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Technical Paper

Exploring effects of initial water content of recycled aggregate and additional water consumption on the permeability resistance of concrete to chlorine salt

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Abstract: Recycled aggregate concrete (RAC) technology is conducive to resource conservation and environmental protection, but the high-water absorption of recycled aggregate makes it difficult to control the durability of RAC. In this study, the combined effects of initial moisture and additional moisture of recycled coarse aggregate (RCA) on the resistance to chloride ion penetration of concrete were investigated. The results show that, when the initial humidity of RCA is lower than 0.25 and the additional water consumption is low, RAC shows a rapid decay of dynamic elastic modulus. In contrast, when the sum of initial water content and additional water content is greater than 80%, the higher the initial water content, the better the compactness and impermeability of concrete. At the same time, the initial water and additional water of RCA have a great impact on the quality of RAC and the depth of damage layer. When the initial water content of RCA is high, the corrosion resistance of RAC decreases with the increase of the additional water. After comprehensive consideration, it is recommended to use RCA with 50% initial water and less than 40% additional water to obtain good durability.

Keywords: Recycled concrete; Initial moisture state; Additional water; Durability.

1. Introduction

As the most widely used building material, concrete has dominated the building materials market since the 1990s [1], but accounting for about 8% of the global total CO_2 emissions [2]. Over the past 20 years, world cement production has increased from 1.1 billion tons to 4.1 billion tons [3], an almost fourfold increase. Cement production is expected to reach 4.83 billion tons in 2030, and the widespread use of concrete will further increase the consumption of natural resources. On the other hand, construction waste has exceeded 4 million tons per year since 2005, with construction and demolition waste accounting for about 30 to 40 percent of the total urban waste. The recycling rate of construction waste in Shanghai and other developed cities is close to 90%, but the recycling level is relatively low [4]. In less developed areas and cities, most of the waste goes untreated and is transported directly to suburbs or rural areas, where it is piled up in the open or disposed of in landfills. If the huge amount of solid waste cannot be reasonably consumed, it will inevitably have many adverse effects, such as occupying precious cultivated land, polluting water resources, increasing carbon emissions, and even causing environmental protection and social problems [5,6]. Recycled concrete technology can not only effectively alleviate the shortage of natural sand and stone resources, but also recycle waste concrete resources to avoid the adverse impact of construction waste on the environment. Recycled aggregate concrete (RAC) refers to the recycled aggregate completely or partly replace natural aggregate [7], according to a certain proportion to join cement, mineral admixture and other groups of allocation system of concrete [8].

Compared with ordinary cement concrete, recycled aggregate with poor performance added into concrete results in more water consumption of new mixed materials and poor compressive strength and durability of hardened materials [9]. In China, there are also serious problems of chloride infiltration causing failure of concrete facilities. For example, due to the salt spread on the overpass and main road every winter, the Xizhimen overpass in Beijing had durability problems such as salt corrosion after only 18 years of operation, which was demolished and rebuilt later. Thus, the durability of

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concrete structure is not only related to the quality of infrastructure construction and service life, but also has a very important effect on our social development and economic construction. Due to the particularity of recycled aggregate, recycled concrete in natural environment faces more complex durability problems than ordinary concrete. Therefore, it is of great theoretical significance and practical application value to study the durability decay rule of recycled concrete under the action of various environmental factors and the methods to improve its durability.

Due to the poor durability problem has not been improved obviously, so the recycled aggregate concrete is less likely to be applied in cement facilities under harsh conditions such as snow melting agent environment in north, northeast and other cold regions or coastal areas, which significantly restricts its application field. Compared with the durability of ordinary concrete, the durability of recycled concrete is more complicated, and the related research started late. Abbas et al. [10] studied the carbonization resistance, freeze-thaw resistance and chloride ion penetration resistance of recycled concrete. Thomas et al. [11] and Leemann et al. [12] studied the effects of different recycled aggregate content and different cementing material types on the compressive strength and carbonization depth indexes of recycled concrete under accelerated carbonization conditions. Pedro et al. [13] used recycled aggregate from two sources (waste and laboratory specimens) to prepare recycled concrete, studied carbonization resistance and chloride ion penetration resistance of recycled concrete under different aggregate content, and tested compressive strength, elastic modulus, water absorption, carbonation depth, chloride ion migration coefficient and other indicators. Kurda et al. [14] studied the influence of high-content fly ash and recycled aggregate on the carbonation resistance of recycled concrete. Alexandridou et al. [15] and Amorim Júnior et al. [16] tested the dynamic elastic modulus, mass loss rate, compressive strength and other indexes of recycled aggregate concrete with different mixtures under freeze-thaw conditions. The results showed that increasing the mixture amount of recycled aggregate could significantly reduce its frost resistance.

