

# Test Study on Impermeability of Recycled Concrete

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**Abstract.** Recycled concrete is a kind of heterogeneous nonuniform dielectric with high porosity and complicated internal structure, and the impermeability of recycled concrete is much worse than that of ordinary concrete. To solve the seepage problem of recycled concrete, the effects from different strength of parent concrete, the ratio of recycled coarse aggregate, fly ash content and water gel ratio as the four aspects were studied by design orthogonal experiment. The results showed that the degree of influence on the impermeability of recycled concrete was from the large to small order: the ratio of water gels, the strength of the matrix concrete, the replacement rate of the recycled aggregate, and the fly ash content.

## 1. Introduction

Recycle Concrete (RC) is a new concrete made of waste concrete blocks after being broken, cleaned and graded, mixed with gradation according to a certain proportion, partially or totally replaced natural aggregates such as sand and gravel, and then added cement and water. The application of recycled concrete technology has significant effect in alleviating the contradiction between supply and demand, protecting the ecological environment and improving economic efficiency, which greatly satisfies the requirements of developing green concrete and realizing the sustainable development of construction resources[1-2].

At present, domestic and foreign scholars mainly focus on the research of the basic material properties and basic mechanical properties of recycled aggregate and recycled concrete [3-10]. It can be seen from the previous studies that the durability of concrete is very important in many factors that affect the service life of building structures. And the impermeability is one of the main factors that affect the durability of concrete. Because recycled concrete is a porous and heterogeneous composite material[4-5], its impermeability is very poor. In addition, during the process of producing recycled aggregate, the small cracks caused by crushing and colliding will also play a negative role in the impermeability of recycled aggregate. Many studies expect to improve the use value of recycled concrete by improving the mechanical properties and durability of recycled concrete by adding various auxiliary materials, changing the replacement ratio of recycled aggregate and extending the age. Therefore, the author uses the orthogonal test method to improve the impermeability of recycled concrete from four aspects: the strength of matrix concrete, the rate of replacement of recycled coarse aggregate, fly ash content and water-cement ratio.



## 2. Test situation

### 2.1. Materials used in the test

Cement used in the experiment is P.O 42.5 ordinary portland cement, and its 28d compressive strength is 43MPa, and the sand used in the experiment is apparent density is 2780kg/m<sup>3</sup>, the fly ash is grade II from Tangshan power plant, with a water content of 0.18%. The natural aggregates are gravel with continuous grading of 5 ~ 20mm in size. The recycled aggregate used in the experiment is 150 mm \* 150 mm \* 150 mm with strength grade of C20, C30, C40 and C50, which is continuously broken through physical crushing and screening. The basic properties of coarse aggregate were tested in accordance with the standard of sand, stone quality and inspection methods for ordinary concrete (JGJ52-2006), and the test results are shown in Table 1.

Table 1. The basic properties of coarse aggregate.

Coarse aggregate type	Coarse aggregate size range/mm	Accumulation density/ (kg/m <sup>3</sup> )	Apparent density/ (kg/m <sup>3</sup> )	Water absorption/ %	Crushing index of coarse aggregate/%
Natural coarse aggregate	— 5~20	1475	2810	0.7	7.2
	C20 5~25	1170	2610	3.81	21.7
Recycled aggregate	C30 5~25	1212	2620	3.53	15.0
	C40 5~25	1232	2670	3.92	13.9
	C50 5~25	1212	2710	5.94	12.7

### 2.2. Design mix of concrete

The test mix proportion of recycled concrete was determined by reference to the normal concrete mix proportion design method. The material used in the experiment replaced by the equal weight, and the test was arranged by orthogonal test method which was arranged in 16 groups as shown in Table 2.

Table 2. Tests scheduled.

Test number	The strength of parent concrete	The ratio of recycled coarse aggregate / %	The amount of fly ash / %	Water - cement ratio
Z1	C20	0	0	0.40
Z2	C20	30	10	0.45
Z3	C20	60	20	0.50
Z4	C20	100	30	0.55
Z5	C30	0	10	0.50
Z6	C30	30	0	0.55
Z7	C30	60	30	0.40
Z8	C30	100	20	0.45
Z9	C40	0	20	0.55
Z10	C40	30	30	0.50

Z11	C40	60	0	0.45
Z12	C40	100	10	0.40
Z13	C50	0	30	0.45
Z14	C50	30	20	0.40
Z15	C50	60	10	0.55
Z16	C50	100	0	0.50

### 2.3. Concrete specimen made and test method

Each 6 test blocks (the size of test blocks is 175mm × 185mm × 150mm) were divided into a group. The recycled coarse aggregate used in the test is dry on the saturated surface. Remove the concrete specimen from the mold after 24 hours, then clean the cement paste film on both ends of the concrete specimen with steel wire brushes and put it into the maintenance room for 28days. The test blocks will be taken out one day before the trial age and be wiped clean. The surface of the specimen is air-dried and sealed by selection of rubber bands with butter and cement. Test measures the impermeability of recycled concrete by stepwise compression method.

