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Study of Method for Improving Strength and Durability of Mortar Using Low-Quality Recycled Fine Aggregate

R. Yuya[1*], N. Matsuda[2], T. Sugiyama[3], and T. Iyoda[4]

[1] *Shibaura Institute of Technology, Tokyo, Japan*

Email: ah17104@shibaura-it.ac.jp
[2] *TOKYO Techno Co., LTD., Tokyo, Japan*

Email: n-matsuda@tokyo-techno.co.jp
[3] *Pozzolith Solutions Ltd., Kanagawa, Japan*

Email: tomomi.sugiyama@pozzolith.com
[4] *Shibaura Institute of Technology, Tokyo, Japan*

Email: iyoda@shibaura-it.ac.jp

ABSTRACT

In recent years, the amount of concrete waste blocks is increased by demolishing and renewing of decrepit concrete structures in Japan. As an effective method of using concrete waste blocks, the use of recycled aggregate can be considered. In order to promote the use of recycled aggregate, it is desired to promote the use of low-quality recycled aggregates that can be produced with less energy and cost. However, concrete and mortar using low-quality recycled aggregate have a problem that their strength and durability are lower than those using normal aggregate. Further, recycled fine aggregate has a more negative influence on the strength and durability of concrete than recycled coarse aggregate. In this study, the authors focused on recycled fine aggregate. The authors examined two improvement methods for mortar using low-quality recycled fine aggregate. The first method is the addition of C-S-H type accelerator and the second method is executing accelerated carbonation of recycled fine aggregate. As a result, the addition of C-S-H type accelerator improved the cement paste, while accelerated carbonation of recycle fine aggregate improved the aggregate itself. It was found that the improvement effect on the bending strength, compressive strength, drying shrinkage, and air permeability coefficient of the mortar was different.

KEYWORDS: *recycled fine aggregate, C-S-H type accelerator, accelerated carbonation, pre-wetting*

1. Introduction

Low-quality recycled aggregate can be produced with less energy and cost than high-quality recycled aggregate, and the generation of fine particle is small. However, recycled fine aggregate is generated in the process of producing recycled coarse aggregate. Further, recycled fine aggregate has a more negative influence on the strength and durability of concrete than recycled coarse aggregate. Considering the spread of recycled fine aggregate, it is necessary to improve these. The author's group has previously reported a low-energy, low-cost method of improving recycled coarse aggregate by accelerated carbonation. It is also reported that the addition of C-S-H type accelerator to normal concrete densifies the voids around coarse aggregate and improve the compressive strength and air permeability coefficient of concrete. In this study, the authors focused on recycled fine aggregate and examined two improvement methods for mortar using low-quality recycled fine aggregate. The first method is the addition of C-S-H type accelerator and the second method is executing accelerated carbonation of recycled fine aggregate.

2. Improvement method of mortar using low-quality recycled fine aggregate

2.1 Addition of C-S-H type accelerator

C-S-H type accelerator is an admixture based on Calcium Silicate Hydrate (C-S-H). It has been explained that C-S-H nanoparticles works as seed of crystal growth in cement hydration process, then setting and strength development in early age are enhanced by this nanoparticles in this accelerator. In this study, 3,5,7,10% was added to the unit amount of water.

2.2 Executing accelerated carbonation of recycled fine aggregate

Carbonation of concrete is considered to cause corrosion of the reinforcing bars in reinforced concrete. But focusing only on concrete, it is known that the volume of mortar increases by 12%, and its strength increases as it becomes dense by carbonation. Therefore, if the mortar adhering to recycled fine aggregate can be densified by carbonated, recycled fine aggregate can be modified, and the strength and durability of mortar can be improved. In this study, recycled fine aggregate was carbonated for 1 week in accelerated carbonation chamber having a temperature of 20°C, a relative humidity of 60% and a carbon dioxide concentration of 5%.

3. Outline of experiment

Low-quality recycled fine aggregate was used as shown in Table 1. N is normal fine aggregate. L and O are recycled fine aggregate. LC and OC were carbonated recycled fine aggregate. Table 2 shows mix proportion. Ordinary portland cement was used. The symbol name is represented by the kind of fine aggregate-modification method. The numbers indicate the addition rate of C-S-H type accelerator and CO_2 indicates accelerated carbonation of recycled fine aggregate. In Table 2, ACX indicates C-S-H type accelerator.

