Improvement mechanism of recycled concrete using C-S-H type accelerator and modifying recycled aggregate by carbonation technology

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Abstract. In Japan, there is concern that concrete blocks due to demolition will increase with the renewal of concrete structures. Although it has been used for roadbed materials as recycling, in recent years, aggregates are removed from the concrete mass by crushing and grinding and used again as concrete aggregates. The quality of recycled aggregates varies depending on the concrete blocks and processing method. In concrete using recycled aggregates, it is necessary to take account of insufficient strength, drying shrinkage, freeze-thaw resistance and so on. In previous study, the quality of recycled aggregates was improved by adsorbing carbon dioxide to recycled aggregates, and recycled concrete used the modified aggregates has been confirmed to increase strength and reduce drying shrinkage. In this study, we focused on the aggregate interface of concrete such as the interfacial transition zone for the purpose of clearing the quality improvement method of recycled concrete. We attempted to modify the aggregate interface using a C-S-H hardening accelerator using two recycled aggregates of different quality. We will also compare which is more effective, concrete that tried to modify the aggregate interface and recycled concrete that uses carbonated modified recycled aggregate. We clarify the matters concerned about recycled concrete.

1. Introduction

In Japan, structures built during the period of high economic growth are increasingly required to be rebuilt or repaired over their life. 30 million tons of concrete are demolished annually. Demolition concrete are increasing year by year. In addition, the ready-mixed concrete left over and returned to the factory is called the return concrete, and the amount of return concrete is increasing. Recently, recycled aggregate is attracting attention from the viewpoint of reducing environmental impact. The recycled aggregate is an aggregate obtained by removing the aggregate from demolition concrete or return concrete so that it can be reused. The quality of recycled aggregate varies depending on the condition and processing method of the original concrete demolition material. In Japan, there are three levels of quality, L, M and H. Standards of recycled aggregate and concrete are specified in JIS A 5021~5023. The worst quality L is aggregate that has just been crushed and has a lot of mortar attached. On the other hand, L has merits such as lower energy cost than others. It was thought that low-quality recycled aggregate could be modified.

Various problems due to the large amount of attached mortar. The big problem is the decrease in strength due to many pores. In addition, high water absorption results in large drying shrinkage, causing freeze-thawing and scaling problems.

Therefore, the purpose of this study is to understand the problems of recycled aggregate and to examine methods that can solve these problems. In previous studies, carbonation of aggregates has been reported as a method of modifying recycled aggregates. It is reported that strength, drying shrinkage, and freeze-thaw resistance were improved. By forcibly carbonating the aggregate, calcium carbonate is generated in the attached mortar. Pores decrease and mortar area becomes denser.

On the other hand, Previous studies have reported that calcium silicate hydrate type accelerator (ACX) is effective in densifying the interfaced at the aggregate interface [1]. ACX is a curing accelerator developed in recent years. It is mainly composed of nanoparticles of calcium silicate hydrate. It is reported that adding 5% of ACX to water densifies the voids in the transition zone around the aggregate. By using ACX, which is said to be effective at the aggregate interface, it is thought it can reform recycled concrete using recycled aggregate.

In this study, we try to understand their impact on concrete by comparing recycled concrete with carbonation of aggregate and recycled concrete with ACX added.

2. Materials and specimen condition

2.1. The kinds of coarse aggregates

It was used recycled aggregate (RL). In addition, the recycled aggregate is carbonated in an environment with a carbon dioxide concentration of 5% (RC). Table 1 shows their physical properties. RL has high water absorption, and carbonation has the effect of reducing water absorption. Before mixing, RL was pre-soaked for 24 hours and the surface dried because the recycled aggregates have high water absorption.

2.2. Mix proportions

Table 2 shows the mix proportions on this research. Concrete with a water binder ratio of 50% was prepared by replacing the ground granulated blast furnace slag by 45%. Concrete using the recycled aggregate was similarly prepared (R, RX3, RX10) and in addition, the concrete using the two types aggregate. One is the pre-wetting was pre-soaked with the ACX solution of 10% concentration for 24 hours (RXW) and the other is the concrete that ACX was sprayed over all sides of the aggregate (RXS) as shown in Figure 1.

