Life-Cycle of Structures and Infrastructure Systems – Biondini & Frangopol (Eds)

Influence of different coarse aggregate types on porosity and various properties in concrete

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ABSTRACT: Greater utilization of recycled aggregate concrete is desirable to realize a sustainable society. To achieve sustainable, it is necessary to clarify the factors that reduce the strength and mass transfer resistance of low-quality recycled aggregate concrete and to develop technologies to improve these factors. In this study, the porosity in the concrete and its effect on each property were identified using a variety of coarse aggregates in order to identify the porosity in recycled aggregate concrete that leads to a reduction in strength and mass transfer resistance. The results show that low-quality recycled aggregate concrete has reduced strength and mass transfer resistance due to increased porosity in the new mortar and at the interface between the aggregate and the new cement paste. A C-S-H type accelerator agent was used as a solution to this problem. Strength and mass transfer resistance of low-quality recycled aggregate concrete were improved by the use of a C-S-H type accelerator.

1 INTRODUCTION

In recent years, concrete waste has been increasing in Japan due to demolition and renewal of aging concrete structures. Figure 1 shows the projected future generation of concrete waste in Tokyo. Concrete waste will continue to increase and is projected to be approximately 1.5 times greater in 2050 than in 2022. Concrete waste is reused as aggregate for roads. However, as road construction in Japan is expected to decrease in the future, new ways of using concrete waste are needed. On the other hand, the use of natural aggregates in concrete needs to be curbed in order to reduce the environmental impact. Against this background, we believe that concrete waste should be recycled as aggregate for concrete and used as recycled aggregate concrete. To promote the use of recycled aggregate concrete, it is necessary to use low-quality recycled aggregate, which can be produced with less energy and cost than the energy and cost-intensive production of high-quality recycled aggregate. However, low-quality recycled aggregate concrete is not widely used because its strength and mass transfer resistance are lower than those of normal concrete. Therefore, it is necessary to clarify the factors that reduce the strength and mass transfer resistance of low-quality recycled aggregate concrete and to develop technologies to improve these factors. So, we thought that the strength and mass transfer resistance of concrete are related to the porosity in the concrete. In this study, the porosity of concrete made with various aggregates was compared with that of low-quality recycled aggregate concrete in order to identify the porosity that leads to reduced strength and mass transfer resistance of low-quality recycled aggregate concrete. The porosity in the concrete was classified as porosity in the aggregate, porosity in the new mortar, and porosity at the interface between the aggregate and the new cement paste. Then, we investigated the use of C-S-H type accelerator as a technique to improve the porosity in the concrete.

2 COARSE AGGREGATE AND CONCRETE OVERVIEW

2.1 *Type and characteristics of coarse aggregate*

The study used the following coarse aggregates to determine the factors that reduce the strength and mass transfer resistance of low-quality recycled aggregate concrete. Table 1 shows the characteristics

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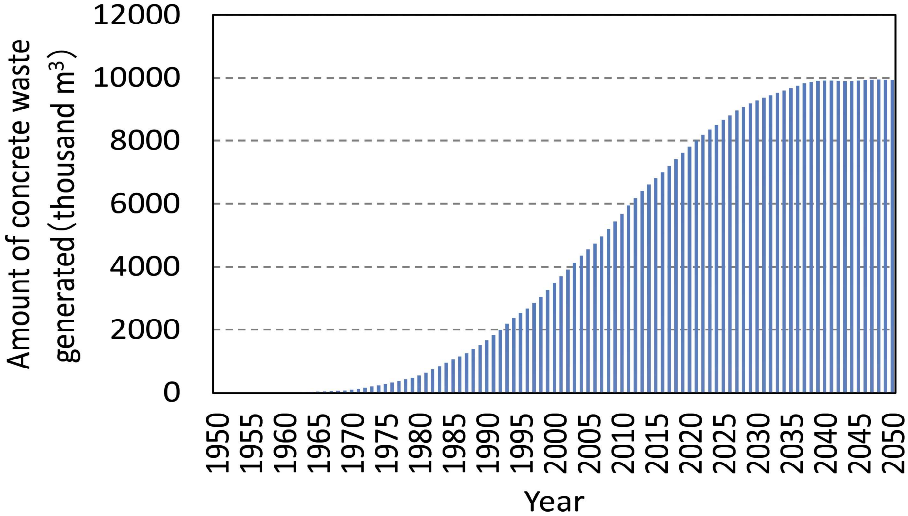