Ying et al. [17] and Zhang et al. [18] studied the influence of recycled aggregate replacement rate on compressive strength, density, chloride ion migration coefficient, etc. of recycled concrete. Pedro et al. [19] studied the influence of different recycled aggregate replacement ratio and different silica fume content on the mechanical properties and durability of high-performance recycled concrete. Beltrán et al. [20] studied the mechanical properties and durability of 100% recycled coarse aggregate concrete with different amounts of biomass ash. Kanish et al. [21] studied the influence of metakaolin and silica fume on the impermeability and durability of recycled concrete at different curing ages. The results showed that for 100% recycled coarse aggregate concrete, the addition of admixtures could not effectively make up for the attenuation of its durability by increasing the amount of recycled aggregate. Debieb et al. [22] studied the effect of recycled aggregate with poor quality on the chloride ion permeability of recycled concrete, and the results showed that the quality of recycled aggregate is very sensitive to the impermeability. Omrane et al. [23] studied the chloride ion diffusion law of recycled concrete containing natural volcanic ash based on Fick's second law and indicated that natural volcanic ash with impermeability can effectively improve the chloride ion penetration resistance of concrete. Lotfy et al. [24], Vázquez et al. [25], Tuyan et al. [26] studied the chloride ion diffusion law of recycled concrete under different water-binder ratio and different recycled aggregate replacement ratio. The results indicate that under low water cement ratio conditions, the higher the RAC content, the better the durability of recycled concrete. Khodai et al. [27] studied the improvement effect of high content of fly ash and mineral powder on chloride ion permeability of self-compacting recycled concrete under different recycled aggregate substitution rates. Sim et al. [28] studied the compressive strength, carbonation resistance and chloride ion penetration resistance of recycled aggregate concrete of construction waste under different fly ash content and different recycled aggregate replacement rate. The results show that recycled coarse aggregate concrete can be used in structural concrete components. Zhang et al. [29] carbonized the recycled aggregate and prepared the recycled mortar. The results showed that the carbonated aggregate reduced the water absorption and chloride ion migration coefficient of the recycled mortar. The influence of carbonized aggregate on the interface area was studied by SEM test. The results showed that carbonization not only improved the interface between old mortar and aggregate, but also improved the interface between new mortar and recycled aggregate.

Based on the characteristics of regional environment and local erosion factors in northwest China, this study simulates the natural environment characteristics of recycled concrete structures in service using the dry-wet alternate cycle method, and simulates the erosion ion composition in the service environment of recycled concrete structures using 5% MgCl-10% NaCl composite chloride solution, and studies the impact of the initial moisture content of recycled aggregate and additional water consumption on the durability of recycled concrete. By testing the dynamic elastic modulus, quality and damage layer thickness of recycled concrete, the influence of initial moisture content of recycled aggregate and additional water consumption on the chloride ion corrosion resistance of recycled concrete was studied.

2. Experimental Program

2.1 Materials.

2.1.1 Cement

The cement used in this study is P·O42.5 Portland cement produced by Fushun Cement Co., Ltd. and Fushun Ausel Technology Co., Ltd. See Table 1 and Table 2 for its physical properties and chemical composition. The fly ash is Class II low calcium fly ash with density of 2080kg/m^3 and specific surface area of 430m^2/kg; Granulated blast furnace slag is S95 grade slag powder with a density of 2810kg/m^3 and a specific surface area of 450m^2/kg. Table 2 shows the chemical composition of fly ash and mineral powder.

2.1.2 Aggregate

All the recycled aggregates after crashed were sieved to the same particle size graduation (5-16 mm and 16-25 mm). Then, the screened recycled coarse aggregate is repeatedly washed and dried. The initial moisture content of the aggregates shall be measured one day before the pouring of the test block α (ratio of water content to water absorption) is adjusted to 0 (absolute dry state), 0.25, 0.5, 0.75, 1.0 (saturated surface dry state). Finally, it is placed in a bag with plastic inner membrane for sealed storage to prevent moisture transfer between the aggregate and the environment.

Fine aggregates are natural river sand graded as medium sand (fineness modulus is 2.61), with an average particle size of 0.15-5 mm. The physical properties were given in Table 3. The test of aggregate properties, such as water absorption, special density, crushing value were performed in accordance with GB/T 14684-2011 [30] and GB/T 14685-2011 [31]. Tap water was used in the experiment.

2.1.3 Superplasticizer

Polycarboxylic acid series of high performance water reducing agent was used in this study. The solid content is 30 wt%.

Table 1 – Physical properties of cement

Specific gravity (kg·m^{-3})	Specific surface area (m^2·kg^{-1})	Standard consistency (%)	Initial set (min)	Final set (min)	Compressive Strength (MPa)		Flexural strength (MPa)	
					3d	28d	3d	28d
3100	345	25.7	90	260	17.0	42.9	3.5	6.5

Table 2 – Chemical compositions (mass fraction, %) of cementitious materials

Cementitious materials	Chemical compositions							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	$K_2O+Na_2O+TiO_2$	L.O.I.
Cement	17.75	6.84	2.59	61.36	3.31	3.50	1.67	1.56
Fly ash	36.30	34.73	3.22	3.77	0.49	0.51	2.56	-
Mineral dust	26.70	15.71	0.34	36.39	9.22	2.40	2.74	-

Table 3 – Properties of aggregates.