Table 1. Details of fine aggregate

Sample name	Surface dry density (g/cm³)	Absolute dry density (g/cm³)	Water absorption rate (%)	Amount of fine particle (%)
N	2.6	2.55	1.92	3.10
L	2.25	2.04	10.42	3.30
LC	2.28	2.11	8.37	
O	2.21	1.94	13.44	12.20
OC	2.24	2.01	11.71	

Table 2. Mix Proportion

Symbol	W/C (%)	Unit weight (kg/m³)			ACX (%)
		W	C	S	
N					-
N-3					3
N-5		254	508	1524	5
N-7					7
N-10					10
L					-
L-3					3
L-5		233	466	1398	5
L-7	50				7
L-10					10
L-CO_2				1417	-
O					-
O-3					3
O-5		230	460	1380	5
O-7					7
O-10					10
O-CO_2				1398	-

3.1 Strength test

Bending and compressive strength test was carried out in 28days, according to JIS R 5201. All specimens were cured in 20°C tap water.

3.2 Air permeability test

The specimens were dried at 40 °C in a drying oven until the weight loss became constant. Measurement was carried out in an air permeability testing equipment. The air permeability coefficient was calculated using Equation (1). All specimens cured for 28days in 20°C tap water.

$$K=2LP_1Q / A(P_1^2 - P_2^2) \quad (1)$$

K：Air permeability coefficient($cm^4/N\cdot s$), L：Specimen thickness(cm), P_1：Loading pressure(N/mm^2), P_2：Outflow side pressure(N/cm^2),Q：Amount of air permeability (cm^3/s), A：permeable area (cm^2)

3.3 Drying shrinkage

Drying shrinkage test was carried out in cured period, 1, 2, 4, 8, 13, 26 weeks after cured period according to JIS A 1129-3. All specimens cured for 28days in 20°C tap water.

3.4 Porosity test

The specimens were used after the compressive strength test. The specimens were dried at 40 °C in a drying oven until the weight loss became constant. Measuring the mass in an absolutely dry state, saturated in a vacuum state, and the saturated water mass and the mass in water were measured. The porosity was calculated by the Archimedes method using these values.

4. Results and discussion

4.1 Strength

Figure 1 shows the results of bending strength at 28days. In most of the mix proportion, the bending strength increased with the addition of C-S-H type accelerator as the addition rate increased. The bending strength of L-CO_2 and O-CO_2 at 28 days increased to almost the same level as N. Figure 2 shows the results of compressive strength at 28days. In all of N, L, and O, the compressive strength increased with the increase in the addition rate of C-S-H type accelerator. The compressive strength of L-CO_2 and O-CO_2 increased significantly, and the improvement effect was greater for O than for L. Figure 3 shows the relationship between compressive strength and bending strength at 28 days. The bending strength was in the range of 1/5 to 1/6 of the compressive strength. But the bending strength of L-CO_2 and O-CO_2 exceeds 1/5 of the compressive strength, indicating that the bending strength with regards to the compressive strength is large. This may be due to the fact that the fine particle in the recycled fine aggregate changed to calcium carbonate by accelerated carbonation, which may have densified the voids or may have affected the cement reaction.

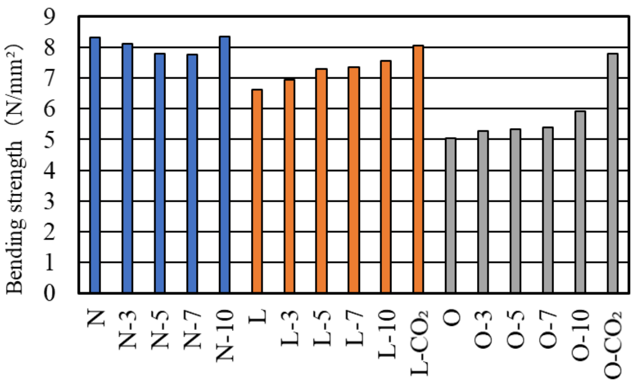


Figure 1. Bending strength (28days)

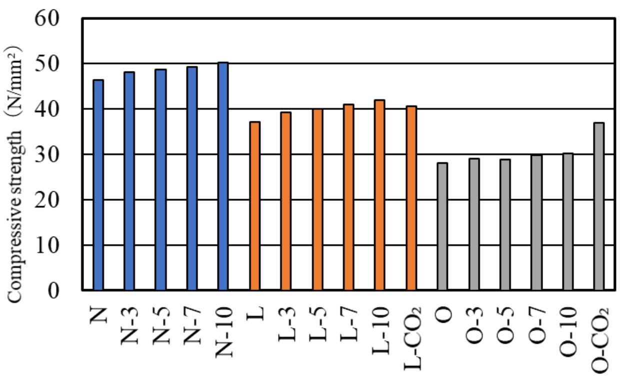


Figure 2. Compressive strength (28days)