Figure 1. The projected generation of concrete waste in Tokyo.

of the coarse aggregates used. Hard sandstone was used because it has lower water absorption than low-quality recycled aggregate. Limestone was used because it has a lower water absorption rate than low-quality recycled aggregate and its main constituent is calcium carbonate. Recycled aggregate was low-quality recycled aggregate. The concrete waste used in this recycled coarse aggregate was constructed in 1966. The cement type of this concrete waste was ordinary Portland cement, and the compressive strength of the concrete was expected to be approximately 22.5 N/mm^2 based on the JASS 5. Artificial lightweight aggregate was used because it has a very highwater absorption rate compared to low-quality recycled aggregate. RLG and LWG are assumed to have high porosity in the aggregate due to high water absorption. We believed that there is a relationship between aggregate porosity and strength, so we conducted a crush value test. The crush value test is specified in JIS A 5023. However, the load was changed from 100kN to 200kN to obtain clear results. Crushed samples passing through a 2.5mm mesh sieve were also measured. The crushing values were larger in the order of HSG < LSG < RLG < LWG. The results indicate that LWG is vulnerable due to the high porosity in the aggregate. The results indicate that LWG is more fragile than RLG due to higher porosity in the aggregate. On the other hand, it has been reported that moisture in artificial lightweight aggregates affects the internal curing effect of concrete. Therefore, we conducted a moisture loss test of RLG and LWG. This method of moisture loss testing was conducted using a drying oven to check for changes in aggregate mass. The temperature and humidity in the drying oven were 20°C and 40-50%, respectively. Since air was circulating inside the drying oven, the specimens were placed in a wire mesh basket and the surrounding area was sealed to prevent sample errors. In addition, covers were installed to prevent wind from blowing directly onto the upper and lower surfaces of the wire mesh cage. The sample was approximately 500 g, and the saturated condition was used as the base point. The moisture loss rate is calculated using Equation 1. The moisture loss rate is expressed as a percentage of the amount of moisture loss relative to the total water in the unit fine aggregate volume. Figure 2 shows the change in moisture loss rate over time. RLG increased moisture loss up to 24 hours, with 30% of the moisture in the aggregate loss at 24 hours. LWG was slower in moisture loss, and 10% of the moisture in the aggregate was lost in 24 hours. From these results, it can be inferred that LWG has a slow moisture loss from the aggregate and provides an internal curing effect in the concrete.

$$moisture\ loss\ rate(vol\%) = \frac{(saturated\ mass - mass\ of\ each\ hour)}{(\text{saturated mass} - \text{oven dry mass})} / unit\ volume \quad (1)$$

Table 1. The characteristics of the coarse aggregate.

Type	Hard sandstone	Limestone	Low-quality Recycle aggregate	Artificial lightweight aggregate
Symbol	HSG	LSG	RLG	LWG
Appearance				
Oven dry density (g/cm^2)	2.64	2.69	2.31	1.33
Water absorption (%)	0.69	0.53	6.58	27.00
Crushing value (%)	4.1	9.7	14.0	22.9

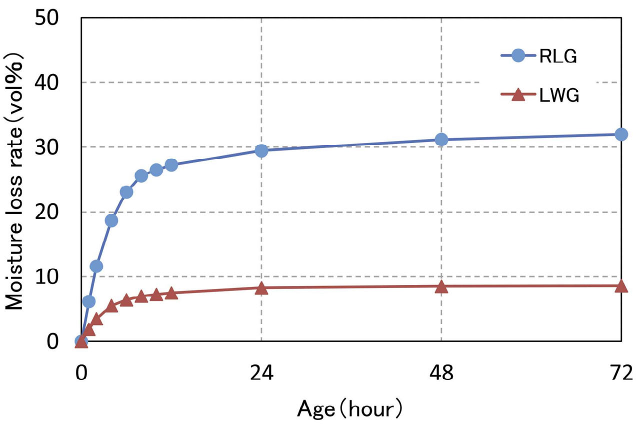

Figure 2. Moisture loss rate.