Type	Size	Apparent Density	Water Absorption (%)	Crushing Value	Mud content (%)	Impurity rate (%)
Sand	0.16-5.0	2740	1.7	/	2.3	0.08
RCA	5.0-25.0	2690	5.2	12.4	0.8	0.5

2.2 Mix proportion design of recycled concrete

The amount of coarse aggregates is usually two-thirds of the total amount of concrete aggregate. In order to make better use of recycled aggregate, coarse aggregate shall be fully or partially recycled aggregate. The recycled concrete mix ratio used in this study is obtained by replacing 100% of natural coarse aggregate in the ordinary concrete mix with recycled coarse aggregate according to the equal volume method. The water-cement ratio of the original ordinary concrete mix is 0.364. The initial moisture content of aggregate has been adjusted to 0, 0.25, 0.5, 0.75 and 1.0 after pretreatment. For the three series of RCAs with initial water content, based on the original mix proportion, the amount of other materials shall be kept unchanged and the additional mixing water consumption shall be determined according to the water absorption of the RCAs. In order to keep the cement-bone ratio of the concrete mix unchanged, the quality of recycled aggregate with different initial water content is calculated according to the formula. The final matching used in the test is shown in Table 4.

Table 4 – Recycled concrete mix ratio (kg/m^3)

Specimen No.	Cement	Fly ash	Slag	San0d	RCA	Water		Superplasticizer
						Free	Additional	
RCA0-AW0.6	230	90	120	770	1020	160	31.82	5
RCA0-AW0.7	230	90	120	770	1020	160	37.13	5
RCA0-AW0.8	230	90	120	770	1020	160	42.43	5
RCA0-AW0.9	230	90	120	770	1020	160	47.74	5
RCA0-AW1.0	230	90	120	770	1020	160	53.04*	5
RCA0.25-AW0.35	230	90	120	770	1033	160	18.56	5
RCA0.25-AW0.45	230	90	120	770	1033	160	23.87	5
RCA0.25-AW0.55	230	90	120	770	1033	160	29.17	5
RCA0.25-AW0.65	230	90	120	770	1033	160	34.48	5
RCA0.25-AW0.75	230	90	120	770	1033	160	39.78*	5
RCA0.5-AW0.1	230	90	120	770	1047	160	5.30	5
RCA0.5-AW0.2	230	90	120	770	1047	160	10.61	5
RCA0.5-AW0.3	230	90	120	770	1047	160	15.91	5
RCA0.5-AW0.4	230	90	120	770	1047	160	21.22	5
RCA0.5-AW0.5	230	90	120	770	1047	160	26.52*	5
RCA0.75-AW0.15	230	90	120	770	1061	160	7.96	5
RCA0.75-AW0.25	230	90	120	770	1061	160	13.26*	5
RCA1.0-AW0	230	90	120	770	1076	160	0*	5

Notes: RCA indicates the initial moisture content of recycled coarse aggregate, that is, the ratio of moisture content to water absorption is. AW refers to the ratio of the mass of this group of additional water to the mass of water contained in the recycled coarse aggregate in the saturated surface dry state. Quality of recycled coarse aggregate: $M_{RCA} = [(1020/\rho_{NA}) \cdot \rho_{RA}] \div (1 - \omega_{wc})$； Additional water consumption： $M_{AW} = (770/\rho_{NA}) \cdot \rho_{RFA} \cdot \omega_{wc} \cdot \beta$； Nominal water-binder ratio： $w/c = (160 + M_{AW})/440$.

2.3 Methods

2.3.1 Corrosion test of compound chloride solution

In the experiment, the dry-wet alternation (soaking and drying cycle) method is used to simulate the regional climate environment in the northwest region, and the 5% MgCl-10% NaCl compound chloride solution is used to simulate the regional corrosive medium, and the RAC durability test is carried out, the process is as follows:

(1) Casting RAC test blocks: the cementitious material, sand and recycled aggregate were poured into the mixer for dry mixing for 1min. Then added water and superplasticizer into the mixer while stirring. After mixing for 3 minutes, mixture was poured out of the mixer and formed in the mold. Compacted the concrete on the vibrating table and discharged the bubbles in the mixture to prevent excessive holes in the concrete. After the vibration, the excess concrete from the upper mouth of the test mold was scraped with the spatula, which can smooth the molding surface of the test blocks.

(2) Maintenance of RAC test blocks: after the test pieces were formed, their surface was covered with impermeable plastic film immediately. Kept the blocks at room temperature for 24h, then numbered them and removed the formwork. Immediately after formwork removal, put them into a standard curing room with a temperature of 20±2 ℃ and a relative humidity of more than 95% for curing until the age of 7 days.

