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Experimental study of the salt solution erosing influence on strength of concrete with recycled coarse aggregate

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There are carried out the experimental study of the loss of the recycled concrete's strength depending on the recycled coarse aggregate substitution ratio, quantity of the fly ash and age of the concrete through investigation of the concrete's compressive strength. It is shown that compared with natural gravel, the recycled coarse aggregates accumulate damages at crushing process and have a lot of micro cracks. In addition, the surface of gravel is wrapped in porous adhesive mortar which provides corrosion resistance of concrete deterioration. With the amount of recycled coarse aggregate increasing, the compressive strength of recycled concrete decreases. The addition of fly ash, which creates a compaction effect, helps improve the erosion resistance of recycled concrete. It is shown that positive effect of aging of recycled concrete is significantly higher than negative effect of salt solution erosion, so with time the strength of recycled concrete is increased.

Keywords: Salt solution, recycled coarse aggregate, coarse aggregate substitution rate, compressive strength.

Проведено экспериментальное исследование потери прочности переработанного бетона в зависимости от коэффициента замены переработанного крупного наполнителя, количества золы-уноса и возраста бетона путем исследования силы сжатия бетона. Показано, что по сравнению с природным гравием, переработанные грубые наполнители имеют много микротрещин, образующихся при дроблении. Кроме того, поверхность гравия покрыта пористым клеевым раствором, который обеспечивает коррозионную стойкость к разрушению бетона. С увеличением количества переработанного крупнозернистого наполнителя прочность на сжатие переработанного бетона уменьшается. Добавление золы-уноса, которая создает эффект уплотнения, помогает усилить эрозионную устойчивость переработанного бетона. Было показано, что положительный эффект старения переработанного бетона значительно выше, чем отрицательный эффект эрозии солевого раствора, поэтому с возрастом прочность переработанного бетона увеличивается.

Експериментальне дослідження впливу ерозійного впливу солей на міцність бетону з переробленим великим наповнювачем. *Лю Фамін, Чжао Лиша, Ян Бінь*

Проведено експериментальне дослідження втрати міцності переробленого бетону в залежності від коефіцієнта заміни переробленого великого наповнювача, кількості золи-винесення та віку бетону шляхом дослідження сили стиснення бетону. Показано, що в порівнянні з природним гравієм, перероблені грубі наповнювачі мають багато мікротріщин, що утворюються при дробленні. Крім того, поверхня гравію покрита пористим клейовим розчином, який забезпечує корозійну стійкість до руйнування бетону. Зі збільшенням кількості переробленого крупнозернистого наповнювача міцність на стиск переробленого бетону зменшується. Додавання золи-винесення, яка створює ефект ущільнення, допомагає посилити ерозійну стійкість переробленого бетону. Було показано, що позитивний ефект старіння переробленого бетону значно вище, ніж негативний ефект ерозії сольового розчину, тому з віком міцність переробленого бетону збільшується.

1. Introduction

With the rapid development of economy and city construction expanding, the scale of construction waste generated every year account for 30%~40% of the total city garbage, it has become the main source of city garbage [1]. The construction waste composition have a lot of species, concrete proportion is the highest among this kind of waste. Traditional processing way of construction waste was mainly landfill or stockpiling, it causes a series of questions about land occupation and environment pollution, construction waste recycling rate is very low. In recent years, scholars from various countries on the sustainable utilization of construction waste were studied. Such as Qiuyi Li[2] had improved aggregate shape and removed hardened mortar of recycled aggregate surface adhesion, achieve the goal of improve aggregate performance. Yi-bo Yang[3] had putted forward technology for waste concrete all preparation for recycled fine aggregate, it overcomes the high cement stone content which causes high bibulous rate in traditional recycled fine aggregate. Eguchi K[4] had studied the shrinkage of recycled concrete based on the theory of composite. It is pointed out that larger drying shrinkage deformation and lower elastic modulus of recycled aggregate make recycled concrete drying shrinkage is bigger.

Reinforced concrete structure in marine environment has great influenced by the erosion effect of chlorine salt. However, the chloride resistant performance of recycled concrete less studied in recent years. There are have many determination methods and indexes of recycled concrete durability, salt solution effect on the properties of recycled concrete is an important aspect of durability evaluation. Improve the chlorine salt resistance of recycled concrete will protect the reinforcing steel bar is not easy to rust and construction waste recycling[5]. In addition, the recycled aggregate can effectively alleviate the problem of sand shortage, and also effectively reduce construction waste emissions. It is the only way to realize sustainable development of construction industry.