Table 1. Physical Properties of Coarse Aggregate

	Surface dry density (g/cm^3)	Dry density (g/cm^3)	Water absorption (%)
RL	2.42	2.29	5.53
RC	2.46	2.36	4.38

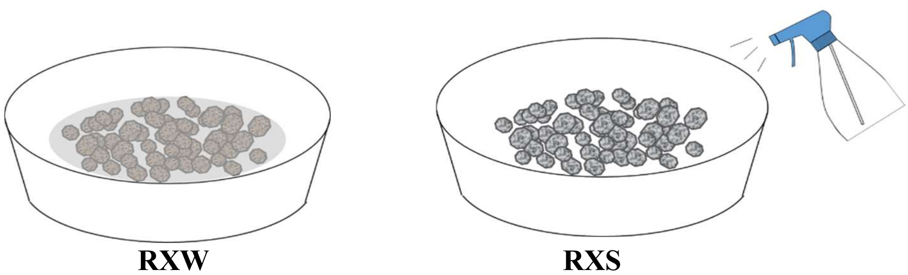

Figure 1. Overview of RXW and RXS

Table 2. Mix Proportion

	W/B	s/a	air	Quantity of material per unit volume of concrete					ACX	Fresh properties	
	(%)	(%)	(%)	W	OPC	GGBFS	S	G	(W×%)	Air(%)	Slump(cm)
R									0	3.5	22.5
RX3									3	3.9	22.2
RX10								**RL** 847	10	2.4	22.8
RXW	50	48	4.5	170	187	153	847		※1	4.1	23.1
RXS									※2	2.3	23.0
RC								**RC** 861	0	4.2	23.4

※1 Pre-wetting with 10% strength ACX
※2 Spraying the same amount of ACX as in RX3

3. Outline of experiment

3.1. Bleeding test
Bleeding was tested to determine the effect of bleeding suppression by the addition of ACX and the modification of aggregate in accordance with JIS A 1123. Concrete was cast into formwork that does not penetrate water, and the formwork size is φ100*200 mm. The test was started by lowering the casting surface by 30mm ± 3mm. Every 10 minutes after the casting, the water that had exuded on the upper surface was sucked with a dropper and transferred to a graduated cylinder for measurement. Measurements were taken until no bleeding was observed. The bleeding amount was determined by Equation 1.

$$B_q = \frac{V}{A} \tag{1}$$

Where:
B_q: Amount of bleeding
V: Total bleeding water volume until the end
A: Area of concrete casting surface

3.2. Drying shrinkage test
Two pieces of concrete of 100*100*400 mm with pins were prepared. The measured value after 7 days of underwater curing was used as the initial value, and after curing, the specimen stands in a constant temperature and humidity room (20°C, 60%RH). The length was measured after 1,4,14, and 28 days in accordance with JIS A 1129.

3.3. Compressive strength test and splitting tensile strength test
Three specimens of φ100*200 mm were prepared for each case, and after curing in water for 28 days, a compressive strength was tested in accordance with JIS A 1108. Also, a splitting tensile strength test was performed in accordance with JIS A 1113.

3.4. Air permeability test
Specimens of 150*150*150mm was prepared and cured for 28 days. After extracting the core to the size of ϕ100*50mm and leaving it in a completely dry state, an air permeability test was performed. In order to understand the effects of bleeding and the quality of the aggregate interface, air permeability test was performed from two directions as shown in Figure 2. In concrete, water rises to the upper surface, so it is considered that there are places where the water rises, and where there is a void after hardening due

to water that could not rise and accumulated on the lower surface of the aggregate. The air permeability coefficient was calculated by using equation (2).

$$K = \frac{2LP_1}{(P_1^2 - P_2^2)} * \frac{Q}{A} \tag{2}$$

Where:

K: Air permeability coefficient ($cm^4/N\cdot s$)
L: Sample thickness (cm)
P_1: Loading pressure (N/cm^2)
P_2: Outflow side pressure (N/cm^2)
Q: Air permeability (cm^3/s)
A: Air permeability area (cm^2)

Figure 2. Air permeability test

3.5. Porosity test

The porosity was calculated by the Archimedes method. The weight saturated with water (W_1) and the weight in water (W_2) were measured, and then the specimens stand in a chamber at 40℃. until the weight loss became constant, and the dry weight (W_3) was measured. The weight was calculated using the mass, and the weight was calculated by Equation (3).

$$\text{Porosity (\%)} = \frac{W_1 - W_3}{W_1 - W_2} \times 100 \tag{3}$$

4. Results

4.1. Bleeding test

In Figure 3, the total amount of bleeding is organized for each specimen. RX3 and RX10 showed non-bleeding. It became clear that the addition of ACX to concrete has a large inhibitory effect. RXW and RXS almost showed inhibitory effect. The reason that RXS had a smaller bleeding amount than RXW is probably that ACX sprayed on the surface diffused during mixing and had the same effect as that added.

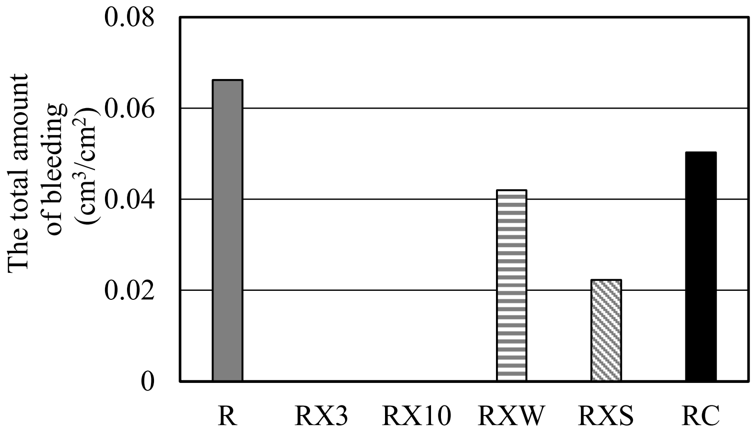

Figure 3. Bleeding amount

4.2. Drying shrinkage test

Figure 4 shows the results of drying shrinkage at 28 days. Drying shrinkage was suppressed by adding ACX. It became clear that adding 10% was more effective than adding 3%. Also, RXW, RXS and RC has almost same shrinkage rate. They did not show a reduction effect more than when ACX was added to the concrete itself. Therefore, drying shrinkage is best when ACX is added to the concrete mixing water.

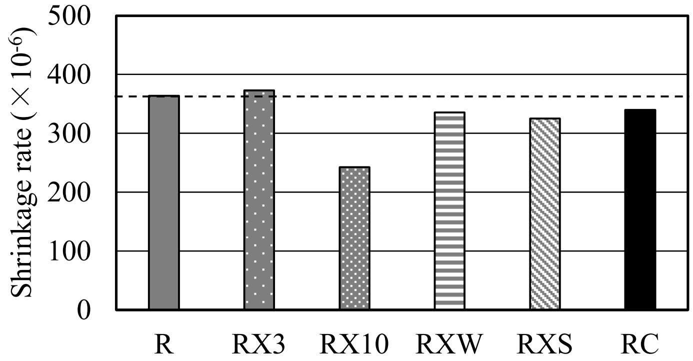

Figure 4. Drying shrinkage rate

4.3. Results of strength test

For concrete using recycled aggregate, RX10 had higher compressive strength, however RXW and RXS did not get stronger. Therefore, adding ACX to concrete is effective for compressive strength, however methods such as pre-wetting and spraying that attempt to modify the aggregate itself have no effect.