(3) Moved the test blocks into the compound chloride solution and carried out the dry-wet alternate test. The dry-wet alternation system was: (a) the water level raised, and the compound chloride solution was soaked for 14 hours; (b) The water level dropped and the room was naturally air-dried for 2h; (c) Put the

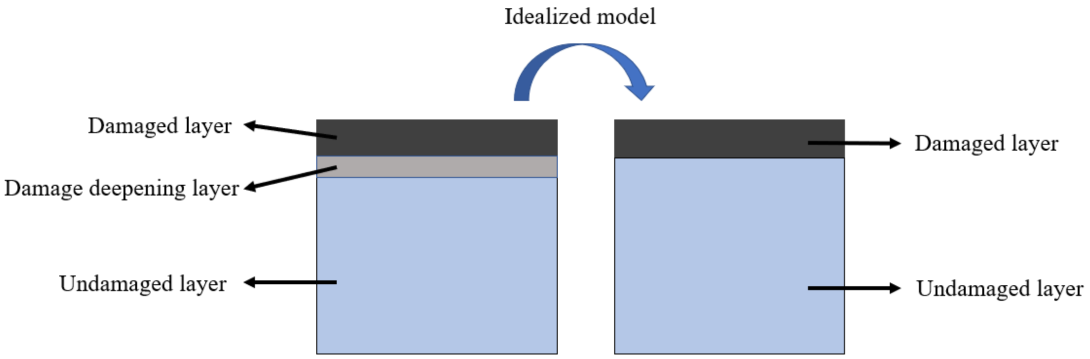
test block into an electric blast drying oven with a temperature of 45±5 ℃ and dried it for 6h; (d) Took the test block out of the drying oven and kept them at room temperature for 2h.

(4) According to the number of dry-wet cycles, the test was designed into 6 age periods, which were 14, 28, 56, 84, 112 and 140 dry-wet cycles respectively. At the end of each test age, the ultrasonic sound time, quality, cube compressive strength and splitting tensile strength of the test block shall be tested.

(5) The immersion solution shall be changed every 28d, the pH value of the immersion solution shall be measured with a portable pH meter every 7d, and the pH value of the solution shall be adjusted within the range of 7.0-7.5 with analytical pure HCl.

2.3.2 RAC damage layer thickness test

For the measurement of the thickness of the damaged layer under the salt solution erosion environment, the ultrasonic flat measurement method is usually used. In this paper, it is assumed that there is a clear boundary between the damaged layer and the undamaged layer of concrete. However, there is no obvious boundary between the damaged part and the undamaged part of concrete in reality. The outermost layer is seriously damaged, and the deeper the damage is, the lighter the damage is. There is an erosion damage transition layer, which is a short dense stage after the expansion of sulfate attack. Therefore, the concrete subject to sulfate attack should be divided into three parts: the damaged layer concrete, the damaged transition layer concrete and the undamaged layer concrete, as shown in Fig. 1 (a). Due to the relatively small thickness of the concrete in the damaged transition layer, in order to facilitate the ultrasonic detection and calculation analysis, this paper classifies it as the undamaged concrete part. This paper also assumes that the concrete in the damaged layer is uniformly distributed, and has an obvious boundary with the concrete in the undamaged layer, as shown in Fig. 1 (b).



(a) Actual section distribution (b) Assumed cross-section distribution

Fig. 1 – Distribution diagram of eroded RAC interface

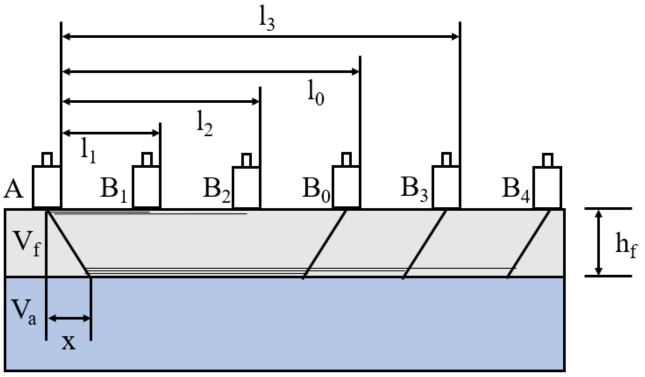


Fig. 2 – Setting of measuring points for damage layer depth

Ultrasonic flat testing method is a kind of nondestructive testing technology, which measures and obtains the results according to the difference of the propagation speed of pulse wave in the damaged layer and the undamaged layer of concrete. Fix the transmitting transducer T of the non-metallic ultrasonic detector at the measuring point A, and the receiving transducer R continuously tests the points B1, B2, B3, etc. along the concrete surface according to a certain distance, and read the corresponding sound at different positions, as shown in Fig. 2. The distance between the measuring point A where the transmitting transducer is located and the edge of the test block is 50mm, and the distance of the receiving transducer is 50mm, 75mm, 100mm, 150mm, 200mm and 250mm respectively. Vaseline is used as coupling agent. The calculation formula of concrete damage layer thickness hf is as follows:

