Study of Improving Performance of Recycled Coarse Aggregate Concrete by Several Methods for Pore Structure Modification

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ABSTRACT

In recent years, there has been an increase in amount of waste concrete generated by the demolition, new construction, and renewal of concrete structures in Japan. There is a need for the widespread use of recycled concrete that can effectively reuse waste concrete. In order to promote the use of recycled concrete, it is desirable to promote the use of low-quality recycled aggregates that can be produced with less energy and cost. Recycled concrete has the problem of low strength and durability compared to normal concrete. The reason is thought that many pores exist in mortar to which recycled aggregate is attached and interfacial transition zone around recycled aggregate. In this study, we focused on two methods for modifying pores of concrete using recycled coarse aggregate. The first method is to modify aggregate by carbonating it. The second method is to modify concrete itself by adding C-S-H nanoparticle accelerator to concrete. It is also intended to modify recycled coarse aggregate using C-S-H nanoparticle accelerator, two methods were investigated: one is to pre-wet recycled coarse aggregate with C-S-H nanoparticle accelerator solution, and the other is to spray C-S-H nanoparticle accelerator onto recycled coarse aggregate and adhere to it. Then we compare strength and durability of the two methods of addition with that of the usual method of adding C-S-H nanoparticle accelerator and the method of modifying aggregates by carbonation. As a result, it is confirmed that there is a difference in the improvement of compressive strength, split tensile strength, mass transfer resistance, and porosity depending on methods of adding the C-S-H nanoparticle accelerator.

KEYWORDS: *Recycled concrete, Recycled aggregate, C-S-H nanoparticle accelerator, Carbonation, Pre-wetting*

1. Introduction

In Japan, more than 90% of waste concrete generated from demolition of structure is reused and most of them used for roadbed material and Backfill material. One way of reusing waste concrete is to use them as recycled aggregate for concrete. Recycled concrete is classified into three categories (H, M and L) according to production methods and absolute dry density and water absorption of recycled aggregate in JIS A5021, JIS A 5022 and JIS A5023. The higher the quality of recycled aggregate, the wider the range of structures in which it can be used, whereas the lower the quality of recycled aggregate, the more limited the range of possible uses, for components and areas where strength and durability are not required. In addition, the higher the quality of recycled aggregate, the higher the production costs and

energy consumption during production, while the lower the quality of recycled aggregate, the lower the production costs and energy consumption during production. Therefore, in order to promote the use of recycled concrete, it is desirable to promote the use of low-quality recycled aggregate, which can be produced with low energy and cost.
However, concrete made of low-quality recycled aggregate has low strength and durability due to the presence of many pores in attached mortar. In this study, we compared two methods of improving performance of concrete with using low-quality recycled coarse aggregate. The 1st method is improving performance of concrete by improving physical properties of aggregate. And 2nd method is improving performance of concrete by improving physical properties of concrete.

2. Outline of the experiment

2.1 Pores in recycled concrete

As shown in Figure 1, it is suggested that there are three locations where pores considered to reduce strength and durability exist in recycled concrete, 1) recycled aggregate, 2) aggregate interface , and 3) new mortar part. In order to improve the quality of recycled concrete, it is important to improve the total porosity of recycled aggregate, aggregate interface, and new mortar part.

2.2 Mix proportions

Table 1 shows the physical properties of aggregates used in this study. In this study, recycled coarse aggregate L was used in all mixture, and recycled coarse aggregate L used in this study was made of returned concrete. Crushed sand was used as fine aggregate. Table 2 shows the planned mix proportions of concrete in this study. In general, the occurrence of ASR in concrete made with low-quality recycled aggregate should be fully considered, since recycled aggregate is difficult to identify original aggregate. In this study, 45% of the cement used was replaced by blast furnace slag powder in order to exclude the effect of ASR. Recycled aggregate is allowed to dry out once and is pre-wetted with tap water for 24 hours before mixing, and just before mixing, water around aggregate is wiped off with rags to make it surface-dry.

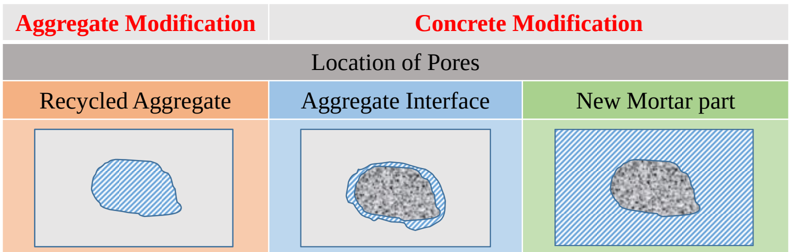

Figure 1. Location of pores

Table 1 Physical properties of aggregates

	Surface dry density (g/cm^3)	Absolute dry density (g/cm^3)	Water absorption rate (%)	Coarse-grained ratio (F.M.)
Recycled coarse aggregate L	2.42	2.29	5.53	6.70
Recycled coarse aggregate L after carbonation	2.46	2.36	4.38	6.7
Crushed sand	2.62	2.57	1.31	2.52

2.3 Experiment overview

(1) Aggregate modification

In this study, We focused on 2 methods of modifying recycled aggregate.