2. Testing raw material and testing program

2.1. Testing Raw Material

(1) Cement: ordinary Portland cement produced by Huaibei Songshan cement co., LTD, strength grade 42.5. The main physical performance indexes as indicated in Table 1.

(2) Fly ash: Grade II ash produced by Anhui Huainan Luoneng power generation co., LTD, the main physical performance indexes as indicated in Table 2.

(3) Fine aggregate: the main physical performance indexes of natural sand as indicated in Table 3.

Table 1. The Main Physical Performance Indexes of Cement

Fineness /%	Water requirement of normal consistency, /%	Setting time /min		Compressive strength /MPa		Flexural strength /MPa	
		Initial setting	Final setting	3d	28d	3d	28d
0.8	27	180	320	23.7	46.6	4.5	8.7

Table 2. The main physical performance indexes of fly ash (%)

Fineness	Water demand ratio	Ignition loss	SO_3 content
18.5	93	2.3	qualified

TABLE III. The Main Physical Performance Indexes of Natural Sand

Name	Fineness modulus	Apparent density /kg.m-3	Bulk density /kg.m-3	Water demand ratio	Strength ratio	Evaluation
Natural sand	2.7	2532	1376	1.00	1.00	II area medium sand

Table 4. The main physical performance indexes of recycled coarse aggregate and natural gravel

Name		Apparent density kg.m^{-3}	Needle content %	Bibulous rate %	Crush index %
Recycled coarse aggregate	After first break	2409	7.6	2.5	17.6
	After plasticed	2437	5.4	1.9	14.3
Natural gravel		2472	6.7	1.8	12.1

Table 5. The mix ratio of recycled coarse aggregate concrete

Group	Water	Cement	Fly ash	Recycled Coarse Aggregate		Natural gravel	Natural sand
				Substitution rate %	Content		
SJ1	200	400	0	0	0	1187	668
SJ2		340	60	0	0	1187	
SJ3		400	0	100	1187	0	
SA1		340	60	30	356	831	
SA2		340	60	60	712	475	
SA3		340	60	80	950	237	
SA4		340	60	100	1187	0	

(4) Coarse aggregate: Use jaw crusher to break building material laboratory waste cube concrete whose compressive strength are 30 ~ 40MPa at first, get recycled coarse aggregate by fully dried, using particle shaping machine for plasticing. Next screened with 4.75mm and more than 4.75mm particles are recycled coarse aggregate which after plasticed. Natural coarse aggregate are natural gravel. The main physical performance indexes of recycled coarse aggregate and natural gravel as indicated in Table IV.

2.2. Testing program

Sand content, gravel content and test method refers to Standard for Technical Requirements and Test Method of Sand and Crushed Stone (or gravel) for Ordinary Concrete (JGJ 52-2006), Recycled Fine Aggregate for Concrete and Mortar (GB/T 25176-2010) and Recycled Coarse Aggregate for Concrete (GB/T 25177-2010). The strength test specimen of recycled concrete were put into the standard curing room for 28 days, and then put into the salt solution. The compressive strength test of recycled concrete according to different ages erosion. Salt solution were divided into 5%NaCl, 5% NaCl+5% Na_2SO_4 and 5% Na_2SO_4 which are three different kinds of salt concentration. The test is mainly to replace all of the recycled coarse aggregate or part of the natural gravel. Through testing under fly ash and salt solution erosion dual function effect on the compressive strength of recycled concrete. The water cement ratio of this test is 0.5.

2.3. Testing mix ratio

The testing specimens were used C30 strength grade as the benchmark and were divided into two groups. SA group is recycled coarse aggregate concrete. SA1, SA2, SA3 and SA4 are respectively on behalf of recycled coarse aggregate content account for 30%, 60%, 80% and 100% of the total coarse aggregate quality. SJ group as the benchmark, SJ1 is not add recycled coarse aggregate and fly ash, SJ2 is not add recycled coarse aggregate but fly ash adding, SJ3 is add 100% recycled coarse aggregate but without fly ash. Put these specimens into three different types of salt solution immersion, soaking time lasting for half a year. In this time, the compressive strength of recycled concrete specimens had been tested under different ages (7 days, 28 days, 60 days, 90 days and 180 days). The mix ratio of recycled coarse aggregate concrete as indicated in Table V.

