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METHOD FOR IMPROVING THE QUALITY OF LOW-GRADE RECYCLED AGGREGATE

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Abstract

There is a shortage of natural aggregates in Japan. In addition, many concrete structures are deteriorating, generating large amounts of concrete waste. These are serious issues in Japan, but recycled aggregates may be one effective way to solve these problems. However, recycled aggregates are not popular due to quality and cost issues. In particular, the residual mortar attached to the original aggregate greatly affects the quality. In this research, two studies were carried out. Firstly, we investigated the influence of the recycled aggregate residual mortar on concrete properties. It was found that the strength of the recycled aggregate concrete has a direct relation to the strength of the original concrete. Second, we examined a method for improving the quality by exposing recycled aggregates to carbon dioxide. The strength of the recycled aggregate concrete increased and the drying shrinkage decreased using this method.

Keywords: *Recycled Aggregate*; *Drying Shrinkage*; *Compressive Strength*; *Splitting Tensile Strength; CO_2.*

1. INTRODUCTION

In recent years, Japan has been facing a shortage of aggregate for use in concrete. Additionally, the generation of large quantities of concrete waste due to the demolition of structures is another problem. In order to solve these issues, the use of recycled aggregates seems to be an effective solution. Recycled aggregates can be classified as H, M, or L, which represent high to low quality, respectively. Following the Japanese Industrial Standard, recycled aggregate H can be used in ready-mixed concrete without restriction; that is, it can be used similarly to normal aggregates. However, the cost is higher than the normal aggregate. On the other hand, recycled aggregate M and L cannot be used in ready-mixed concrete. These lower quality recycled aggregates have restricted applications even though they are low cost. Therefore, problems with cost and quality prevent the spread of recycled aggregates.

The target of this research is to increase the usage of low-quality recycled aggregates. Low-quality recycled aggregates have a large volume of attached mortar, which has a large effect on concrete performance. In addition, the mix proportions of the attached mortar are often unclear, so we prepared recycled aggregate with controlled mix proportions to clarify the effect of the original concrete's mix proportions. Concrete using this recycled aggregate was prepared and the strength of the recycled aggregate concrete was measured. Furthermore, it was considered that low-quality recycled aggregate might be more widely used if the quality of the recycled aggregates was improved. So, we also developed a

Table 1 Original concrete compressive strength

W/C (%)	Compressive strength(N/mm^2)	
	7day	28day
30 (R30)	64.0	76.6
50 (R50)	28.7	36.9
70 (R70)	14.3	19.3

Table 2 Aggregate type and physical properties

	Aggregate type	Name	Water absorption (%)	Fineness modulus (%)	Standard
Fine aggregate	Mountain sand	S	0.91	2.91	-
Coarse aggregate	Crushed stone	N	0.54	6.60	-
Recycled coarse aggregate	W/C 30%	R30	6.15	6.68	low
Recycled coarse aggregate	W/C 50%	R50	6.55	6.79	low
Recycled coarse aggregate	W/C 70%	R70	6.64	6.66	low

Table 3 Mix proportion

Aggregate Type	W/C (%)	s/a (%)	Unit weight(kg/m^3)							
			W	C	BFS	S	N	R30	R50	R70
N	50	50	172	189	155	888	911	-	-	-
R30	50	50	172	189	155	888	-	801	-	-
R50	50	50	172	189	155	888	-	-	784	-
R70	50	50	172	189	155	888	-	-	-	750
RM (7:3)	50	50	172	189	155	888	-	560	-	225
RM(5:5)	50	50	172	189	155	888	-	400	-	375
RM (3:7)	50	50	172	189	155	888	-	240	-	525

Table 4 Test method

Test method	Number of specimens	Test age (week)	Curing method
Compressive strength test	3	4	In water
Splitting tensile strength test	30	4	In water

method to improve the quality of recycled aggregates and compared the strength and drying shrinkage of the concrete using the improved recycled aggregates with that using common recycled aggregates.

2. EFFECT OF ATTACHED MORTAR

2.1 Preparation of recycled aggregate

The effect of different original concrete mix proportions on the strength of recycled aggregate concrete was investigated. First, concrete with W/C of 30%, 50%, and 70% were cast. After 28 days of water curing, this concrete was exposed to the atmosphere for 7 days, then crushed in a jaw crusher to produce the recycled aggregate. Table 1 show the compressive strengths of the original manufactured concrete.

2.2 Concrete mix proportions, used materials and test methods

Table 2 shows the physical properties of the aggregate, and Table 3 shows the mix proportions of the recycled aggregate concrete. Blast furnace slag cement was used to reduce environmental impact and suppress the alkali silica reaction. Table 4 shows the test methods. As the recycled aggregate concrete's strength was considered to have a large variation, the number of specimens for the splitting tensile test was increased.

2.3 Results and discussions

Figure 1 shows the compressive strength, splitting tensile strength and coefficient of variation. The strength of the recycled aggregate concrete tended to be higher when using recycled aggregate from higher strength original concrete. Figure 2 shows the relationship between the strength and the mixing ratio of R30. It can be determined from this figure that the strength of the recycled aggregate concrete is higher when more aggregates from higher strength original concrete are used.