Table 2 Planned mix proportions of concrete

Type		Pores to be improved	W/C(%)	s/a(%)	air(%)	Unit Weight(kg/m³)					ACX
Name	Improving method					W	OPC	GGBFS	S	G	Addition rate (%)
N	Normal		50	48	4.5	170	187	153	847	847	0
CO_2	Aggregate carbonation	① Aggregate itself								861	0
ACX-D	Pre-wetting (Solution concentration 10%)	① Aggregate itself								847	0
ACX3%	Accelerator (W×3%)	② Aggregate interface ③ Motar part									3
ACX10%	Accelerator (W×10%)	② Aggregate interface ③ Motar part									10
ACX-S	Spray adhesion (Same amount as ACX3%)	② Aggregate interface									3

1st method of modifying recycled aggregate is carbonation of recycled aggregate. The author's research suggests that carbonation of aggregate is a technique based on the carbonation mechanism of concrete, and that the densification of the mortar to which recycled aggregate are attached to mortar by carbonation is a mechanism that increases the strength and durability of the concrete [1]. Carbonation of recycled aggregate was carried out in a neutralisation accelerator at 20°C, 60% RH and 5% CO_2 concentration for one week. Forced carbonation of recycled aggregate may improve porosity of recycled aggregate by densifying pores in recycled aggregate. (CO_2)

2nd method of modifying recycled aggregate is pre-wetting with solution of C-S-H nanoparticle accelerator diluted in water to a concentration of 10%. C-S-H nanoparticle accelerator is admixture mainly composed of calcium silicate hydrate nanoparticles, which are introduced into liquid phase of the concrete as crystal core of C-S-H, causing C-S-H to grow and accelerate hydration. Fukasawa's research suggested that the addition of C-S-H nanoparticle accelerator as an admixture to normal concrete improves the resistance to mass transfer and the addition of a large amount of C-S-H nanoparticle accelerator increases compressive strength [2].We thought that this method would allow C-S-H nanoparticle accelerator to penetrate mortar, which is attached to recycled aggregate, and that this would improve porosity of the recycled aggregate. (ACX-D)

(2) Concrete modification

In this study, We focused on 2 methods of modifying performance of recycled concrete.

1st method of modifying performance of recycled concrete is the addition of C-S-H nanoparticle accelerator to concrete as a method of modifying concrete. For studying about effect of quantity of C-S-H hardening accelerator in morter part for modifying performance of recycled concrete, two types of mixes were prepared. One with 3%, the other with 10% C-S-H nanoparticle as an admixture in relation to the unit water content, in the consideration that the addition of C-S-H hardening accelerator would provide the same durability-enhancing hardening in recycled concrete as in normal concrete. The addition of C-S-H nanoparticle accelerator as admixture to recycled concrete may improve porosity at aggregate interface and mortar. (ACX3%, ACX10%)

2nd method of modifying performance of recycled concrete is to add C-S-H nanoparticle accelerator to recycled aggregate by spraying it with mist spray. It was thought that this method would allow a greater amount of C-S-H nanoparticle accelerator to be placed around recycled aggregate, and effectively modify porosity of aggregate interface. (ACX-S) The amount of C-S-H nanoparticle accelerator added is the same as when 3% is added per unit water volume as an admixture, and a comparison is also made with the case where C-S-H nanoparticle accelerator is added as an admixture (ACX3%).

In all mix proportions, recycled aggregate was pre-wetting with water for 24 hours before making comcrete.

2.4 Conducted experiment

To evaluate the strength and durability of recycled concrete**,** we conducted 5 tests, the compressive strength test, split tensile strength test, drying shrinkage test, porosity test and air permeability test.

(1) Compressive strength test

φ100×200mm size cylinder specimens were used, and the specimens were cured in water at 20°C for 28 days. After curing of the specimens, we conducted compressive strength test. in accordance with JIS A 1108.

(2) Split tensile strength test

φ100×200mm size cylinder specimens were used, and the specimens were cured in water at 20°C for 28 days. After curing of the specimens, we conducted compressive strength test. in accordance with JIS A 1132.

(3) Drying shrinkage test

100×100×400mm size cylinder specimens were, and after 7 days of curing the specimens in water at 20°C , they were subjected to the dial gauge method in accordance with JIS A 1129-3.