3. Testing result and analysis

3.1. The compressive strength after salt solution erosion at different ages

According to Standard for Test Method of Mechanical Properties on Ordinary Concrete (GB/T 50081-2002), The compressive strength of after eroding recycled coarse aggregate concrete which are 150mm×150mm×150mm cube specimens as calculated in formula(1):

$$f_c = \frac{F}{A} \quad (1)$$

Table 6. The compressive strength results of recycled coarse aggregate concrete

Specimen number	Compressive strength after salt solution erosion, MPa				
	7d	28d	60d	90d	180d
SJ1-1	33.4	36.6	37.2	37.7	40.1
SJ1-2	32.3	35.9	36.4	37.3	39.2
SJ1-3	32.8	36.2	37.9	37.8	40.4
SJ2-1	35.2	38.5	39.4	39.7	42.6
SJ2-2	33.7	36.4	37.1	38.2	40.9
SJ2-3	35.8	39.2	40.6	41.4	42.7
SJ3-1	28.4	28.7	29.6	31.2	32.1
SJ3-2	26.4	27.2	29.3	30.8	31.4
SJ3-3	29.5	30.3	30.5	30.9	32.3
SA1-1	34.3	33.6	35.5	34.6	38.8
SA1-2	32.2	34.6	34.4	36.2	37.9
SA1-3	33.7	35.2	37.6	37.7	40.5
SA2-1	30.8	32.1	33.4	32.9	34.8
SA2-2	29.1	30.6	32.2	31.6	33.5
SA2-3	31.2	33.4	32.8	35.6	36.1
SA3-1	28.4	29.7	31.8	32.7	33.3
SA3-2	29.7	30.4	30.8	31.2	33.0
SA3-3	30.2	31.7	32.4	31.9	34.6
SA4-1	29.1	30.5	31.6	32.2	33.5
SA4-2	28.2	29.9	30.6	30.9	32.3
SA4-3	30.1	32.7	34.3	33.1	35.8

Note: In the table, – 1 means soaking in 5%NaCl salt solution, – 2 means soaking in 5%NaCl+5%Na_2SO_4 salt solution, – 3 means soaking in 5%Na_2SO_4 salt solution.

Where,

f_c – the compressive strength of recycled concrete specimens, MPa;

F – the compressive failure load of specimens, N;

A – the compression area of each specimen, mm^2.

The compressive strength of recycled coarse aggregate concrete after salt solution erosion as indicated in Table 6.

3.2. Salt solution effects on the compressive properties of recycled coarse aggregate concrete

3.2.1. Different substitution rate of recycled coarse aggregate

Take the SJ2, SA1, SA2, SA3, SA4 as a batch, then draw the result of the experiment as shown in Figure 1and Figure 2.

It is shown from Fig.(1) and Fig.(2) that when the substitution rate of recycled coarse aggregate increase, no matter what kind of salt solution immersion, the compressive strength of recycled concrete are all decreased obviously. In 5%NaCl salt solution erosion after 7d, the compressive strength of recycled concrete were lost 0.9MPa and 4.4MPa. 6.8MPa and 6.1MPa,

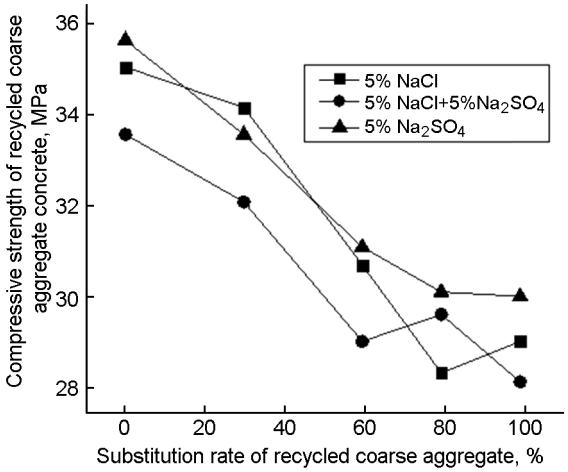

Fig. 1. The relationship between different substitution rate and compressive strength of recycled coarse aggregate (7d)