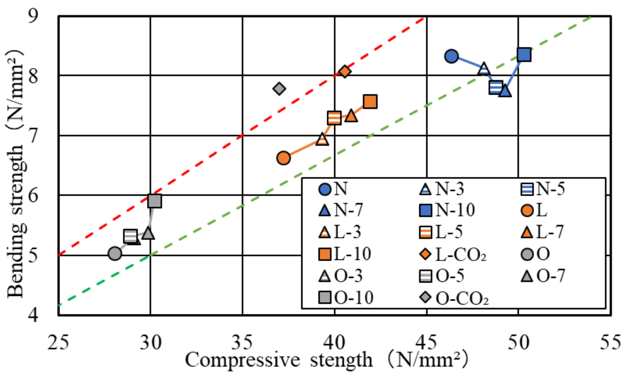


Figure 3. Relationship between compressive strength and bending strength (28 days)

4.2 Air permeability

Figure 4 shows the results of air permeability coefficient at 28 days. In N and L, the addition of C-S-H type accelerator improved the air permeability coefficient as the addition rate increased. On the other hand, in O, the air permeability coefficient was greatly improved at an addition rate of 3%, and the improvement effect on air permeability coefficient did not change as the addition rate was increased. The air permeability coefficient of L-CO_2 and O-CO_2 increased significantly, and the improvement effect was greater for O than for L. This may be related to the fact that O contains fine particle than L. Figure 5 shows the relationship between compressive strength and air permeability coefficient at 28 days. In N and L, the addition of C-S-H type accelerator has a high improvement effect on compressive strength. On the other hand, in O, the addition of C-S-H type accelerator has a high improvement effect on the air permeability coefficient. This indicates that the packing behavior of C-S-H nanoparticles in N, L and O may be different.

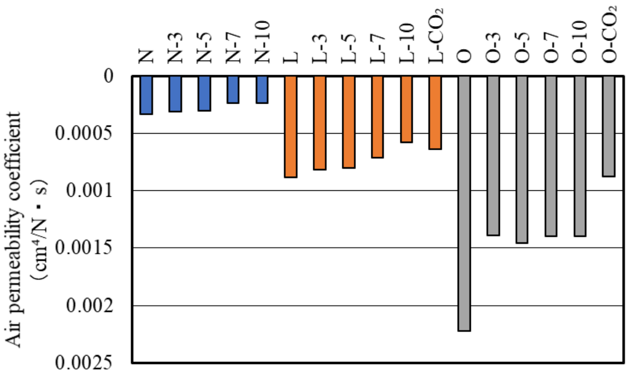


Figure 4. Air permeability coefficient (28days)

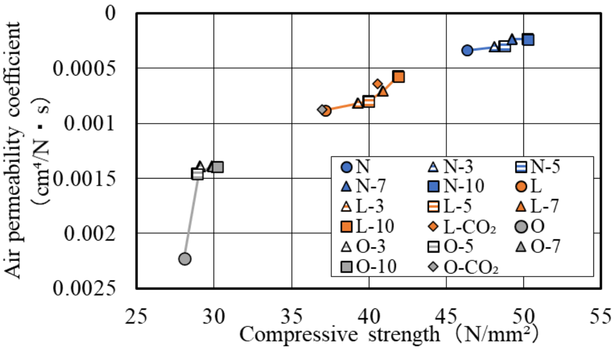


Figure 5. Relationship between compressive strength and air permeability coefficient (28days)

4.3 Drying shrinkage

Figure 6 to 8 shows length change rate. First of all, in N, no suppression of length change rate was observed even when the addition rate of C-S-H type accelerator was increased. The same result was observed in L and O. Therefore, only 10% addition is indicated and other addition rates are not indicated. Accelerated carbonation of recycled fine aggregate greatly suppressed the length change rate, by about 400 μm in L, about 1000 μm in O. In order to suppress the length change rate, it is considered necessary to reduce the amount of water in the mortar. In this study, since the unit water content was constant for each type of fine aggregate, the addition of C-S-H type accelerator did not change the water content in the mortar, and thus the length change rate was not suppressed. On the other hand, accelerated carbonation of recycled fine aggregate decreased the water content (the water absorption rate) of fine aggregate and thus the length change rate was suppressed. Figure 9 shows the relationship between the water absorption rate of fine aggregate and length change rate. As the water absorption of fine aggregate decreased, the length change rate was suppressed, and thus there was a correlation between the water absorption of fine aggregate and the length change rate.