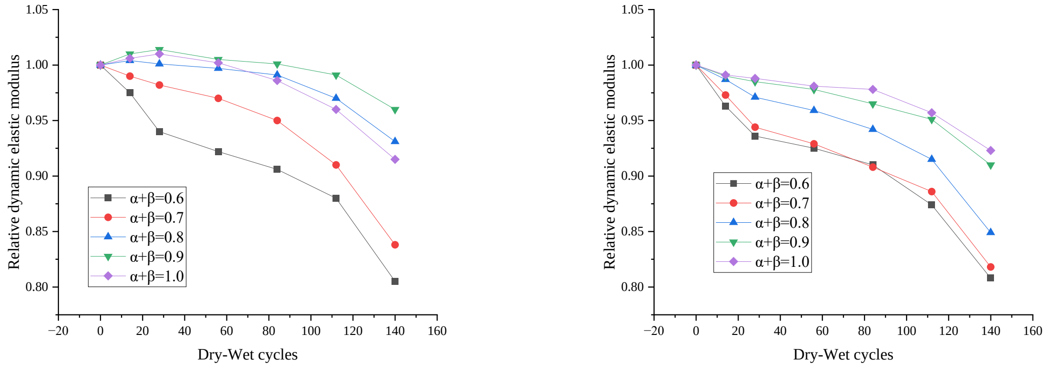
$$h_f = \frac{l_0}{2}\sqrt{\frac{V_a - V_f}{V_a + V_f}}$$

Note: h_f—Thickness of concrete damage layer (mm),
x — Horizontal projection of propagation path through damage layer (mm),
V_f —Propagation velocity of ultrasonic wave in the damaged layer (km/s),
V_a —Propagation velocity of ultrasonic wave in undamaged layer (km/s),
l_0 —Distance between two transducers in case of sudden change of sound speed (mm).

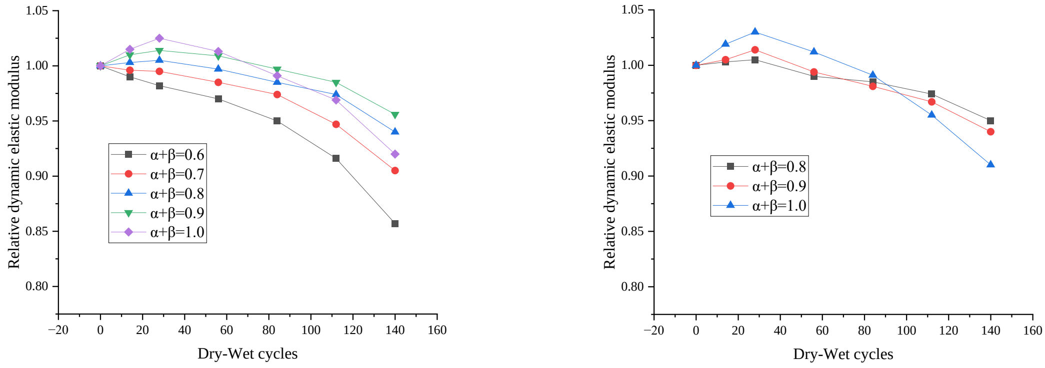
3 Results and discussions

3.1 Dynamic modulus of elasticity

The relative dynamic modulus of elasticity of RAC eroded by compose chloride salt generally presents two laws: (a) with the increase of the number of dry and wet alternations, it presents a trend of first increasing and then decreasing, (b) it keeps declining. This is directly related to the initial moisture content of recycled aggregate. In addition, the quality of RAC first increases and then decreases with the increase of dry-wet cycles, but the degree of decline is still related to the initial water content of recycled aggregate. The change rule of relative dynamic modulus of elasticity in 5% MgCl-10% NaCl composite chloride solution with different additional water consumption is as shown in Fig. 3.



(a) α=0 (b) α=0.25



(c) α=0.5 (d) α=0.75

Fig. 3 – Relative dynamic elastic modulus of RAC with different additional water consumption

When using absolutely dry recycled aggregate (initial moisture content α= 0) prepare RAC, its relative dynamic modulus of elasticity is greatly affected by the additional water consumption, as shown in Fig. 3 (a). When additional mixing water rate β is 0.6 and 0.7, its relative dynamic modulus of elasticity goes through three stages: slow decline stage, stable stage and rapid decline stage. In the first stage, there are two main reasons. Reason 1: Because the initial water absorption rate of the dry recycled aggregate is very fast, it absorbs a large amount of free water in a short time, resulting in the actual water-binder ratio of the mixture is far lower than the water-binder ratio calculated in the design mix ratio. A large number of cementitious materials in recycled concrete do not participate in hydration reaction, resulting in low internal density of concrete and poor resistance to chloride ion penetration. Reason 2: The alternation of dry and wet causes micro-damage inside the concrete and crystal damage formed by chloride salt. The appearance of the second stage is mainly due to the expansion products generated by the chloride corrosion reaction filling the pores, which to a certain extent plays a compaction role and alleviates the corrosion rate of chloride on recycled concrete, so the decay rate of dynamic elastic modulus also slows down. With the growth of erosion time, the expansion of erosion products produces more cracks, and a large number of corrosive ions enter the concrete, which aggravates the erosion damage. The relative dynamic modulus of elasticity decreases rapidly and enters the third stage.

