The 16th International Congress on the Chemistry of Cement 2023 (ICCC2023)
"Further Reduction of CO_2 -Emissions and Circularity in the Cement and Concrete Industry"
September 18–22, 2023, Bangkok, Thailand

A Study on Mortar Properties Focusing on Water Absorption Ratio of Carbonated Recycled Fine Aggregate

Y. INOUE[1*], Y. IKEO[2], and T. IYODA[3]

[1] *Shibaura Institute of Technology, Tokyo, Japan*
Email: mh22001@shibaura-it.ac.jp
[2] *Takenaka Corporation, Chiba, Japan*
Email: ikeo.yousaku@takenaka.co.jp
[3] *Shibaura Institute of Technology, Tokyo, Japan*
Email: iyoda@shibaura-it.ac.jp

ABSTRACT

In Japan, concrete waste has been reused as roadbed material. In the future, the amount of concrete waste generated is expected to increase due to the increase in demolition of concrete structures. Therefore, the amount of concrete waste generated is expected to exceed the demand for roadbed material. Also, new road construction is expected to decline. This means that, concrete waste should be reused as recycled aggregate for concrete. Recycled aggregates are classified as class H, M, and L in order of aggregate quality in Japan. Recycled aggregate class L can be produced with less energy and cost. Meanwhile, concrete made with Recycled aggregate class L has low strength and large drying shrinkage. To promote the use of recycled aggregate concrete, technology for modifying Recycled aggregate class L at low cost is required. We have proposed a method of carbonating recycled aggregate using CO_2 gas. This method improves the water absorption ratio and density of the aggregate by carbonating the attached mortar. It is reported that the higher the density and lower the water absorption ratio of the recycled aggregate, the higher the concrete's property. The density and the water absorption ratio of the recycled aggregate depend on amount of attached mortar, type of raw aggregate, and carbonation. In this study, the water absorption ratio of recycled fine aggregate was improved by focusing on carbonation period and carbonation method of the aggregate. Regardless of the method, the mortar's property was found to improve along with the improvement in water absorption ratio by carbonation. It is estimated that the water absorption ratio of the aggregate can be used to determine the mortar's property. Improvement of the recycled fine aggregate and mortar property was significant when the aggregate was soaked in calcium hydroxide and carbonated for 7days.

KEYWORDS: *recycled fine aggregate, carbonation, water absorption ratio, carbonation period, mortar properties*

1. Introduction

In order to achieve a sustainable society, efforts to reduce the impact on the environment and to create a recycling-oriented society are required in the construction field as well. In Japan, 90% concrete waste generated when concrete structures are demolished has been reused as roadbed and backfill materials. However, a decrease in new road construction is expected in the future. On the other hand, the amount of concrete waste is expected to increase with the demolition of many concrete structures constructed during the period of rapid economic growth. Therefore, the amount of concrete waste generated is expected to exceed the demand for roadbed material. Thus, concrete waste should be reused as recycled aggregate for concrete. And it is hoped that the use of concrete with recycled aggregate will be promoted. However, recycled aggregate is rarely used in Japan.

In Japan, recycled aggregate is classified into three types using aggregate quality. They are called class H, M, and L, in descending order of quality. Recycled aggregate class L can be produced with less energy and cost than recycled aggregate class H and class M. And it generates less by-product fine powder. On the other hand, concrete made with low-quality recycled aggregate has problems when compared to concrete made with normal aggregate. It has lower strength and higher drying shrinkage. If recycled aggregate concrete is to become widely used, there is a need for a technology to modify low-quality recycled aggregate that does not require special manufacturing equipment. We have previously proposed a method of carbonation of recycled aggregate using CO_2 gas as a modification technology for low-quality recycled aggregate.

Among them, recycled fine aggregate is noted to have a significant improvement effect due to forced carbonation. Figure 1 shows an image of the mechanism of carbonation of recycled aggregate. Carbonation converts calcium hydroxide in the aggregate to calcium carbonate. When calcium carbonate with a large volume is produced, the voids in the aggregate are filled, water absorption ratio is reduced, and absolute dry density is increased. It is reported that, in general, the higher the density of the recycled aggregate and the lower the water absorption ratio, the higher the physical properties of the recycled aggregate. They are highly dependent on the amount of attached mortar, the type of original aggregate, and the presence or absence of carbonation.

In this study, we focused on the number of days of aggregate carbonation and carbonation methods to improve the water absorption ratio of recycled fine aggregate. The same low-quality recycled fine aggregate was modified by several methods. We examined the effect of water absorption ratio of those aggregates on the strength and durability of the mortar.