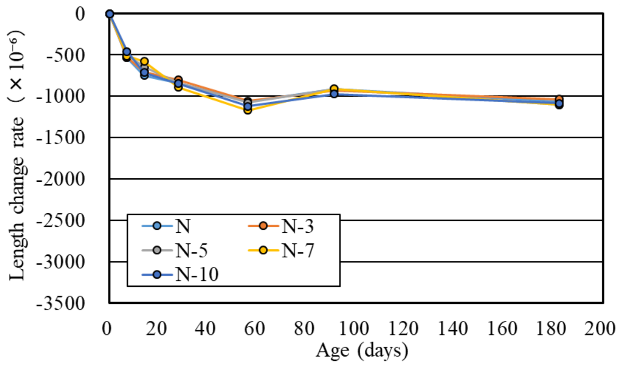


Figure 6. Length change rate (N)

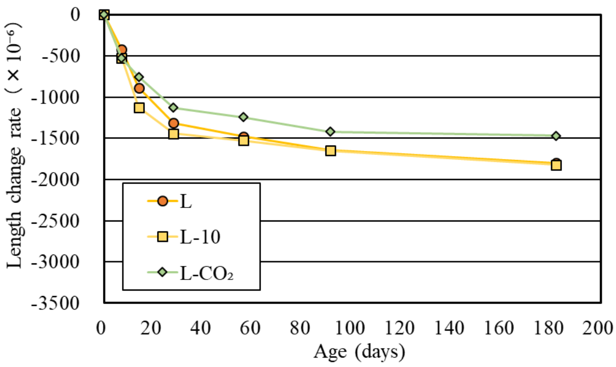


Figure 7. Length change rate (L)

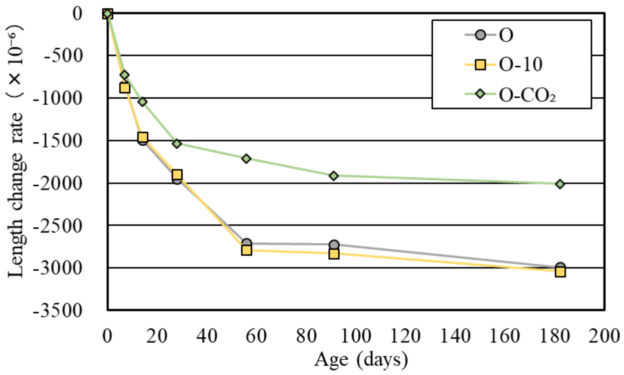


Figure 8. Length change rate (O)

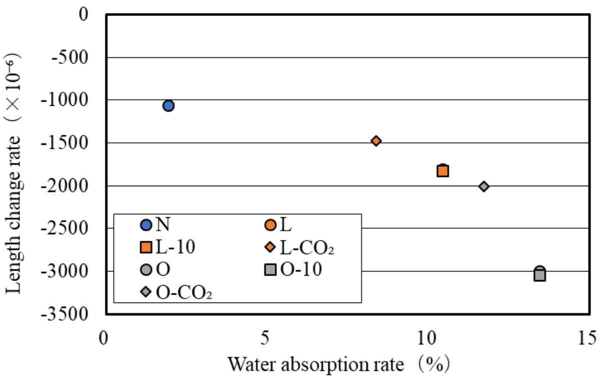


Figure 9. Relationship between the water absorption rate of fine aggregate and length change rate

4.4 Porosity

Figure 10 shows the results of the porosity test. In N, L, and O, the porosity was not improved by the addition of the C-S-H type accelerator. Figure 11 shows the relationship between porosity and compressive strength, Figure 12 shows the relationship between porosity and air permeability coefficient. Normally, the hydration of cement proceeds on the surface of cement particles and hydrates are generated on the surface. The hydrates generated on the surface inhibit the diffusion of ions from the cement particles. It is thought that hydrates grow on C-S-H nanoparticles when C-S-H type accelerator is added. This would reduce the thickness of the hydrates generated on the surface of the cement particles which causes diffusion inhibition. Therefore, it is considered that the addition of C-S-H type accelerator improves the strength and air permeability coefficient but does not reduce the porosity. On the other hand, it is considered that the accelerated carbonation of recycled fine aggregate densified the mortar attached to the aggregate and reduced the amount of porosity in the mortar. Therefore, it is considered that the strength and air permeability coefficient of the mortar were improved with the reduction of porosity.