2.2 *Mix proportion of concrete*

Table 2 shows the mix proportions. Ordinary Portland cement(OPC) (density: 3.15 g/cm^3) and blast furnace slag cement type B(BB)(density: 3.04 g/cm^3) were used as cement. The reason for using blast furnace slag cement was the thought that the effect on porosity in concrete depends on the type of cement. The fine aggregate consisted of crushed sand (saturated density: 2.64 g/cm^3) and sand (mountain sand) (saturated density: 2.58 g/cm^3) in a 7:3 ratio by volume. AE water reducer was used as an admixture. The amount of admixture added was set to achieve a slump of 12 ± 2.5 cm and an air of 4.5 ± 1.5%.

3 OUTLINE OF EXPERIMENT

3.1 *Compressive 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.

Table 2. The mix proportions.

Symbol	Aggregate	Cement	W/C (%)	s/a (%)	Air (%)	Unit Weight (kg/m^3)			
						W	C	S	G
NHSG	HSG	OPC	50.0	48.0	4.5	170	340	853	937
NLSG	LSG								951
NRLG	RLG								866
NLWG	LWG								595
BHSG	HSG	BB						847	931
BLSG	LSG								945
BRLG	RLG								861
BLWG	LWG								592

3.2 *Air permeability test*

Cylindrical specimens of φ100 × 200 mm size were used for the test, cured in water at 20°C for 28 days, and cut into cylindrical specimens of φ100 × 50 mm in size. The specimens were dried in a drying room at 40°C until the mass was 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.

3.3 *Porosity test*

Cylindrical specimens of φ100 × 200 mm size were used for the test, cured in water at 20°C for 28 days, and cut into cylindrical specimens of φ100 × 50 mm in size. After that, it was the specimens were dried at 40 °C in a drying oven until the weight loss became constant and measured the mass in an absolutely dry state. The porosity was calculated by the Archimedes method using these values.

4 RESULTS AND DISCUSSION

4.1 *Compressive strength test*

Figure 3 shows the compressive strength. The mix proportions using OPC resulted in the lowest compressive strength of the RLG. This result was 67% of the compressive strength of HSG. On the other hand, LWG resulted in higher compressive strength than RLG. The BB mix proportions resulted in the lowest compressive strength of the RLG. This result was 82% of the compressive strength of HSG. LWG also showed greater water absorption and crushing values than RLG, but there was no relationship between these results and compressive strength.

4.2 *Air permeability test*

Figure 4 shows the results of the air permeability test. The permeability coefficient of RLG was large than that of HSG. Comparing OPC and BB results, the overall air permeability of BB was greater. In particular, LWG resulted in a very large air permeability when BB was used. The reason for this may be that the type of porosity affecting the air permeability coefficient is different between OPC and BB cement. These results indicate that the compressive strength and air permeability coefficient of low-quality recycled aggregate concrete are significantly lower than those of ordinary concrete. This is thought to be due to the effect of porosity in the concrete.

4.3 *Effect of porosity in concrete on compressive strength and air permeability coefficient*

Figure 5 shows the relationship between porosity and compressive strength in concrete. LWG had the largest porosity in the concrete, but the compressive strength results were higher than RLG. This trend was also true for BB. The reason for the increased porosity of concrete with

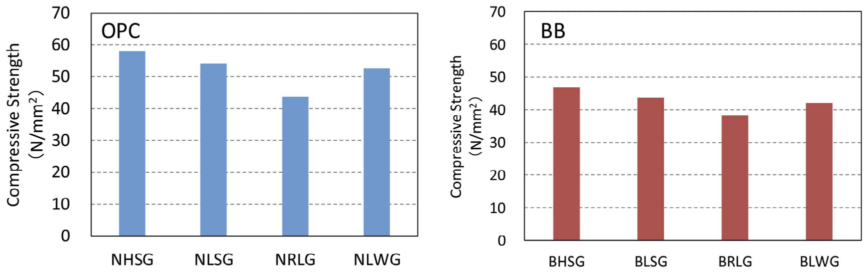

Figure 3. Compressive strength.

