coarse and fine aggregate: calculated by mass method.

$$m_{fo} + m_{co} + m_{go} + m_{so} + m_{w0} = m_{cp}$$

$$\beta_s = \frac{m_{s0}}{m_{g0} + m_{s0}} \times 100\%$$

From the known data, the amount of coarse aggregate per cubic meter is 1128kg, the amount of fine aggregate per cubic meter is 752kg.

(7) Initial mix ratio.

Cement: water: sand: crushed stone =325:195:752:1128,

$C_0 : W_0 : S_0 : G_0$=1:0.60:2.31:3.47.

(8) Final mix ratio.

Considering the water content of sand and gravel, the adjusted final mix ratio is:

Cement: water: sand: crushed stone =320:160:750:1100,

$C_0 : W_0 : S_0 : G_0$=1:0.50:2.34:3.44.

(9) Water reducing agent.

The influence of water reducer on unit water consumption is not considered in this test. The amount of water reducer per cubic meter of concrete is 3.25kg.

3.2 Test protocol

The concrete impermeability test specimen is a head cone according to the test Code for Cement and Cement Concrete of Highway Engineering (JTG 3420-2020)The specific parameters are upper diameter 175mm, lower diameter 185mm and height 150mm respectively. The influence of water ash ratio, water reducing agent and fly ash content on the fully recycled concrete, the water ash ratio is 0.3,0.35,0.4,0.45 and 0.5; the water reducing content is 0%, 0.2%, 0.3%, 0.4%, 0.5% and 0.6%; and the fly ash content is 0%, 10%, 20%, 30% and 40%. A total of 16 test groups with 6 specimens for each group are shown in Table 3.

Table 3. Recycled concrete mix proportion (kg/m^3)

water cement ratio	Water-reducing agent mixing amount of (%)	Wa-ter-redu cing agent	Fly ash dosage (%)	flyash	cement	water	Regenera-tion of coarse aggregate	sand
0.30	0	0	0	0	400	183.36	1100	750
0.35	0	0	0	0	400	203.36	1100	750
0.40	0	0	0	0	400	223.36	1100	750
0.45	0	0	0	0	400	243.36	1100	750
0.50	0	0	0	0	400	263.36	1100	750
0.30	0	0	0	0	400	183.36	1100	750
0.30	0.2	0.8	0	0	400	183.36	1100	750
0.30	0.3	1.2	0	0	400	183.36	1100	750
0.30	0.4	1.6	0	0	400	183.36	1100	750
0.30	0.5	2.0	0	0	400	183.36	1100	750
0.30	0.6	2.4	0	0	400	183.36	1100	750
0.30	0	0	0	0	400	183.36	1100	750
0.30	0	0	10	40	400	183.36	1100	750
0.30	0	0	20	80	400	183.36	1100	750
0.30	0	0	30	120	400	183.36	1100	750
0.30	0	0	40	160	400	183.36	1100	750

3.3 Test process

HP-40 automatic pressurized concrete impermeability meter is used for impermeability test, according to GB 50164 " Concrete Quality Control Standard The impermeability marking method is used to measure the impermeability of concrete. The immark test is as follows:

6 round-shaped specimens in a group, the specimens are loaded into the im-moometer for test. The applied water pressure shall be started at 0.1MPa and increased by 0.1MPa every 8 hours. Keep applying water pressure until 3 of the 6 specimens are penetrated by pressure water. The test is stopped then the water pressure value at this time is recorded and the antipermeability mark is calculated according to formula (1).

$$P=10H-1 \quad (1)$$

Formula: P —— concrete impermeability grade;
H —— 6 specimens have 3 specimens with water pressure, MPa.

4 Test results and analysis

4.1 Influence of water-cement ratio on the impermeability of reclaimed concrete

In this experiment, 5 groups of water-ash ratio were designed. After preparing standard curing, the impermeability test was conducted, and the following five water pressure and impermeability grades were obtained (Table 4).

Table 4. Impermeable pressure and grade of recycled coarse aggregate concrete

Effective water-ash ratio	water gage (MPa)	Anti-seepage grade
0.30	1.7	>P12
0.35	1.4	>P12
0.40	1.3	P12
0.45	0.9	P8
0.50	0.4	—

The water cement ratio affects the impermeability of concrete. When the water-cement ratio is 0.3, the fully recycled coarse aggregate concrete reaches the maximum impermeability pressure of 1.7MPa; when the water cement ratio is 0.5, the impermeability pressure of fully reclaimed coarse aggregate concrete reaches the minimum of 0.4MPa, and the concrete does not have the impermeability. The reason for the above phenomenon is that the water contained in the cement hydration slurry increases, which makes the cement stone and water slowly form an irregular and interconnect capillary system. With the evaporation of water, the water-cement ratio increases, and the pores of the cement slurry increases in the hydration reaction, making the impermeability of concrete worse and worse.