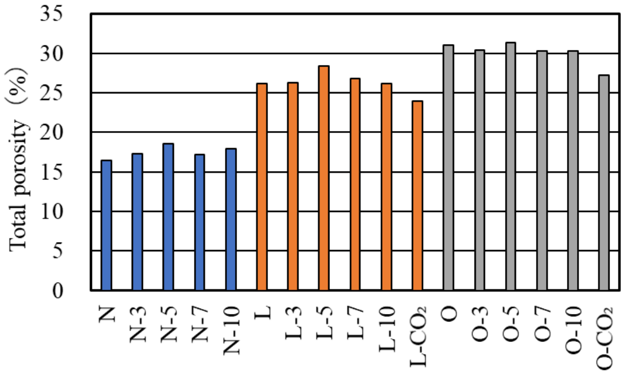


Figure 10. Total porosity

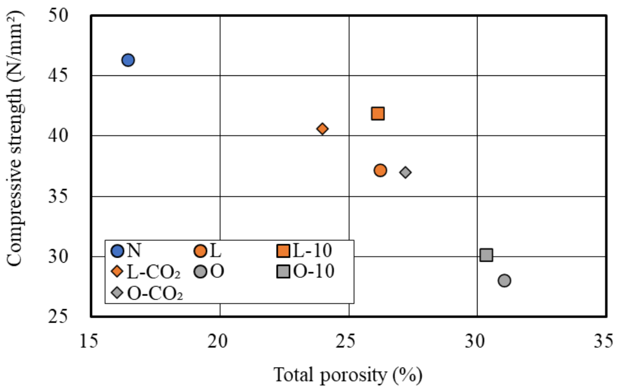


Figure 11. Relationship between porosity and compressive strength

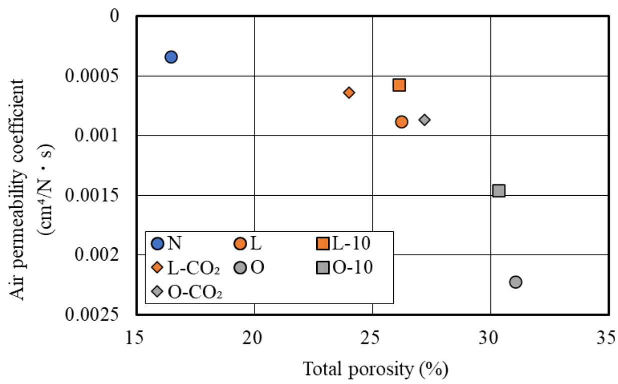
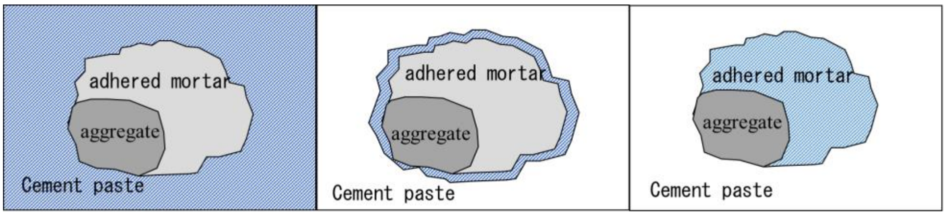


Figure 12. Relationship between porosity and air permeability coefficient

4.5 Differences in packing behavior of C-S-H nanoparticles on addition of C-S-H type accelerator

In all of N, L, and O, the compressive strength increased with the increase in the addition rate of C-S-H type accelerator. On the other hand, in the air permeability test, the improvement effect differed depending on the kind of fine aggregate. In N and L, air permeability coefficient improved with the increase in the addition rate of C-S-H type accelerator, while in O, the air permeability coefficient was greatly improved at an addition rate of 3%, and the improvement effect on air permeability coefficient did not change as the addition rate was increased. Thus, it is considered that the packing behavior of C-S-H nanoparticles on addition of C-S-H type accelerator may be different between N, L and O. In the air permeability test, it is considered that there are three places where air can pass through: the mortar adhering to the fine aggregate, the transition zone, and the cement paste (Figure 13). Also, the difference between N, L and O is the density and water absorption, but the most important difference is the amount of fine particles. The amount of fine particles in O is 12.20%, and C-S-H nanoparticles may have adhered to these fine particles, thus the packing behavior may be different from N, L. Figure 14,15 shows packing behavior of C-S-H nanoparticles. In N and L, C-S-H nanoparticles are introduced into the cement paste and the transition zone when C-S-H type accelerator added, and as the addition rate increased, the places where air can pass through gradually decreased, thus improving the air permeability coefficient. On the other hand, in O, fine particles were involved in the packing effect of C-S-H nanoparticles, and high mass transfer resistance is obtained at a low addition rate, and even if the addition rate is increased, the improvement in air permeability is the same as at a low addition rate.