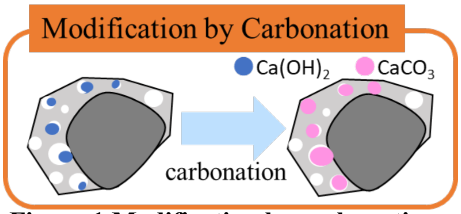

Figure 1 Modification by carbonation

2. Modification of Recycled Fine Aggregate by Carbonation

Table 1 shows the physical properties of the recycled fine aggregate used in this study, and Figure 2 shows the relationship between the absolute dry density and water absorption ratio of the aggregate before and after modification. In this study, the recycled fine aggregate of lower quality than Class L was used as recycled fine aggregate before modification (A). The following studies were conducted to confirm the effects of different carbonation periods and modification methods. These modifications brought all the recycled fine aggregate within the class L. First, we extended the carbonation period. Carbonation of aggregate was performed using an accelerated carbonation system at 20°C, 60% relative humidity, and 5% CO_2 concentration. The extended periods were 7, 14, 28, and 56 days (A-7d, 14d, 28d, 56d). 7 days carbonation resulted in the same improvement as in the previous studies. The improvement effect has varied in previous studies, but this time the improvement effect was different from previous studies. Focusing on the carbonation period, the physical properties of the aggregate are more improved by extending the period compared to the 7days carbonation. However, the physical property data for 28 days and 56 days are almost the same. Also, aggregates were prepared to confirm whether the improvement in water absorption ratio by carbonation was significant. (B). It has the same water absorption ratio together with A-7d.

Next, the fine particles were pre-cut and carbonated in water using carbonated water (C). The same improvement was observed in carbonation in water (CC).

In a different carbonation method, the aggregate was soaked with calcium hydroxide water solution (hereafter referred to as CH) (D). A saturated water solution of calcium hydroxide was used. Then, after soaking, carbonation was performed for 7 days (DC). When the aggregate was impregnated with CH, the physical properties were within the class L as well as others. Furthermore, the aggregate with 7days carbonation showed improved physical properties compared to the aggregate with only 7days carbonation. The improvement effect of CH soaking is as follows. Figure 3 shows an image of modification by CH soaking. CH soaking of the recycled fine aggregate initially allows CH to penetrate the voids in the attached paste of the aggregate. When this recycled fine aggregate is carbonated, the CH originally present in the attached paste of the aggregate is carbonated, as well as the CH that has been soaked in the paste. We consider that the effect of improvement will be greater. In this study, the water absorption ratio confirmed here was used as an indicator of the aggregate, and the mortar property using these modified aggregates were compared.

Table 1 Physical properties of the recycled fine aggregate

Sumple name	Modification Method		Surface Dry Density (g/cm³)	Absolute Dry Density (g/cm³)	Water Absorption ratio (%)
A	No Modification		2.20	1.94	13.24
A-7d	Carbonation Period	7days	2.24	2.02	10.75
A-14d		14days	2.27	2.05	10.59
A-28d		28days	2.27	2.06	10.22
A-56d		56days	2.27	2.06	10.26
B	Water Absorption Ratio		2.25	2.04	10.45
C	Fine particle cut		2.24	2.01	11.46
CC	carbonation in water		2.25	2.04	10.20
D	CH Sorking		2.23	1.98	12.59
DC	CH Sorking & Carbonation		2.25	2.04	10.58

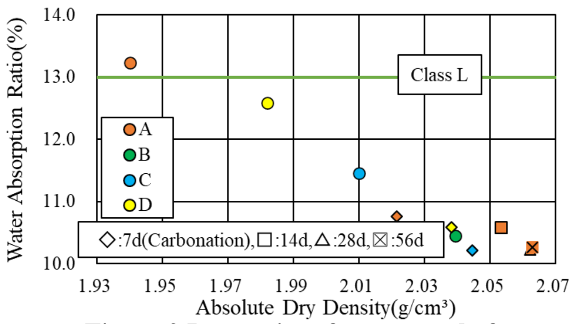

Figure 2 Properties of aggregate before and after modification aggregate

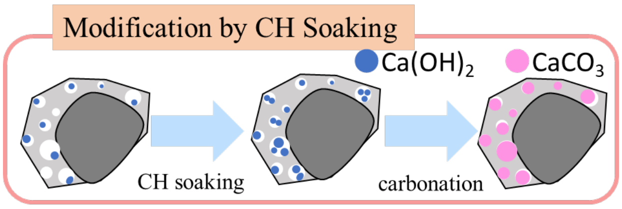

Figure 3 Modification by CH soaking

3. Mortar using Modified Aggregate

3.1 Materials and Mix Proportion

The mortar was formulated with a water cement ratio 50% and fine aggregate to cement ratio 3.0. The cement used was Ordinary Portland Cement. The recycled fine aggregate shown in Table 1 was used as the fine aggregate. Recycled aggregate has a high water absorption ratio, and slump loss is a concern if used as is. The fine aggregate was prewetted for 24 hours before mixing and used as a surface dry condition.

3.2 Testing Methods

(1) Compressive strength test
Mortar bars of 40 × 40 × 160 mm were used, and the test was conducted in accordance with JIS R 5201 after water curing for 28 days.