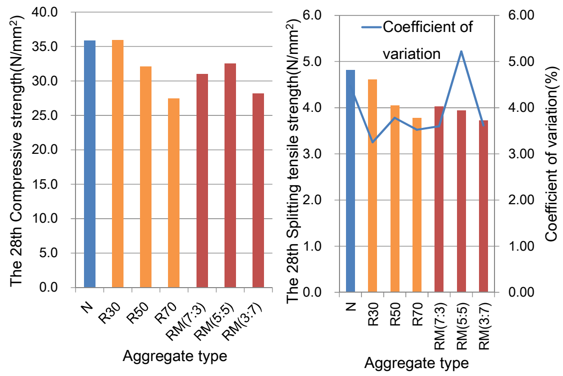

Figure 1 Result of strength tests

Furthermore, there is a positive correlation between them. It was considered that high strength of the recycled aggregate was due to the strong adhesion of mortal to original aggregate, which increased the strength of the recycled aggregate concrete.
For the splitting tensile test, it is thought that the coefficient of variation is small because it is approximately 5% or less.

3. QUALITY IMPROVEMENT OF RECYCLED AGGREGATE (STRENGTH TEST)

3.1 Quality improvement method, concrete mix proportions, materials and test methods

The quality improvement method consists of placing the recycled aggregates in a carbonation test chamber (controlled temperature was 20 degree Celsius, relative humidity was 60% and concentration of CO_2 was 5%) for one week. By doing this, it was believed that the attached mortar would carbonated, and become denser,[1] and the water absorption would decrease. Table 5 shows the aggregate type and physical properties. As shown in Table 5, the water absorption of the recycled aggregates was reduced, and the quality was improved. The mix proportion and test methods were the same as 2.2.

3.2 Results and discussions

Figure 3 shows the compressive strength, splitting tensile strength and coefficient of variation. The compressive strength and splitting tensile strength of the recycled aggregate concretes increased after exposure to CO_2.

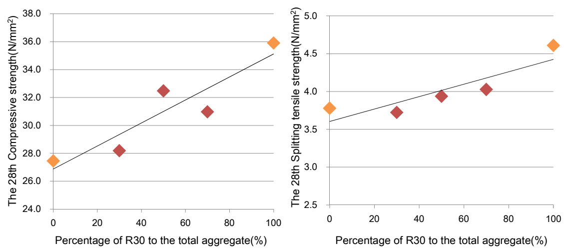

Figure 2 Relationship of strength and mixing ratio for R30

Table 5 Aggregate types and physical properties

	Aggregate type	Name	Water absorption (%)	Fineness modulus (%)	Standard
Fine aggregate	Mountain sand	S	0.91	2.91	-
Coarse aggregate	Crushed stone	N	0.54	6.60	-
	Recycled aggregate	L	6.82	6.81	Low
		Lc	6.62		Low
		M	3.28	6.73	Middle
		Mc	2.84		Higt

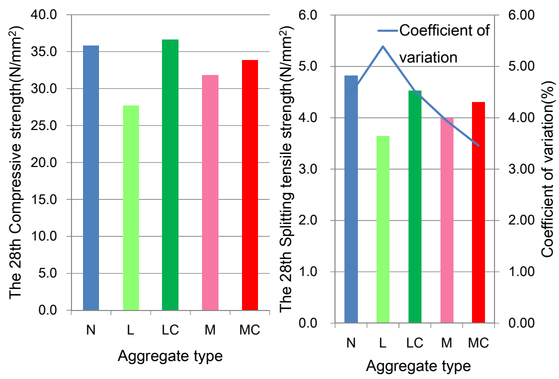

Figure 3 Result for strength test

It is considered that the strength of the mortar attached to the recycled aggregate increased due to carbonation. However, it is necessary to examine this further in the future.
For the splitting tensile test, it is thought that the coefficient of variation is small because it is approximately 5% or less. Furthermore, the coefficient of variation tended to decrease after exposure to CO_2.

4. QUALITY IMPROVEMENT OF RECYCLED AGGREGATE (TEST FOR MEASUREMENT FOR LENGTH CHANGE)

4.1 Quality improvement method

The quality improvement method is the same as 3.1.

4.2 Concrete mix proportions, materials and test methods

Table 6 shows the aggregate type and physical properties. In addition, the mix proportion was the same as 2.2.

The test for measuring the change in length was performed after 7 days of water curing, after which the concrete was placed in an environment with a temperature of 20 degrees Celsius and relative humidity of 60%, in a temperature and humidity testing room. This method thus examined the drying shrinkage. The drying ages were 1, 2, 3, 4, 8, 10, 13, and 16 weeks. The reported values are the average drying shrinkage ratio of three specimens.