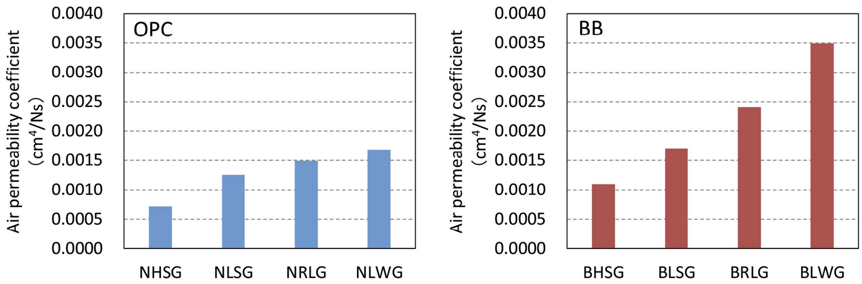

Figure 4. Air permeability coefficient.

LWG may be the high porosity in the aggregate. Therefore, the weak spots in the concrete can be considered to be the interface porosity between the new mortar or aggregate and the new paste, rather than the porosity of the aggregate. Figure 6 shows the relationship between the porosity and air permeability coefficient of concrete. The air permeability coefficient of the OPC mix proportions with the increase in the porosity in the concrete. RLG has an increased porosity and larger permeability in the concrete than HSG, suggesting that mass transfer resistance is reduced. On the other hand, the slope of the equation calculated by the method of least squares based on the relationship between the porosity and permeability in concrete is different for OPC and BB. Based on these results, we believe that the type of porosity depended on is different between OPC and BB. Therefore, we classified the porosity in concrete into aggregate porosity and other porosities and investigated the effect of porosity on the compressive strength and mass transfer resistance of low-quality recycled aggregate concrete.

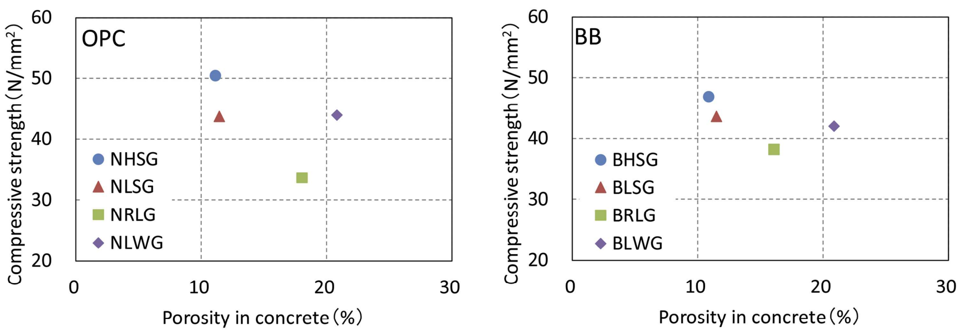

Figure 5. The relationship between porosity and compressive strength in concrete.

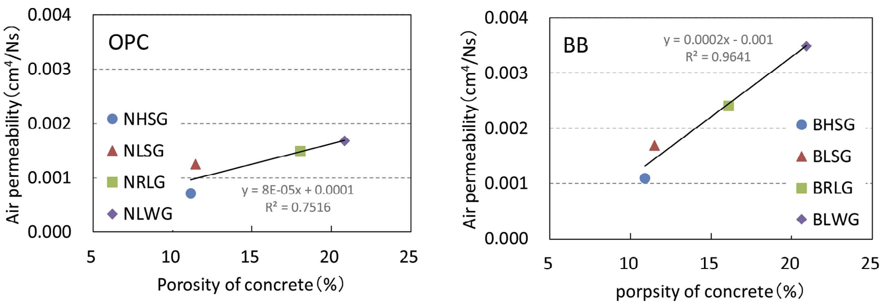

Figure 6. The relationship between porosity and air permeability coefficient in concrete.