(2) Air permeability test
A cylindrical specimen of φ100 × 25mm cured in water for 28 days was placed in a drying oven at 40°C until its mass became constant, and the test was conducted. Air was allowed to permeate through the material at a pressure of 0.1 MPa in an air permeability testing chamber. The amount of air permeation was measured by the water displacement method using a measuring cylinder, and the permeability coefficient was calculated from the following equation (1).

$$K = \frac{2LP_1}{(P_1^2 - P_2^2)} \cdot \frac{Q}{A} \qquad (1)$$

K: Air permeability coefficient (cm^4/N·s), L: Specimen thickness (cm), P1: Loading pressure(N/mm^2), P2: Outflow side pressure (N/cm^2), Q: Amount of air permeability (cm^3/s), A: permeable area (cm^2)

3.3 Results and Discussion

Figure 4 shows the relationship between compressive strength and water absorption ratio of aggregate, and Figure 5 shows the relationship between air permeability and water absorption ratio of aggregate. For all modification methods, we observed a tendency for the physical properties of the mortar to improve as water absorption ratio improves. Comparing A-7d and B, mortar properties are better A-7d. It can be said that the improvement of water absorption ratio by carbonation is significant. When carbonated, there is a correlation between the water absorption ratio of the aggregate and the mortar's property. Focusing on the carbonation period, the improvement effect of A-28d is significant, as are the physical properties of the aggregate. We had previously assumed 7days as a carbonation technique. However, the extended period, 28days carbonation, is found to be more effective. Similarly, carbonation in water showed almost the same improvement as A-28d. Yet, carbonation in water cuts off the fine particles that have a large amount of attached paste as a pre-processing step. It is thought that this is because of cutting off the fine particles. It should be examined whether there is a difference in the improvement effect of carbonation in water with fine particles left in the water.

Focusing on the different modification methods, first, the air permeability was improved when CH was soaked. Furthermore, when CH was soaked and 7days carbonation was performed, both strength and air permeability were greatly improved. The results were like those of A-28d. From the above, it is considered that the physical properties of mortar are greatly affected by the improvement of water absorption ratio due to carbonation. In the future, it is necessary to confirm whether the improvement in water absorption ratio and mortar properties due to CH soaking is greater when the carbonation period is extended.

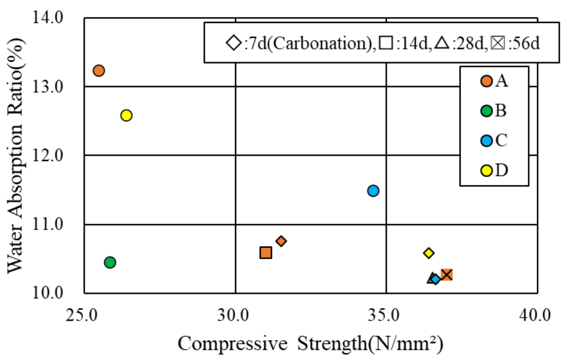

Figure 4 Compressive Strength

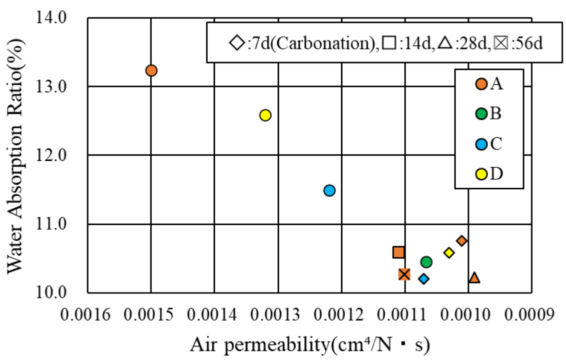

Figure 5 Air Permeability

4. Conclusions

(1) Carbonation of recycled fine aggregate modified water absorption ratio, and properties of mortar using modified recycled fine aggregates improved. As well, it is significant that carbonation improves water absorption ratio. Furthermore, there was a correlation between water absorption ratio of recycled fine aggregate modified by carbonation and physical properties of mortar using the aggregate. It is also evident that the improvement is greater when the carbonation period is extended. It may be possible to assume some improvement effect of the mortar from the improvement of water absorption ratio.

(2) Carbonation of recycled fine aggregate after impregnation with CH has a greater improvement effect than carbonation alone. This is thought to be due to the fact that CH soaking increases the amount of calcium hydroxide water solution that can be carbonated.

Acknowledgements

This paper is based on results of "Development of Materials, Manufacturing Methods and Quality Control System on Innovative Carbon Negative Concrete", JPNP21014, commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

References

Takahiro, K., Nobuhiro, M and Takeshi, I. (2010) "METHOD FOR IMPROVING THE QUALITY OF LOW-GRADE RECYCLED AGGREGATE", *The 6th International Conference of Asia Concrete Federation*, pp1137-1141

Nobuhiro, M., Takahiro, K., Mina, M and Takeshi, I. (2014) "Study of Low-Energy Type Recycled Aggregate Production Method by Forced Adsorption of CO_2 Gas", Concrete Annual Journal of Engineering, vol.36, No.1, pp.1732-1737

Nobuhiro, M and Takeshi, I. (2019) "Proposal of Technology for Modification of Low-Quality Recycled Aggregate by Carbonation and Effect of Modified Recycled Aggregate on Concrete", Concrete Engineering Journal, vol.30, pp.65-76