The greater the amount of ACX added, the greater the splitting tensile strength. RXW showed no increase in strength, but RXS showed the same degree of increase in strength as the addition of ACX. A possible reason for this is that the pre-wetting aggregate was not able to play a role in modifying the aggregate interface by wiping the surface. In addition, RC showed the highest strength among concrete using recycled aggregate.

Comparing the compressive strength with the split tensile strength, the effect on the split tensile strength is seen in RC. Therefore, it was considered that the splitting tensile strength increased because the strength of the aggregate itself increased due to carbonation, but the compressive strength of the aggregate interface and mortar did not change.

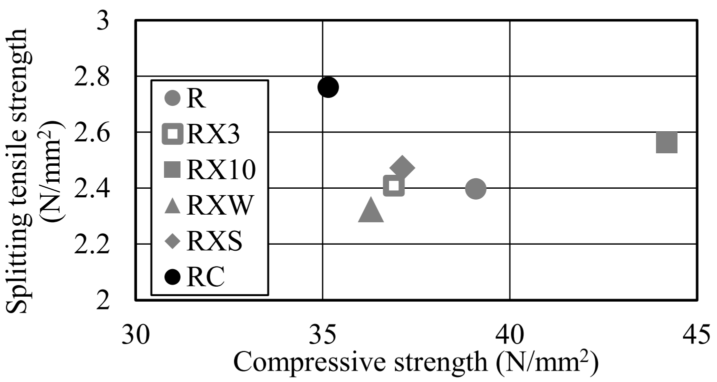

Figure 5. Compressive strength and splitting tensile strength

4.4. Air permeability test

4.4.1. Air permeability coefficient. Figure 6 shows the permeability coefficient calculated from the result of the permeability test in the horizontal direction on recycled concrete. The significant improvement of the air permeability by adding ACX is apparent. Due to the modification of the recycled aggregate itself, it is considered that RXW and RC had been densified by the mortar attached to the recycled aggregate.

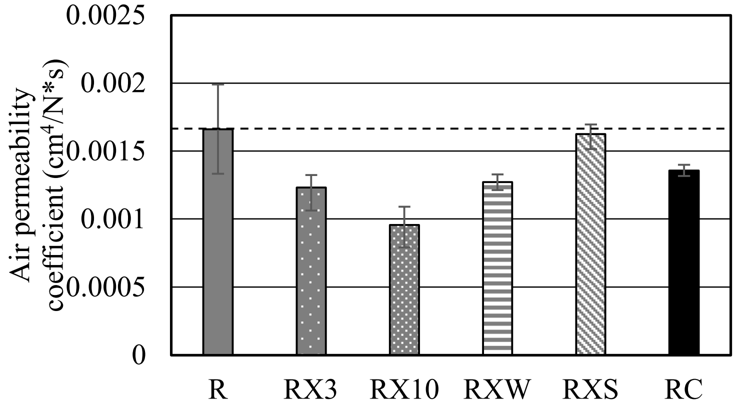

Figure 6. Air permeability coefficient (horizontal)

4.4.2. The relationship between compressive strength and air permeability coefficient. As shown in Figure 7, for concretes other than RXS, there was a correlation that the compressive strength decreased as the air permeability decreased. It was cleared that RX10 had significantly improved concrete. Only the permeability was improved with almost the same strength excluding RX10. Since the mortar content in the concrete does not change, it is considered that the compressive strength shows approximately the same value. Whether or not the improvement in the air permeability coefficient has been observed in that is whether the part which becomes the air pass has been reformed. In the case of RXS, the strength of the aggregate itself was considered to have increased due to the high splitting tensile strength, but it was considered that the concrete was not modified as RX3 and RX10.