5 CLASSIFICATION OF POROSITY IN CONCRETE

5.1 *Method for classifying porosity in concrete*

The porosity in concrete was classified into aggregate porosity and other porosity, and the factors that reduce the compressive strength and mass transfer resistance of low-quality recycled aggregate concrete were examined. Therefore, the porosity in concrete was classified into aggregate porosity, new mortar porosity, and interface porosity between the aggregate and the new cement paste(aggregate interface). Aggregate porosity was calculated by multiplying the water absorption of coarse aggregate by the absolute volume of coarse aggregate. The porosity of the new mortar was calculated by the Archimedes method, and the porosity in the new mortar was multiplied by the absolute volume of the new mortar. The porosity at the interface between the aggregate and the new cement paste was defined as the porosity in the concrete minus the porosity in the aggregate and in the new mortar.

5.2 *Porosity in classified concrete*

Figure 7 shows the results of the classification of porosity in concrete. LWG has the largest increase in porosity in the concrete. However, the majority of the porosity in the aggregate. RLG shows an increase in porosity at the new mortar and aggregate interface. This trend is more pronounced for OPC than for BB. Therefore, low-quality recycled aggregate concrete exhibits reduced compressive strength and mass transfer resistance due to increased porosity at the interface between the new mortar and aggregate. On the other hand, the LWG also has less porosity at the new mortar and aggregate interface than the RLG. We believe the reason for this is the internal curing effect of the artificial lightweight aggregate. The high-water absorption of the artificial lightweight aggregate may have promoted hydration of the interface between the new mortar or aggregate and the paste through an internal curing effect. However, we believe that low-quality recycled aggregate has different moisture behavior in the aggregate than artificial lightweight aggregate. The reason for this is that, since low-quality recycled aggregate has no internal curing effect, we believe that moisture movement from the aggregate increased the porosity of the new mortar and the interface between the aggregate and the new cement paste. However, BB showed a slight increase in porosity in the new mortar of the LWG. This is thought to be an increase in large capillary pores, given the results of the air permeability coefficient. These results suggest that the effects of moisture and moisture movement in aggregates may differ between OPC and BB.

6 TECHNOLOGY TO IMPROVE POROSITY IN CONCRETE

The C-S-H type accelerator was used to improve the porosity in the new mortar and the interface porosity between the aggregate and the new cement paste in low-quality recycled

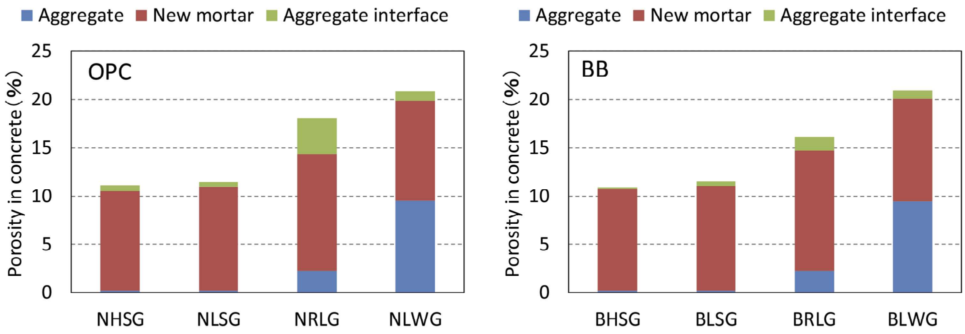

Figure 7. The classification of porosity in concrete.

aggregate concrete. C-S-H type accelerator are new admixtures containing CSH nanoparticles. In previous studies, it has been reported that C-S-H nanoparticles improve compressive strength and mass transfer resistance by densifying the porosity at the new mortar and aggregate interface. Therefore, we used the C-S-H type accelerators in the mix proportions of BB shown in Table 2. The reason for using C-S-H type accelerator in BB is that previous studies have reported that the reaction of blast furnace slag is accelerated by the addition of C-S-H type accelerator. Based on the above, we believe that the C-S-H type accelerator can improve the strength and mass transfer resistance of low-quality recycled aggregate concrete.