(4) Air permeability test

150×150×150mm size cylinder specimens were used, the specimens were cured in water at 20°C for 28 days, and cores of φ100×50mm cylindrical specimens were taken from a height of 50 mm from the top and bottom surfaces. The specimens were dried in drying room at 40°C until their masses reached constant. After that, air was allowed to permeate through at a pressure of 0.1 MPa, and the amount of air permeation was measured using water displacement method using cylinder, and permeability coefficient was calculated.

(5) Porosity test

The specimens which, used in air permeability test were used for porosity test. The specimens were placed in a drying oven, and their dry weight was measured when they reached constant mass. After the dry mass measurement, the sample was placed in a container filled with water, placed in a vacuum chamber, vacuum aspirated for 6 hours, and then kept in vacuum for 1 day to measure the water saturated mass. The porosity of the entire concrete was calculated by measuring the mass in water and using the Archimedes method.

3. Results and discussion

3.1 Compressive strength and porosity

Figure 2 shows the relationship between compressive strength and porosity rate. In comparison with N, porosity rate didn’t change much in adding C-S-H nanoparticle accelerator (ACX3%, ACX10%), while ACX10% increased compressive strength. Porosity rate of concrete was greatly improved by CO_2 and ACX-D, but compressive strength was not increased. Since compressive strength was not improved in focusing on the improvement of the porosity of recycled aggregate itself or aggregate interface, it is assumed that the increase in compressive strength of recycled concrete is due to the improvement of porosity of mortar part, by high addition of C-S-H nanoparticle accelerator (10% ACX).

3.2 Split tensile strength and porosity

Figure 3 shows the relationship between split tensile strength and porosity rate. In case of which CO_2 and ACX-D were designed to modify recycled aggregate itself, porosity rate was improved and split tensile strength was increased compared with N. In the case of which ACX-S, ACX3% and ACX10% were adding C-S-H nanoparticle accelerator, split tensile strength and porosity rate was improved. Although they were improved split tensile strength and porosity rate smaller than in CO_2 and ACX-D. The results suggest that split tensile strength depends on the amount of pores in recycled aggregate itself the best. And split tensile strength can also be improved by improving physical properties of recycled aggregate and pores at aggregate interface.

3.3 Result of air permeability and porosity

Figure 4 shows the relationship between the rusult of air permeability and porosity rate. CO_2 and ACX-D, which are designed to improve physical properties of recycled aggregates, show significant improvement in porosity rate, but improvement in mass transfer resistance was small. On the other hand, ACX-S, ACX3%, and ACX10%, which were designed to improve porosity of concrete, improved the mass transfer resistance, especially ACX10% was the best. This result suggests that to improve the resistance to mass transfer, it is important to improve pores of aggregate interface. In addition to that, by improving pores of morter part, the resistance to mass transfer is more improved. On the other hand, porosity rate of concrete is not rerated with the resistance to mass transfer.
It is unclear whether porosity rate test using the Archimedes method measures porosity of recycled concrete in recycled aggregate itself, at aggregate interface or in mortar part, and porosity in each of these areas. It is necessary to investigate whether addition of C-S-H nanoparticle accelerator to the recycled concrete improves porosity of recycled aggregate, aggregate interface or mortar part, and how the improvement in porosity affects the strength and durability of concrete.

