Study for re-ASR behaviour of recycled concrete using ASR-generated concrete and considering countermeasure technology

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Abstract. It is predicted that the concrete volume to be discarded will increase due to the renewal of the concrete structures and the increase in the returned concrete from construction site. The use of this concrete block as recycled aggregate is very important in terms of sustainability. However, recycled aggregate concrete is difficult to use due to large problems such as drying shrinkage and freeze-thaw action. On the other hand, the aggregate used for the raw concrete is often unknown, suggesting the danger of ASR. There is no previous research about what kind of danger is caused when an aggregate having an ASR risk is used as a recycled aggregate. Therefore, in this study, recycled aggregate was made from raw concrete where ASR occurred, after that recycled concrete was manufactured using this aggregate. After this, ASR tests were conducted again for the recycled concrete. In addition, we examined whether recycled concrete using aggregates with properties improved by using the previously reported carbonation technique could be an ASR countermeasure technology. As a result, it was found that the recycled concrete using the ASR-generated raw concrete as aggregate can suppress ASR by using recurring ASR aggregate treated by carbonation technology.

1. Introduction

It is predicted that the concrete volume to be discarded will increase due to the renewal of the concrete structures and the increase in the returned concrete from construction site. It is important to use the recycled aggregate from this concrete to achieve sustainability society. Further, in order to spread recycled aggregate concrete, it is desired to use low-quality recycled aggregate that also generates few by-products such as fine powder and can be manufactured reducing energy and cost. However, recycled aggregate concrete has significant problems such as low strength, drying shrinkage and freeze-thaw. Furthermore, the recycled aggregate reactiveness is often unknown for the danger of alkali-silica reaction (ASR). It should be noted that in ASR, alkali supply from attached mortar on recycled aggregate is also assumed. There has been little discussion about the dangers that would occur if concrete with reactive aggregates were used as recycled aggregate. In order to promote the use of low-quality recycled aggregate in the future, it is necessary to get more knowledge about ASR.

On the other hand, in past works, the authors have proposed a modification technique by carbonation for the purpose of improve low-quality recycled aggregate. This technology focuses on the carbonation mechanism of concrete, it applies high-concentration carbon dioxide on the recycled aggregate to carbonate the mortar in the recycled aggregate, thereby modifying the recycled aggregate itself. It has been confirmed that recycled aggregate modified by this technique meliorate concrete strength, length change by drying shrinkage and freeze-thaw resistance. However, the impact on ASR has not been studied. Carbonation was expected to have the effect of lowering the alkali concentration of the mortar, and was thought to be helpful in suppressing ASR.

Therefore, in this study, the raw concrete was prepared by using the reactive coarse aggregate in order to develop ASR. The recycled coarse aggregate was manufactured from this raw concrete with confirmed ASR, and the recycled concrete was prepared. At that time, recycled coarse aggregates low (L) and high (H) quality were produced. The recidivism of ASR (re-ASR) of this recycled concrete were experimentally investigated. In addition, the effect of ASR suppression using modified recycled aggregate by carbonation was also investigated.

2. Outline of the experiments

2.1. Preparation of raw concrete and ASR characteristics

Table 1 shows the types and physical properties of the aggregates. Regarding the rock types of each coarse aggregate, OG is crushed hard sandstone, KG is andesite, and SG is gravel. The ASR characteristics of the aggregate used were confirmed by the chemical method (JIS A 1145), the mortar bar method (JIS A 1146) and the accelerated mortar bar method (ASTM C 1567). The test results of the chemical method are shown in Table-1. The OS (fine aggregate), OG and SG were judged as "harmless" and KG was judged as "not harmless". Figure 1 shows the results of the mortar bar test using JIS. All the coarse aggregates were judged to be "harmless" with less than 0.1% of expansion ratio at the age of 26 weeks. However, for KG, the expansion increased after 13 weeks of age, and it is estimated that the expansion further increased after 26 weeks. Figure 2 shows the results of the accelerated mortar bar test by ASTM. The KG and SG were judged "harmful", and OG was "harmless". It can be seen that the expansion amount of KG greatly exceeds 0.2% at 14 days of age, and the reactivity is high. The SG gradually expanded from around 5 days of age and exceeded 0.2% at 14 days of age, indicating that it is an aggregate with low to moderate reactivity. Based on the above results, KG and SG were determined to be reactive aggregates, and OG was determined to be harmless aggregates.