Fig. 3 (a) shows when the additional water rate increases to more than 0.8, although the dynamic elastic modulus change rule of RAC can still be divided into three stages, it is significantly different from the test group with the additional water rate of 0.6 and 0.7. At this time, the dynamic modulus of elasticity changes in three stages: small increase, slow decline and rapid decline. Compared with the two test groups with low additional water, the difference of dynamic elastic modulus change law mainly occurs in the first stage before 28 dry and wet cycles. The main reason for the small increase in the range of 0.004-0.01 in the first stage is that the water absorption rate of the dry aggregate decreases rapidly after it absorbs more free water in the early stage. However, due to the increase of additional water, there is still a lot of free water left in the mixture system, which improves the hydration degree of the cementitious material, makes the early internal structure of RAC more compact, effectively hinders the erosion of chloride to RAC, so the early dynamic elastic modulus increases with the occurrence of hydration reaction. In addition, when using dry recycled aggregate to prepare recycled concrete, the decay rate of the dynamic elastic modulus of RAC after 28 dry and wet cycles generally slows down with the increase of the additional water rate. But add water to saturation (i.e α+β= 1.0), due to too much additional water, the water-cement ratio of recycled concrete is too large. After 28 dry and wet cycles, the dynamic elastic modulus of the test group decays faster.

When the initial moisture content of recycled aggregate is 0.25, the dynamic modulus of elasticity of RAC still undergoes a slow decline stage, a stable stage and a rapid decline stage. Moreover, from Fig. 3 (b), the decline rate of dynamic elastic modulus slows down with the increase of additional water consumption. Therefore, when adopting RAC with α=0.25 preparing recycled aggregate, it is recommended to add water to saturation to obtain higher dynamic elastic modulus.

When initial water content α=0.5 and additional water rate β 0.1-0.2 (i.e α+β= 0.6 & 0.7), the dynamic modulus of elasticity experienced two stages of slow decline and rapid decline. When the additional water consumption rate increases to more than 0.3 (i.e α+β= 0.8, 0.9 & 1.0), the dynamic elastic modulus of RAC can be divided into three stages: small increase, slow decrease and rapid decrease. In addition, adding water until the recycled aggregate to be saturated (i.e α+β=1.0), the dynamic elastic modulus of RAC before 56 dry and wet cycles is the highest. After that, the descending speed is accelerated, and is lower than "α+β= 0.9" test group, below 84 cycles dynamic elastic modulus of the "α+β=0.8" test group. When the initial moisture content of recycled aggregate is 0.75, the development law of its dynamic elastic modulus is the same as the corresponding α=0.5 RAC test group in the series.

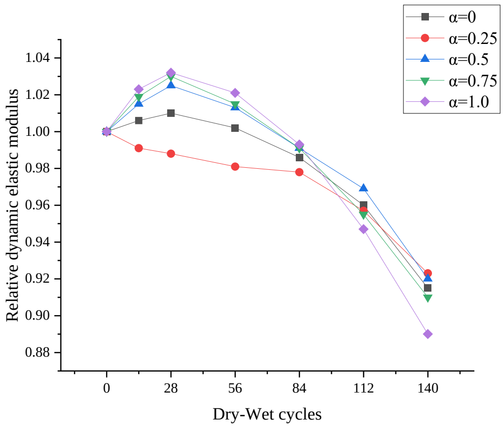
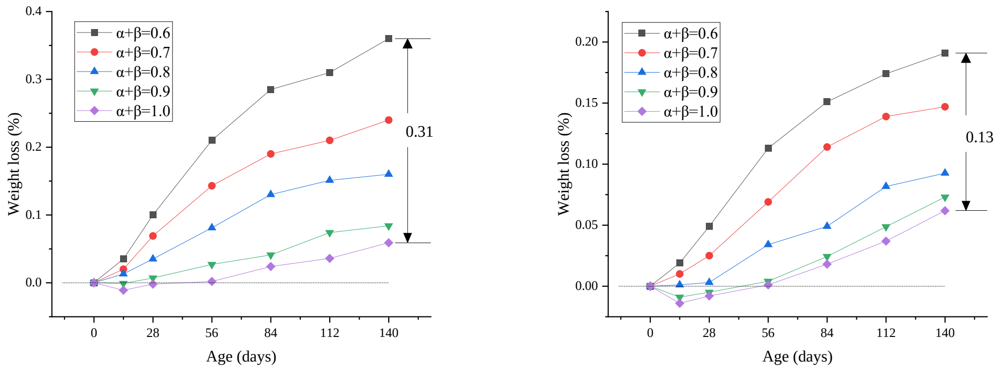