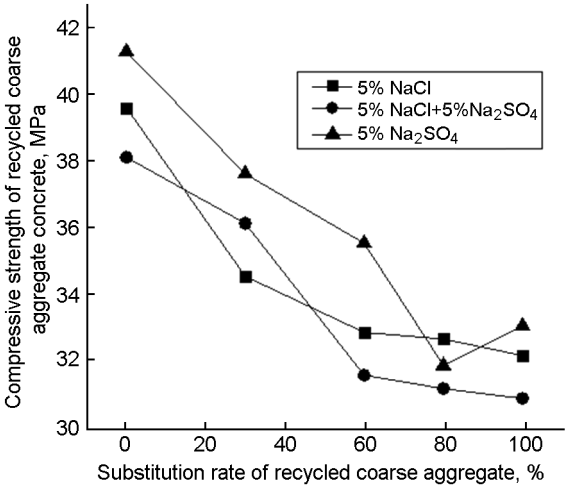

Fig. 2. The relationship between different substitution rate and compressive strength of recycled coarse aggregate (90d)

the loss rate is as high as 19.3%. In 5%NaCl salt solution erosion after 90d, the compressive strength of recycled concrete were lost 6.3MPa, 6.8MPa, 7.0MPa and 7.5MPa, the is as high as 18.9%. Obviously, the higher recycled coarse aggregate substitution rate, the worse salt solution erosion resistance. This is mainly because the cumulative damage of recycled coarse aggregate in crushing process and exist a lot of micro crack. In addition, the surface of gravel are wrapped in porous adhesive mortar [6-7].

When recycled coarse aggregate substitution rate reached 100%, the highest compressive strength of recycled concrete loss. The compressive strength loss rate had reached to 17.3%, 16.3% and 15.9% respectively. After 90d erosion in salt solution, the compressive

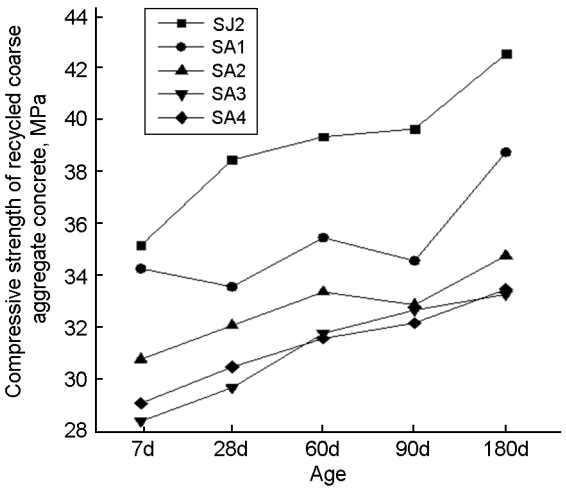

Fig. 3. The compressive strength of recycled concrete in 5%NaCl salt solution (1).

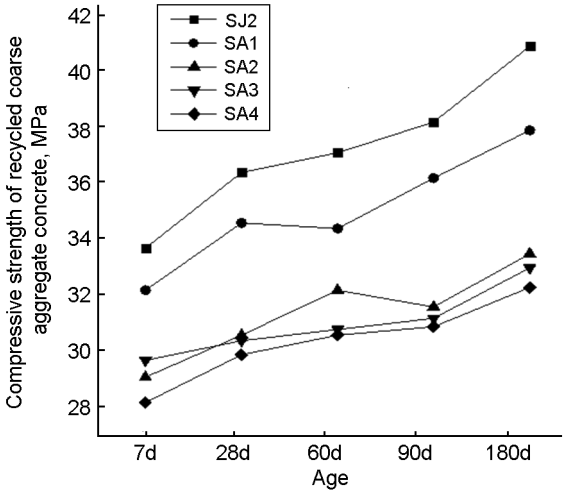

Fig. 4. The compressive strength of recycled concrete in 5%NaCl salt solution (2).