## 3. Test Results and Analysis

### 3.1. Test results

The previous experience has proved that orthogonal test is an effective method to solve the problem of multifactorial test. And the design principle and theory of orthogonal test are strictly followed in the experiment. The influence of four factors on the impermeability of recycled concrete can be tested by the test results of 16 groups of specimens. The results of orthogonal test are shown in Table 3.

Table 3. The results of orthogonal test.

Test number	Parent concrete strength	Replacement rate of recycled aggregate / %	The amount of fly ash / %	Water cement ratio	The impervious pressure
Z1	C20	0	0	0.40	2.1
Z2	C20	30	10	0.45	1.6
Z3	C20	60	20	0.50	1.0
Z4	C20	100	30	0.55	0.8
Z5	C30	0	10	0.50	1.2
Z6	C30	30	0	0.55	0.9
Z7	C30	60	30	0.40	1.5
Z8	C30	100	20	0.45	0.7
Z9	C40	0	20	0.55	0.9
Z10	C40	30	30	0.50	0.9
Z11	C40	60	0	0.45	0.5
Z12	C40	100	10	0.40	1.2

Z13	C50	0	30	0.45	1.1
Z14	C50	30	20	0.40	1.8
Z15	C50	60	10	0.55	0.5
Z16	C50	100	0	0.50	0.4

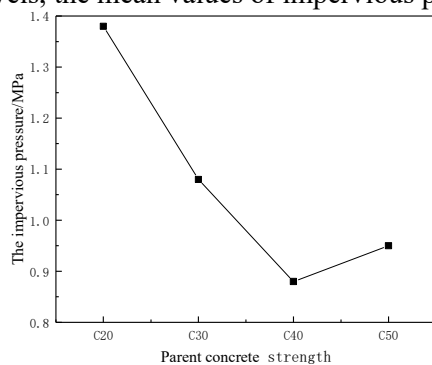
### 3.2. Test data analysis

Table 4 is the variance analysis about the influence of four factors on the impermeability of recycled concrete, and the probability value of variance model test is less than 0.05. Therefore, at the significance level of 0.05, the assumption that the test variance model test didn't take the interaction between factors into account is fairly well established. From the F value, it is known that water-cement ratio is the most important factor, the replacement rate of recycled aggregate ranks second, the strength of matrix concrete is in the third place and the influence of fly ash content is the least in the test factors affecting the impermeability of recycled concrete.

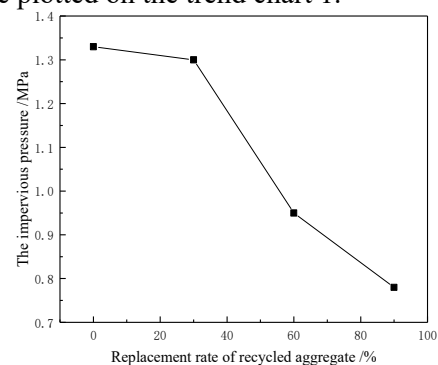
Table 4 . Analysis of variance table.

Sources of variation	Quadratic sum	Free degree	Mean square	F	Sig
Correction model	3.488	12	0.291	126.818	0.001
Intercept	18.276	1	18.276	7974.818	0.000
Parent concrete strength	0.582	3	0.194	84.636	0.002
Replacement rate of recycled aggregate	0.972	3	0.324	141.364	0.001
The amount of fly ash	0.052	3	0.017	7.545	0.066
Water - cement ratio	1.882	3	0.627	273.727	0.000
Error	0.007	3	0.002		
Total	21.770	16			
Calibration total	3.494	15			

In order to clearly reflect the trend of the impermeability grade of recycled concrete at different factor levels, the mean values of impervious pressure are plotted on the trend chart 1.