Fig. 4 – Effect of initial moisture content of aggregate on dynamic elastic modulus of RAC

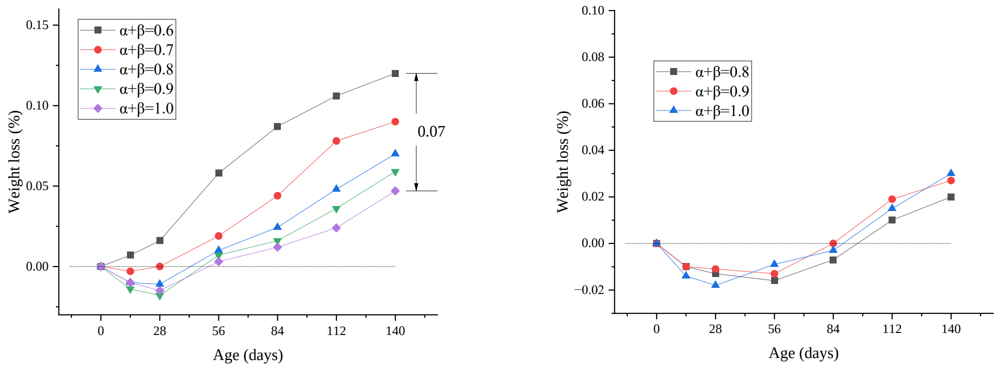
Fig. 4 shows the dynamic elastic modulus development rule of RAC when recycled aggregate with different water content is added to saturation. The curves of the test results are very similar, showing the characteristics of the rising stage and the falling stage before the first 28 dry and wet cycles. It is worth noting that in "α=0.25" experimental group, the image curve showed a continuous downward trend, and the early dynamic modulus of elasticity did not experience an upward stage. When the dry-wet cycle achieves 140 times, the relative dynamic modulus of elasticity of five groups of RAC are very close (the range is only 0.033). This means that when additional water added to the recycled aggregate saturation, the dynamic elastic modulus of RAC is not affected by the initial water content.

3.2 Quality of recycled concrete

In the environment of dry-wet cycle, chloride solution has two main effects on the change of concrete quality. On the one hand, the corrosion products generated by the reaction of chloride ions entering the concrete and hydration products are filled and aggregated in the concrete pores, temporarily improving the concrete compactness, which is manifested as the increase of quality. On the other hand, the corrosion products have expansibility, and the crystal salt expansion stress generated by salt solution under the alternate action of dry and wet causes the concrete to crack and flake, and the quality of the concrete is reduced. The change rule of mass loss of RAC using recycled aggregate vegetation with different initial moisture content in 5% MgCl-10% NaCl compound chloride solution is shown in Fig. 5. It can be seen from the figure that when the initial moisture content of recycled aggregate is different, the change trend of mass loss rate of RAC under the action of composite chloride and dry-wet cycle is also significantly different.



(a) α=0 (b) α=0.25



(c) α=0.5 (d) α=0.75

Fig. 5 – Mass of RAC with different additional water consumption

When the recycled aggregate is in an absolutely dry state, it will absorb more free water in a short time, resulting in poor compactness and impermeability of RAC. At the same time, if the additional water consumption rate is also very low（α+β≤ 0.8), then the quality of RAC will continue to decline. Moreover, the mass loss rate and loss rate decrease with the increase of the additional water consumption rate. Especially when the additional water rate is the lowest（α+β= 0.6), the rate of mass loss is the largest, and the appearance of partial mortar aggregate completely peels off in the later stage, which is most seriously corroded by chloride. When the additional water rate is high（α+β= 0.9 & 1.0), because there is more free water left in the mixture system that can react with the cementitious material, its early compactness is improved. Thus, before the age of 14 days, the quality of RAC had a very insignificant increase; At the later stage of erosion, the quality decline is the least, and the change range of quality loss rate is the smallest.

When water content α increasing to 0.25, the mass loss rate of RAC has been significantly alleviated (compared with α=0), and the mass loss rate within 140 days has decreased to within 0.2%. When α+β=0.9 & 1.0, the quality of RAC before 28 days of age is higher than that before chloride erosion, and after 56 days of age is lower than that before erosion. When water content αincreases to 0.5, the quality change trend of RAC is same as α=0.25

test group. When the moisture content of recycled aggregate increases to 0.75, the quality change of RAC is little affected by the additional water rate. The three curves in Fig. 5 (d) are very close.

By comparing the fluctuation range of RAC quality at 140 days in the four figures in Fig. 5, it can be found that the RAC performance fluctuates the most when using absolute dry aggregate to prepare RAC. With the increase of the moisture content of recycled aggregate, the loss of the quality of RAC within 140 days and the range of loss are decreasing. Therefore, when RAC is prepared with recycled aggregate with water content of 0.75, the resistance of concrete to chloride ion erosion is the most stable.