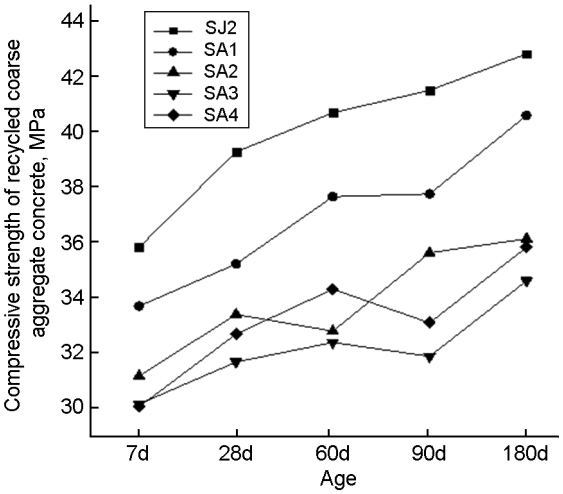

Fig. 5. The compressive strength of recycled concrete in 5%NaCl salt solution (3).

strength loss rate had reached to 18.9%, 19.1% and 20.1%. This is mainly because micro crack and defect of adhesive mortar are more obvious when the recycled aggregate replace all natural gravel, so the ability of salt solution erosion resistance had fell sharply.

3.2.2. Different Ages

It is shown from Fig. (3), Fig. (4) and Fig. (5) that when recycled concrete age increase, no matter what kind of salt solution immersion, the compressive strength of recycled concrete are all rise obviously. The compressive strength of SJ group specimens after 180 days salt solution immersion increased significantly greater than the other groups, among the increase rate of SJ2-1 group is as high as 21.0%.This is mainly because natural gravel have smaller porosity and stronger permeability than recycled coarse aggregate. After a long time soaking in salt solution, or in the salt solution can react with cement hydration products and create dilatants, expansive force is greater than concrete tensile strength will lead to concrete cracking [8]. In the long run, concrete strength will gradually decline. The surface of recycled coarse aggregate are wrapped in porous adhesive mortar, these dilatants can't filled fully, so the compressive strength of recycled concrete after immersion is less than ordinary concrete.

It is also shown from Fig. (3), Fig. (4) and Fig. (5) that concrete compressive strength in 5%NaCl+5%Na_2SO_4 is lower than the other kinds of salt solution. In different ages, the compressive strength of SA4-2 had reduced 6.3%, 8.6%, 10.8%, 6.6% and 9.8% relative to SA4-3 group. The compressive strength of SA4-2 had reduced 3.1%, 2%, 3.2%, 4% and 3.6% relative to SA4-1 group. By analyzing testing data, we had found that the recycled concrete in chloride salt environment erosion degree is more serious than it is in sulfate environment. Two kinds of mixed salt solution is coupling effect on recycled concrete. Mixed salt solution can accelerate recycled concrete erosion degree.

3.2.3. Fly Ash

Take the SJ1, SJ2, SJ3, SA4 as a batch, then draw the result of the experiment as shown in Fig. (6), Fig. (7) and Fig. (8).

Through Fig. 6, Fig. 7 and Fig. 8 can be seen, no matter what kind of salt solution immersion, the compressive strength of SJ2 group is highest and SJ3 group is lowest. It can be found that improving the erosion resistance of concrete effectively after fly ash added. For example, the compressive strength of SA4 group specimens which were higher than SJ3 group which without fly ash adding. In 5%Na_2SO_4

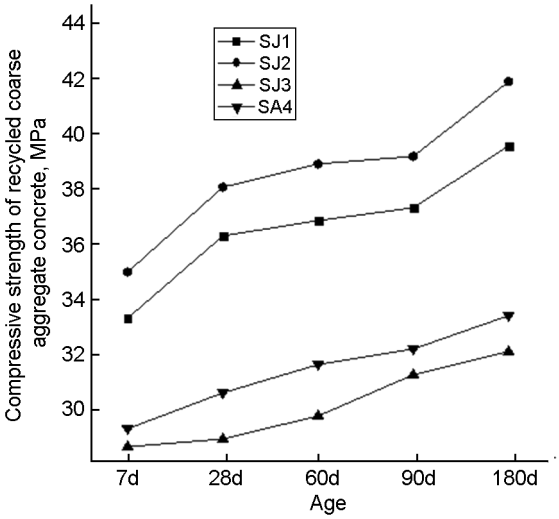

Fig. 6. The compressive strength of recycled concrete in 5%NaCl salt solution (4).