(a)



(b)

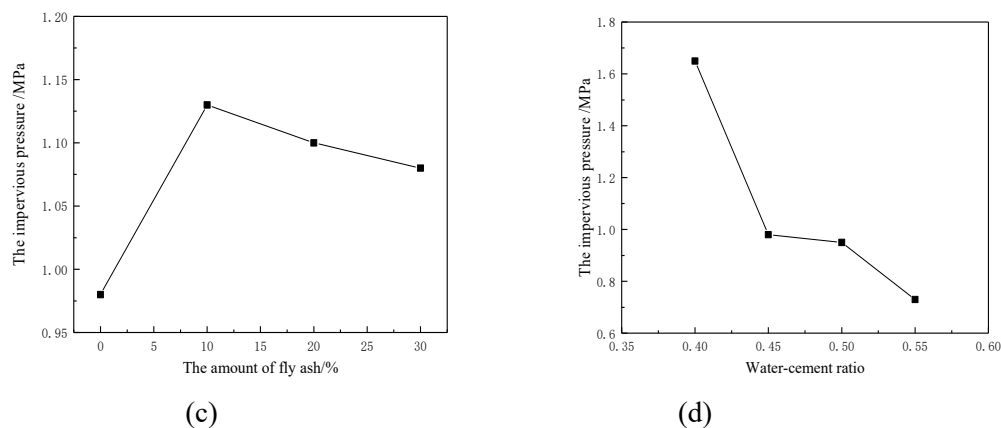


Figure 1. Change diagram of impervious pressure trend.

The figure (a) shows that when the strength of parent concrete ranges from C20 to C40, the impermeability of recycled concrete becomes worse with the increase of its strength. The reason is that when the strength of the parent concrete is bigger, it is harder for the former cement mortar attached to the surface of recycled aggregate to fall off during the process of crushing, and the gap is getting wider between the recycled concrete and the former cement concrete. When the strength of parent concrete is greater than C40, the cohesive between the former cementing material and the stone in the recycled coarse aggregate will become the most important factor. And as the matrix strength is higher, the cohesive force is greater and the density of recycled aggregate is higher, the impermeability of recycled concrete is improved to a certain extent. The figure (b) shows that the higher the replacement ratio of recycled aggregate to natural aggregate is, the worse the impermeability of recycled concrete is. The reason is that the apparent density of recycled coarse aggregate is relatively small, and there will be many tiny cracks in the process of physical crushing. In addition, the formation of new and old interface of recycled coarse aggregate will also have adverse effects on the internal pore structure of recycled concrete. So, the impermeability of recycled concrete decreases with the porosity of recycled concrete increases. The figure (c) shows that a small amount of fly ash can effectively refine the capillary channel of recycled aggregate and enlarge the compactness of recycled concrete. When the content of fly ash reaches 10%, the impermeability of recycled concrete is the best, but the continuous increase of fly ash content will reduce the effective bond between cement and coarse aggregate, and also increase the porosity in the transition interface area, so the impermeability of recycled concrete will be reduced. In figure (d), the impermeability of recycled concrete is gradually worse along with the increase of water - cement ratio. As cementing material decrease, the demand for water reduce. The extra free water will occupy a certain space inside the concrete so as to increase the porosity of recycled concrete, and decrease its impermeability.

### 3.3. Regression model

In order to further study the internal relationship between the strength of parent concrete, the replacement ratio of recycled aggregate, the water - cement ratio and the impermeability of recycled concrete, a multivariate factor and linear regression model with three factors is established.

Table 5. Linear regression coefficient table.

Factor	Coefficient	Standard deviation	Value t	Sig
Constant term	4.469	0.566	7.897	0.000
Parent concrete strength	-0.15	0.006	-2.681	0.020
Replacement rate of recycled aggregate	-0.006	0.002	-3.742	0.003
Water-cement ratio	-5.450	1.100	-4.953	0.000

The Table 5 reveals the coefficient relationship among these factors. Supposing that  $x_1$ ,  $x_2$ ,  $x_3$  represent the parent strength of concrete, replacement rate of recycled aggregate and water-cement ratio, then the linear relationship between the impervious pressure  $y$  and three kinds of factors is:

$$y = -0.15x_1 - 0.006x_2 - 5.450x_3 + 4.469$$

#### 4. Conclusions

1) The water - cement ratio as the most significant factor affects the impermeability of recycled concrete. The larger the value, the worse the permeability of recycled concrete.

2) When the strength of matrix concrete ranges from C20 to C40, the impermeability of recycled concrete becomes worse with the increase of strength. However, when the bond strength between the recycled aggregate and the cementitious material is stronger and the density of the coarse aggregate is increased by  $s$ , the strength of the matrix concrete is greater than that of C40, and the impermeability of the recycled concrete is improved.

3) Because the recycled aggregate exists self-defect with the regenerated aggregate, the higher the replacement rate is, the worse the permeability of recycled concrete is.

4) To a certain extent when the amount of fly ash is 10%, the inner hole structure and impermeability of recycled concrete can be effectively improved.

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