The CO_2 adsorption rate was also measured. The weight of the recycled aggregates during carbonation was periodically measured, and the absorption rate calculated using the following formula.

$$Tc = (S2-S1)/S1 \quad (1)$$

Where, Tc: CO_2 adsorption rate (%), S1: original mass (g), S2: mass at each time point (g)

4.3 Results and discussions

The results of the test for length change are shown in Figure 5 for recycled aggregate M and in Figure 4 for recycled aggregate L. For recycled aggregate L, drying shrinkage reduction was particularly observed in the recycled aggregate LA. It was a reduction of about 200×10^{-6}. In LA, the original concrete was waste fresh concrete, so it was considered that the improvement method was more effective and carbonation of mortar progressed easily. For recycled aggregate M, an effect of exposure to CO_2 was not observed.

From these results, it is considered that the effect of carbonation on drying shrinkage was small because there was not much reduction for recycled aggregate M compared with recycled aggregate L. Figure 6 shows the relationship between the CO_2 adsorption rate and drying shrinkage reduction rate after 10 weeks. It can CO_2 adsorption rate increases the drying shrinkage reduction rate also increases. From this result, it is possible that the drying shrinkage reduction rate can be estimated from the CO_2 adsorption rate. However, since the

Table 6 Aggregate types and physical properties

	Aggregate type	Name	density in saturated surface-dry condition (g/cm^3)	Water absorption (%)	Standard
Fine aggregate	Mountain sand	S	2.61	0.91	-
Coarse aggregate	Crushed stone	N	2.72	0.54	-
Recycled coarse aggregate	Waste fresh concrete + Demolished concrete	MA	2.58	3.01	Middle
		MAc	2.57	2.62	High
		MB	2.54	3.94	Middle
		MBc	2.55	3.34	Middle
	Waste fresh concrete	LA	2.37	7.44	Out of standard
		LAc	2.34	6.40	Low
	Demolished concrete	LB	2.45	5.69	Low
		LBc	2.43	5.40	Middle
		LC	2.45	5.42	Low
		LCc	2.48	4.54	Middle

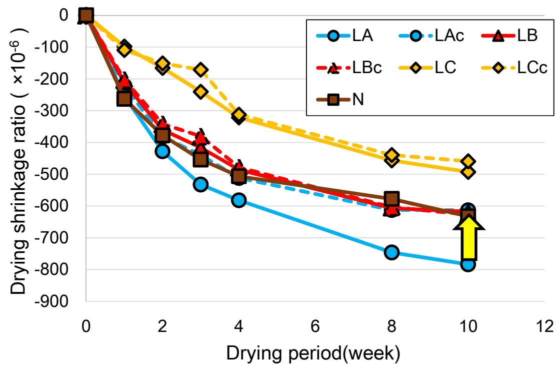

Figure 4 Test result for measurement for length change (recycled aggregate L)

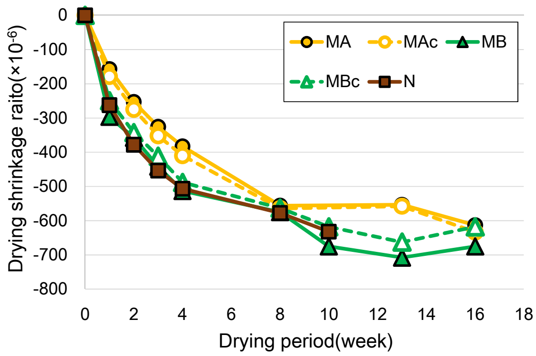

Figure 5 Test results for measurement for length change (recycled aggregate M)

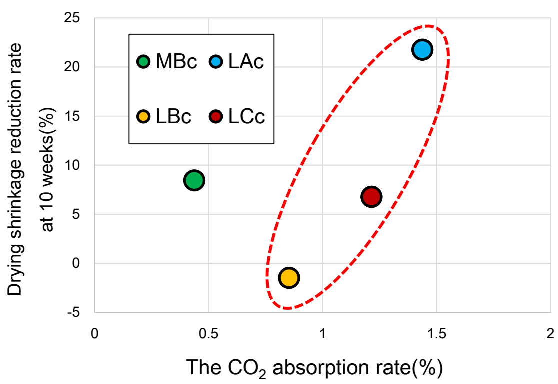

Figure 6 Relationship of CO_2 adsorption rate and drying shrinkage reduction rate at 10 weeks

number of specimens was small, it is necessary to perform further tests in the future to confirm this correlation.

5. CONCLUSION

The following results were obtained in this research.

(1) For compressive strength and splitting tensile strength, it was confirmed that, recycled aggregate concrete's strength is dependent on the strength of the original concrete.

(2) The strength of recycled aggregate concrete was confirmed to increase when the recycled aggregates were exposed to CO_2.

(3) Exposure recycled aggregate L to CO_2 was confirmed to reduce drying shrinkage in recycled aggregate concrete.

(4) For recycled aggregate L, a linear correlation between CO_2 adsorption rate and drying shrinkage reduction rate was found, and the drying shrinkage reduction rate may be estimated using the results.

REFERENCES

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