4.2 Influence of water-reducing agent on the impermeability performance of reclaimed concrete

In this experiment, 6 groups of water-reducing agents were designed. After preparing standard curing, the impermeability test was conducted, and the following 6 water pressure and impermeability grades were obtained (Table 5).

Table 5. Impermeable pressure and grade of recycled coarse aggregate concrete

Water-reducing agent mixing amount of (%)	water gage (MPa)	Anti-seepage grade
0	0.8	P7
0.2	0.8	P7
0.3	0.9	P8
0.4	1.3	P12
0.5	1.5	＞P12
0.6	1.3	P12

The reclaimed concrete measured in this test has immopermeability, in which the impermeable pressure of the reclaimed concrete with the amount of 0.5% is the strongest, which increases the water pressure by 0.7MPa compared with the unadded water reducer. The effect of 0.2% water reducing agent was the same, and the effect of 0.5% polycarboxylic acid water reducing agent was the best. The reason for this phenomenon is that the reclaimed concrete can improve the impermeability. Add water reducing agent to the concrete mixture to evaporate the residual water under the action of cement hydration, so that the concrete pores are not easy to be separated by water. Polycarboxylic acid water reducing agent also has dispersion and air absorption, which makes the concrete pore more uniform and improves the pore structure; the pore diameter is more refined, and the porosity is continuously reduced, improving the compaction.

4.3 Impact of fly ash on recycled concrete

In this experiment, 5 groups of fly ash content were designed. After preparing standard curing, the impermeability test was carried out, and the following 5 water pressure and impermeability grades were obtained (Table 6).

Table 6. Impermeable pressure and grade of recycled coarse aggregate concrete

Fly ash dosage is (%)	water gage (MPa)	Anti-seepage grade
0	0.8	P7
10	1.5	P>P12
20	1.3	P12
30	1.2	P11
40	1.0	P9

The mixed amount of fly ash of 10% and 20% has the highest impermeability grade, but the impermeability resistance of recycled concrete with 10% is better. The impermeability pressure of the mixed amount of 10% fly ash is 1.5MPa, which is 0.7MPa higher than that without fly ash. The reason for this phenomenon is that a small amount of fly ash, play the volcanic ash activity, equivalent to increase the cement hydration reaction and the amount of adhesive material reaction, reactants increase concrete fluidity, increase the rate of cement mortar reaction process, improve cement mortar and workability, indirectly improve the water and impermeability of concrete[12]. Without changing the fluidity of concrete and adding the admixture unchanged, adding fly ash can play the role of reducing water agent to assume the role of reducing water. The pore structure of concrete is greatly enriched, the pores become smaller, and the compactness of concrete can be improved, so as to improve the impermeability of concrete.

5 Conclusion

The following key results are reached after this research examines the relationship between the impermeability of recycled aggregate concrete and the water ash ratio, fly ash dose, and water reduction agent:

(1) The pore structure within concrete may be altered by the water-cement ratio to a certain degree; the effects of this ratio are comparable for both regular and recycled concrete. The water cement ratio increases from 0.3 to 0.4 in this interval, the rate of impermeability of reclaimed concrete decreases faster, the water cement ratio increases from 0.4 to 0.5, the rate of impermeability of reclaimed concrete starts to slow down. The water cement ratio gradually increases, the impermeability water pressure of reclaimed concrete slowly decreases, the impermeability gradually decreases.

(2) The permeability of concrete is influenced by the size of the water agent content. As the water agent dosage increases to 0.5%, the concrete's pore structure and structural compaction both clearly improve, and the recycled concrete's overall permeability is at its best. To enhance the impermeable performance of concrete, a little quantity of polycarboxylic acid water reduction agent can be used. This will lengthen the mixture's setting time, slow down the rate of hydration heat release, and increase the segregation phenomena of fresh concrete.

(3) Fly ash itself has the characteristics of small particle size. When the amount of fly ash is less than 10%, fly ash can play the role of refining the capillary channel of the recycled aggregate, so as to make the internal void structure is more dense, and the anti-permeability performance of the recycled concrete is constantly rising. When the amount of fly ash exceeds 10%, the seepage pressure of reclaimed concrete begins to be gradually reduced. One is because of the incorporation of excessive fly ash, in the preparation of recycled concrete, the fine aggregate as concrete will change the particle size grading of the original aggregate, so that the small holes inside the concrete can not be completely filled. Second because the same quality of fly ash instead of cement, the increasing amount, and as an important adhesive material, the relative proportion of cement will be reduced, aggregate and cement, sand, stone bonding effect, the interface transition area of pores lack of adhesive material and aggregate filling, difficult to compact, the density of recycled concrete will be reduced[13]. When excessive fly ash is added, the particle size grading of the original aggregate is changed, and the small holes inside the concrete cannot be completely filled, so the impermeability of recycled concrete and the amount of incorporation will show a negative correlation.

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