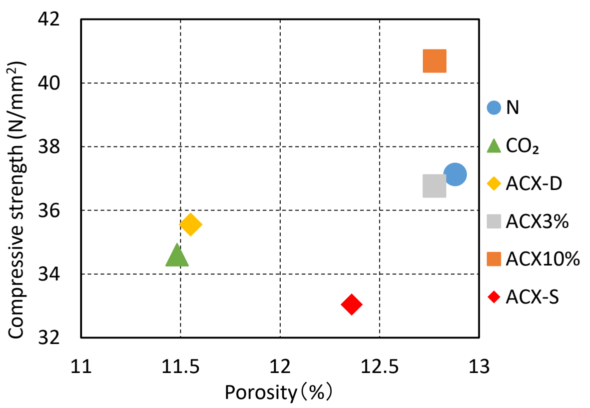

Figure 2. Compressive strength and porosity

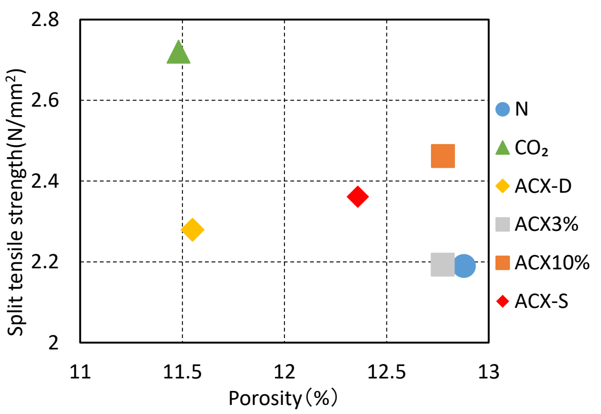

Figure 3. Split tensile strength and porosity

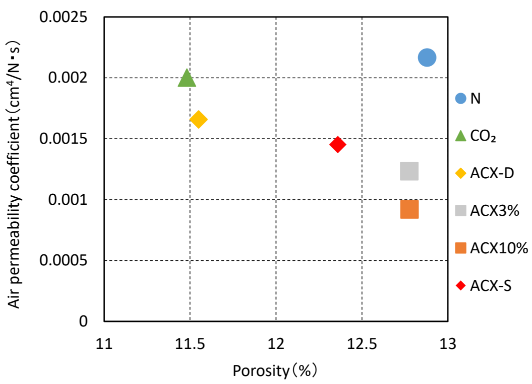

Figure 4. Air permeability and porosity

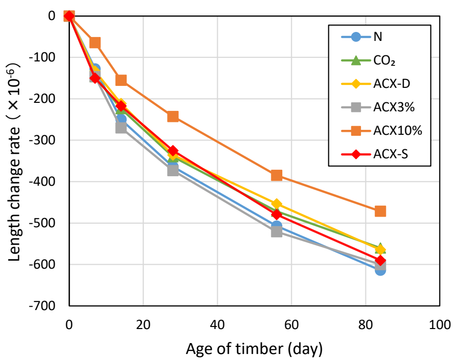

Figure 5. Drying shrinkage

3.4 Drying shrinkage

Figure 5 shows the results of drying shrinkage test. Compared to N, ACX10% reduced drying shrinkage. CO_2 and ACX-D showed a slight decrease in drying shrinkage compared to N, CO_2 and ACX-D showed almost the same trend of drying shrinkage. ACX3% showed almost the same trend of length change compared to N. At ACX10%, the length change due to drying shrinkage decreased, it is suggested that the addition of C-S-H nanoparticle accelerator in morter enough reduce drying shrinkage in recycled concrete

4. Summary of effects of recycled concrete modification methods

Table 3 shows the relationship among targeted porosity and improvement in strength and durability for each mix proportions. The following is a discussion of where the strength and durability can be improved by modifying pores present. To improve split tensile strength, it is important to improve porosity of either 1) recycled aggregate, 2) aggregate interface, or 3) new mortar part. Also in order to improve porosity of concrete, it is important to 1) improve porosity of recycled aggregate. In order to improve the resistance to mass transfer, it is important to improve porosity of 2) aggregate interface, and to improve porosity of 3) new mortar part and matrix, can improve the compressive strength and drying shrinkage resistance too. In the future, it is expected to clarify that how the method of addition of C-S-H nanoparticle accelerator to aggregate interface, recycled aggregate itself can improve porosity rate and mass transfer resistance, therefore, we would like to elucidate the mechanism of the improvement of porosity and mass transfer resistance of recycled concrete by adding C-S-H nanoparticle accelerator .

Table 3 Relationship between targeted porosity and improvement in strength and durability

<table>
<tr><td colspan="2">Pores for improvinging</td><td colspan="2">1) Recycled Aggregate</td><td colspan="3">2) Aggregate Interface</td><td colspan="2">3) NeW Mortar Part</td></tr>
<tr><td colspan="2">Mix proportion</td><td>ACX-D</td><td>CO_2</td><td>ACX3%</td><td>ACX10%</td><td>ACX-S</td><td>ACX3%</td><td>ACX10%</td></tr>
<tr><td rowspan="5">Physical characteristics</td><td>Compression strength</td><td colspan="2"></td><td colspan="3"></td><td colspan="2">○</td></tr>
<tr><td>Split tensile strength</td><td colspan="2">○</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>Porosity</td><td colspan="2">○</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>Mass transfer resistance</td><td colspan="2"></td><td colspan="3">○</td><td colspan="2">○</td></tr>
<tr><td>Drying shrinkage</td><td colspan="2"></td><td colspan="3"></td><td colspan="2">○</td></tr>
</table>

5. Conclusion

The effect of pores improvement method on the strength and durability of recycled concrete is shown below.

(1) Addition of C-S-H nanoparticle accelerator to concrete improves porosity of aggregate interface and mass transfer resistance. Compressive strength is improved by adding large amount of C-S-H nanoparticle accelerator.

(2) Adhesion of C-S-H nanoparticle accelerator to aggregate surface improves porosity of aggregate interface and increases the resistance to material penetration.

(3) Pre-wetting with a solution of C-S-H nanoparticle accelerator improves porosity of concrete by improving porosity of recycled aggregate.

(4) The carbonation of recycled aggregate improves split tensile strength. The porosity of recycled aggregate is also improved by carbonation, thus improving porosity of the concrete.

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