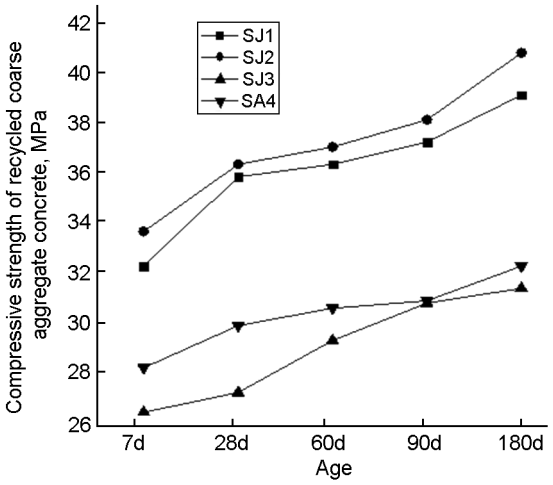

Fig. 7. The compressive strength of recycled concrete in 5%NaCl salt solution (5).

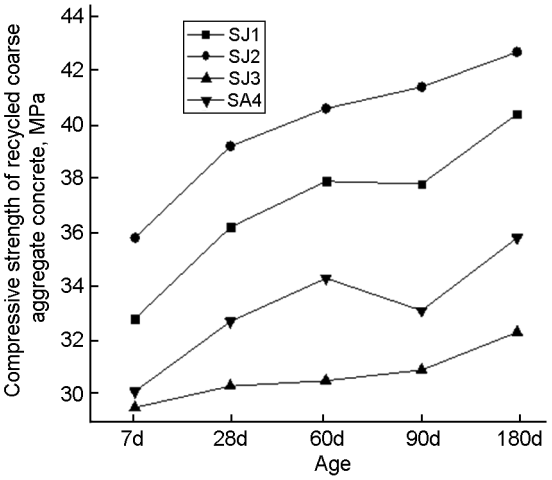

Fig. 8. The compressive strength of recycled concrete in 5%NaCl salt solution (6).

salt solution and different ages, the compressive strength of SA4 group had increased 2.0%, 7.9%, 12.5%, 7.1% and 10.8% relative to SJ3 group. The compressive strength of recycled concrete in 5%Na_2SO_4 is generally larger than other two kinds of salt solution. It is shown that after fly ash substituting partial cement, the sulfate resistance ability of recycled concrete is superior to chloride resistance. This is mainly because the fly ash have played a volcano ash effect, meanwhile filled compaction effect. The recycled concrete is one kind of multicomponent and multiphase complex system, each component material is not easy to achieve together and even. Fly ash powder can be filled between the cement hydration products, so improving the gradation and aperture of recycled concrete cementing material effectively. It makes the cement structure more compaction, blocking the erosive path of chlorine salt and sulfate, so improving the compressive strength of recycled concrete correspondingly[9].

It is not difficult to find that using recycled coarse aggregate to prepare concrete can content strength requirement through data in Table 6. The recycled concrete strength was decrease little when substitution rate of recycled coarse aggregate at around 30%. Adding fly ash, the later strength of recycled concrete can at the same level as ordinary concrete. According to the requirement added moderate amount of fly ash or some other active material into concrete in engineering practice, in order to improve the pore structure of recycled concrete [10]. It is appropriated that Substitution rate of recycled coarse aggregate is no more than 30% of natural gravel.

4. Conclusions

(1) Along with increasing content of recycled coarse aggregate, the compressive strength of recycled concrete is on the decline. Poorer chloride and sulfate resistance of recycled concrete than ordinary concrete. This is because adhesive mortar and damaging stone have negative impact on the durability of recycled concrete.

(2) The addition of fly ash, It can be improve the erosion resistance of recycled concrete effectively because of adding fly ash. This is mainly because the fly ash have played a volcano ash effect, meanwhile filled compaction effect. Blocking the erosive path of harmful substances and making the microstructure of cement stone more compact, so improved the strength of recycled concrete and durability correspondingly.

(3) Sulfate resistance is superior to chlorine resistance when substituting fly ash for partial cement. The coupling effect of sulfate and chloride salt will accelerate decreasing strength of recycled concrete.

(4) Age impact on developing strength of recycled concrete is higher than salt solution erosion. So the longer time, the higher strength of recycled concrete. But there are have negative effect on strength growing in salt solution environment. This is mainly because after a long time soaking in salt solution, Cl^- or SO_4^{2-} in the salt solution can react with cement hydration products and create dilatants, expansive force is greater than concrete tensile strength will lead to concrete cracking, also reduced the strength and durability of concrete. This researchable area needs further validation.

Acknowledgements

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