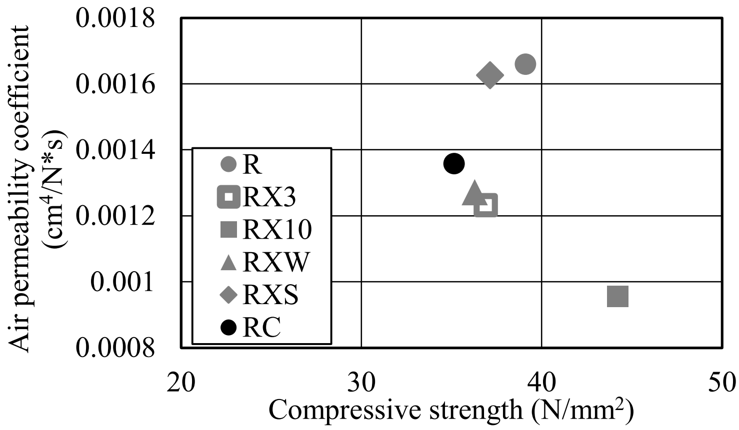

Figure 7. Compressive strength and air permeability coefficient

4.4.3. Air permeability coefficient in horizontal and vertical direction. In order to see the effect of the aggregate interface, the horizontal axis shows the air permeability coefficient in the horizontal direction and the vertical axis shows the air permeability coefficient in the vertical direction in Figure 8. In R and RC, it was found that the air permeability in the vertical direction was high, and it is considered that ACX bleeding water path was formed, and the air became easier to pass because R and RC had high bleeding amount. On the other hand, the values in the horizontal and vertical directions were almost the same for all RX3, RX10, RXW, and RXS using ACX. It is considered that the gap at the aggregate interface was improved by ACX. In addition, RC was a modification of the mortar attached to recycled aggregate, so the aggregate interface was not modified.

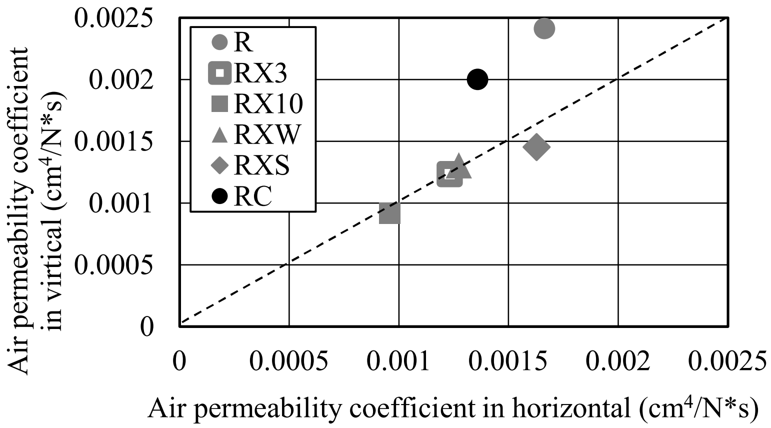

Figure 8. Air permeability coefficient in horizontal and vertical direction

4.5. Relationship with porosity

4.5.1. The relationship between porosity and strength. Figure 9 shows the relationship between porosity and strength. RX10 improved both strengths over RL, however the pore was almost same. On the other hand, the strength of RXS did not increase and the porosity decreased. For this reason, it is considered that RXS with ACX closer to the aggregate also contributed to the modification of the aggregate. RC contributed to splitting tensile strength rather than compressive strength.