Figure 8 shows test results for compressive strength and air permeability test of concrete with C-S-H type accelerator. Compressive strength and permeability of LSG and RLG were improved by the use of C-S-H type accelerator. This is due to the improved porosity of the new mortar and aggregate interface. This image is shown in Figure 9. HSG and LWG have fewer porosity in the concrete, making it difficult for C-S-H nanoparticles to penetrate into the porosity. LSG has fewer porosity in the concrete, but the aggregate features calcium carbonate, which promotes the effect of the C-S-H type accelerator. On the other hand, RLG increases the porosity at the new mortar aggregate interface, which makes it easier for CSH nanoparticles to penetrate into the porosity. We believe that the compressive strength and air permeability coefficient were improved by the C-S-H nanoparticles densifying the porosity. The reason for using C-S-H type accelerator in BB is that previous studies have reported that the reaction of blast furnace slag is accelerated by the addition of C-S-H type accelerator. Based on the above, we believe that the C-S-H type accelerator can improve the strength and mass transfer resistance of low-quality recycled aggregate concrete.

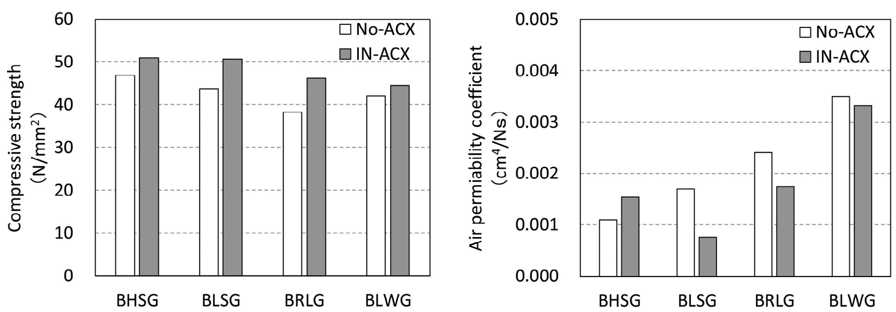

Figure 8. Test results of concrete with C-S-H type accelerator.

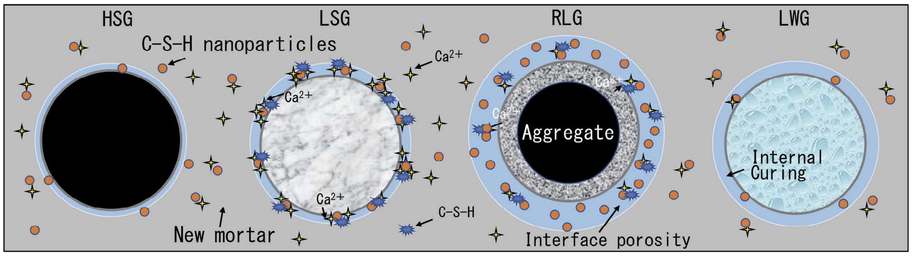

Figure 9. Image of porosity improvement by C-S-H type accelerator.

7 CONCLUSION

1) Compressive strength and mass transfer resistance of low-quality recycled aggregate concrete were lower than those of normal concrete.
2) The low quality recycled aggregate concrete had increased porosity at the new mortar and aggregate interface. This would have resulted in a decrease in compressive strength and mass transfer resistance.
3) The compressive strength and permeability of concrete made with limestone aggregate and low-quality recycled aggregate were improved by using the C-S-H type accelerator.

In the future, we will study the moisture behavior of low-quality recycled aggregate. In addition, we would like to investigate carbonation technology as a method to control moisture movement from the aggregate.

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