1. Cement paste   2. Transition zone   3. Mortar adhering to fine aggregate

Figure 13. Places where air can pass through

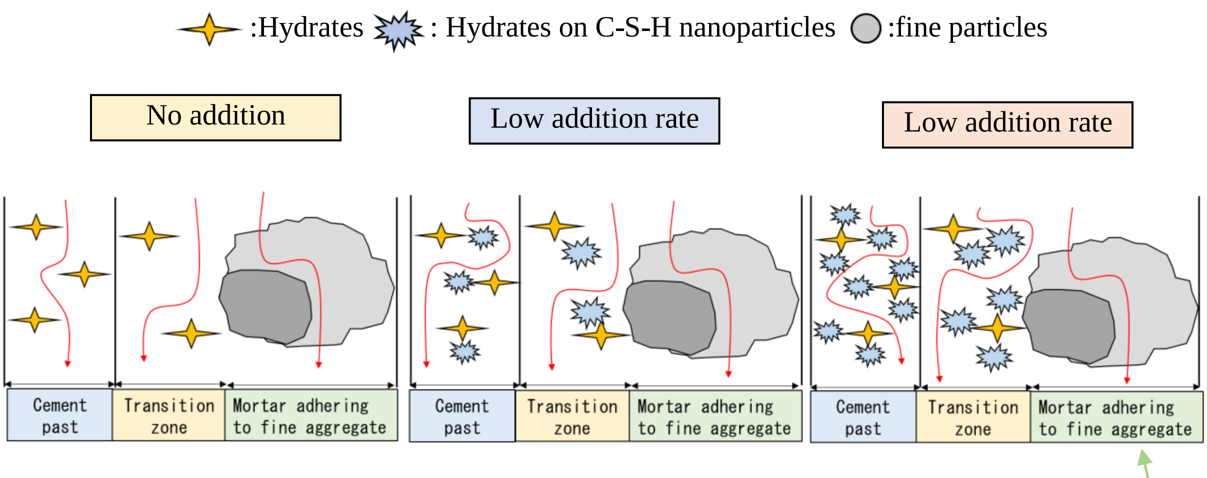


Figure 14. Packing behavior of C-S-H nanoparticles (N, L)

In N, it doesn`t exist.

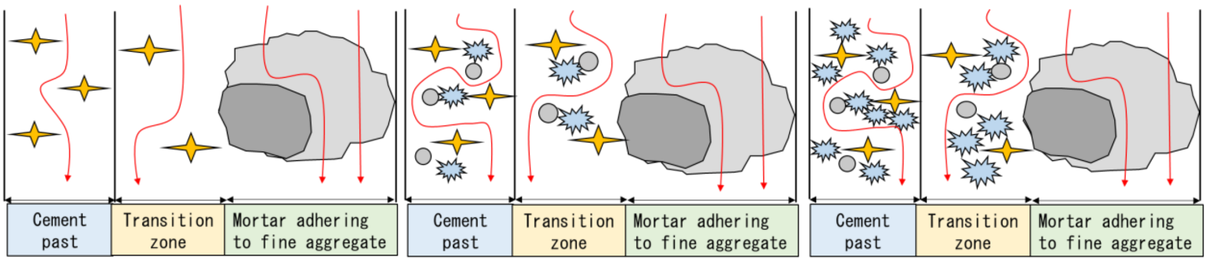


Figure 15. Packing behavior of C-S-H nanoparticles (O)

5. Conclusions

The authors examined two improvement methods for mortar using low-quality recycled fine aggregate and considered the following.

(1) The addition of C-S-H type accelerator and the accelerated carbonation of recycled fine aggregate had an effect on the strength and air permeability coefficient.

(2) However, the addition of C-S-H type accelerator did not suppress the length change rate because the water content of the mortar did not change, on the other hand, the accelerated carbonation of recycled fine aggregate suppressed the length change late because the water absorption rate of fine aggregate decreased.

(3) Therefore, in this study, it was considered that the method of accelerated carbonation of recycled fine aggregate had a high improvement effect.

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