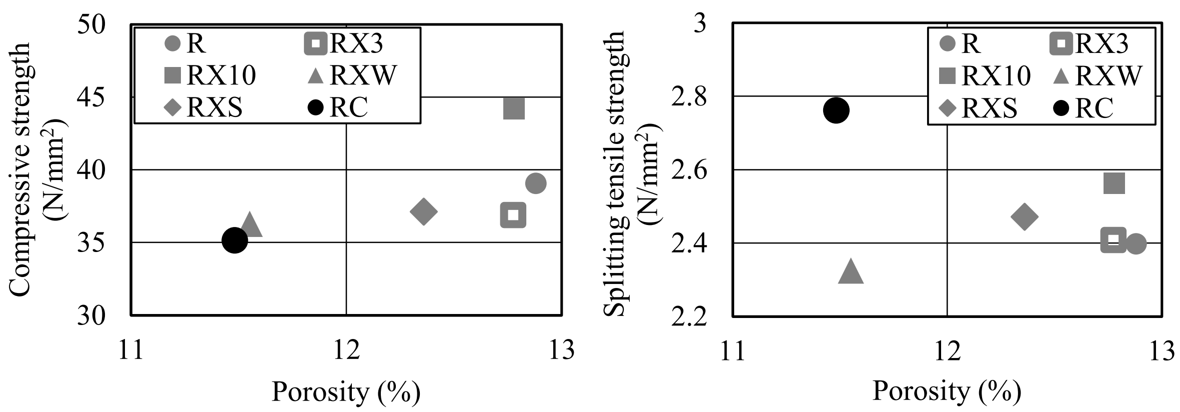

Figure 9. The relationship between porosity and strength

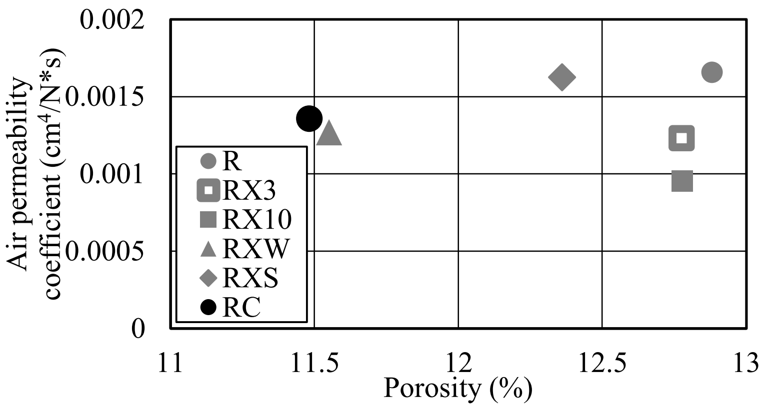

Figure 10. The relationship between porosity and air permeability

4.5.2. The relationship between porosity and air permeability coefficient. Figure 10 shows the relationship between porosity and air permeability. The RC and RXW obtained by modifying the aggregate have almost the same air permeability as RC, however the porosity decreased. On the other hand, those with the addition of accelerators to concrete, such as RX3 and RX10, improved the air permeability, however the porosity was not improved. Therefore, it was found that although the modified mortar portion of the recycled aggregate had a significant effect on the porosity, even if the aggregate was modified, air permeability was not improved.

4.6. Consideration

Based on the above results, it was considered possible to summarize the thoughts and sort out the degree of influence that each part of concrete has on physical properties. Table 3 shows the parts that affect each characteristic. In this study, it was clear that the properties affected by the modified part changed. The properties affected by the respective modifications of the aggregate, the transition zone, and the mortar portion are represented by "●". The parts that do not have an impact are marked as "■", and those that are difficult to judge are marked as "▲".

Table 3. List of contributions by modification

	Compressive strength	Splitting strength	Dry shrinkage	Air permeability		Porosity
				Vertical	Horizontal	
Aggregate	▲	▲	●	■	■	●
Transition zone	●	●	▲	▲	●	▲
Mortar	●	■	●	▲	▲	▲

5. Conclusion

- The quality of recycled concrete improved most when calcium silicate hydrate type accelerator was added to water at 10%.
- Air permeability can be improved by pre-wetting or spraying with calcium silicate hydrate type accelerator. However, it increases in compressive strength cannot be expected.
- Forced carbonation of recycled aggregate increases the strength of the aggregate itself and increases the split tensile strength. However, it does not improve the air permeability or compressive strength because it does not modify the aggregate interface in the recycled concrete.
- In the future, we would like to study methods for promoting the use of recycled coarse aggregate and study of recycled fine aggregate. In addition, we aim to sort out which part has the greatest effect on the physical properties of concrete.

6. References

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