Fig. 6 shows the quality change trend of RAC when recycled aggregate with different water content is added to saturation. It can be seen from the figure that when the water added to saturation, the quality of RAC in all test groups increases first and then decreases. When the initial moisture content of aggregate within the range of 0-0.25, the quality of RAC only rises 14 days ago. Then it begins to decline, and the mass loss rate becomes positive at the age of 56 days. When the moisture content of recycled aggregate in the range of 0.5-1.0, the quality of RAC increases by 28 days, and the growth rate also becomes larger. Due to the high moisture content of aggregate, the slow water absorption rate, and the additional water consumption will not make the effective water-binder ratio too large, the RAC is relatively dense, the impermeability is improved, and the fluctuation range of the mass loss rate is very small (± 0.02%), until the age of 112 days, the mass loss rate becomes positive.

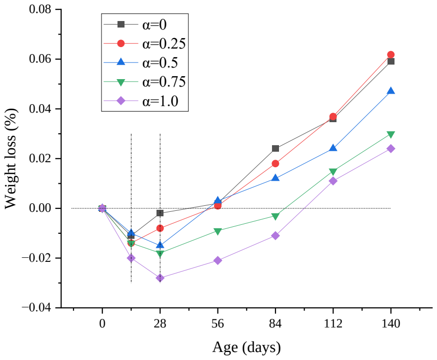


Fig. 6 – Effect of initial moisture content of aggregate on RAC quality

3.3 Thickness variation of RAC damage layer

The thickness of concrete damage layer and relevant characteristic values of each group of RAC at the age of 140 days are shown in Table 5 under the coupling effect of compound chloride solution erosion and dry-wet cycling environment.

The data in the table shows that when the initial moisture content of recycled aggregate used for RAC preparation is 0.5, the ultrasonic wave velocity (V_a) in the undamaged layer of RAC decreases slightly with the increase of additional water consumption. The reason is that the water absorption rate of recycled aggregate in this state is relatively low, and the additional water absorbed is relatively small. With the increase of the additional water consumption, the effective water-cement ratio of RAC is also improved, the material compactness is reduced, and the ultrasonic speed is reduced. The ultrasonic wave velocity (V_f) in the damaged layer of RAC is significantly lower than that in the undamaged layer (V_a), which indicates that the concrete in the damaged layer has poor compactness, and the ultrasonic wave velocity (V_f) in the damaged layer gradually decreases, which further indicates that the deterioration degree of the damaged layer of concrete gradually increases with the corrosion damage of the composite chloride salt. When α value remains unchanged at 0.5 and the β value increases from 0.1 to 0.4, the damage layer thickness (h_f) decreases by 20%. But when β When the value is 0.5, the damage layer thickness (h_f) slightly increases, and the corrosion resistance of RAC slightly decreases.

When additional water reaches saturation（α+β=1.0), the change rule of damage layer thickness is to increase first and then decrease. The test group "RCA0.25-AW0.75" was the most severely corroded by chloride. When the α value continues to increase, the aggregate water absorption and additional water consumption decrease simultaneously, the compactness and impermeability of RAC are improved, and the deterioration degree is gradually weakened.

4 Conclusion

Recycled concrete (RAC) technology has great potential in alleviating the pressure of sand and stone shortage in natural river courses and reducing the pressure of environmental pollution caused by a large number of construction and demolition waste. However, the high water absorption of recycled aggregate makes it difficult to control the durability of reinforced concrete produced by recycled aggregate. This study discusses the combined effect of initial moisture content and additional moisture content of recycled coarse aggregate (RCA) on the chloride corrosion resistance of concrete, hoping to make contributions to the practical application of recycled coarse aggregate in concrete production. According to the test results and discussion of this study, the following conclusions can be drawn:

(1) The relative dynamic elastic modulus of RAC eroded by composite chloride salt generally presents two laws: (a) When the initial water content of aggregate or the additional water content is high（$\alpha \geq 0.5$ or $\beta \geq 0.9$), with the increase of dry and wet alternation times, it shows a trend of increasing first and then decreasing. (b) When the water content of aggregate and the additional water consumption are low ($\alpha \leq 0.5$ and $\beta \leq 0.7$), the relative dynamic elastic modulus keeps decreasing.

(2) The quality change rule of RAC eroded by complex chloride salt is relatively complex. It is not only necessary to consider the two effects of chloride solution on the quality change of concrete, but also the different water content of aggregate and additional water rate will cause significant differences in the quality loss law.

(3) The corrosive ions in the complex chloride environment react with the cement cementitious matrix in the concrete to produce the corrosion products, which eventually lead to the defects in the concrete microstructure and form the damage layer from the surface to the inside. When the concrete damage layer is thicker and the sound velocity is lower, it indicates that its compactness is reduced and the damage degree is increased. The damage and deterioration of concrete can be effectively judged by measuring the thickness of concrete damage layer.

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