Table 1. The types and physical properties of the aggregate

	Kinds	Dry density (g/cm^3)	Water absorption ratio (%)	F.M.	Sc (mol/l)	Rc (mol/l)	Classify of ASR
OS	Fine Agg.	2.55	2.18	2.82	28	84	Harmless
OG	Coarse Agg.	2.63	0.89	6.62	40	78	Harmless
KG		2.72	1.72	6.41	388	94	Not harmless
SG		2.60	1.18	7.41	73	107	Harmless

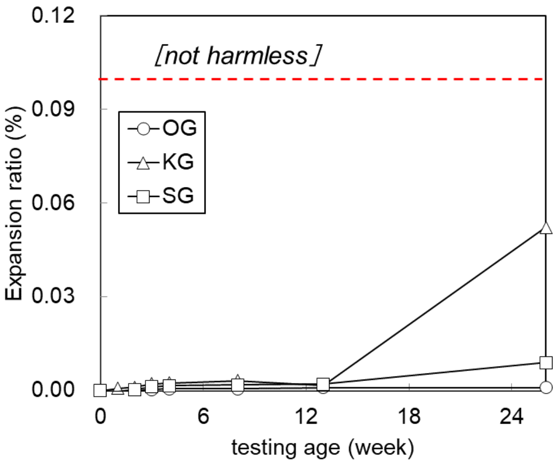

Figure. 1 Mortar bar test on JIS

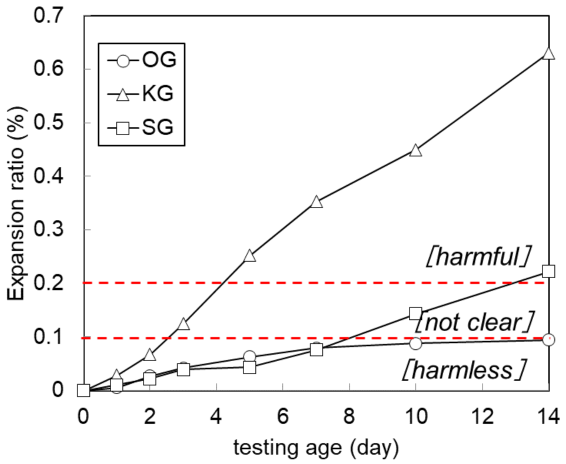

Figure. 2 Accelerated mortar bar test on ASTM

Using these aggregates, raw concrete was produced with the planned composition shown in the Table 2. The cement used was ordinary Portland cement with a Na_2O equivalent of 0.57%. In order to promote ASR, NaOH was added during mixing so the amount of alkali in concrete increased to 7.0 kg/m^3. Table 2 also shows the fresh properties of the raw concrete and the compressive strength when cured in tap water for 28 days. Regarding the fresh properties and compressive strength of the raw concrete, there was no significant difference between the slumps, although it varied slightly. However, the compressive strength was slightly lower due to ~~on~~ the effect of adding NaOH. Next, a RILEM AAR-3 (38°C concrete prism test) test was performed to evaluate ~~on~~ the ASR characteristics of the raw concrete. Figure 3 shows the results of the RILEM AAR-3 test. The criteria for RILEM AAR-3 is described as those samples with a swelling above 0.04% at the age of 52 weeks are judged to be harmful. The KG aggregate concrete (KC) increases the swelling from around 10 weeks of age and 0.04% at the age of 52 weeks. Cracks were confirmed at 14 weeks. The swelling of SC gradually increased around 10 weeks, and slightly exceeded 0.04% at 52 weeks. On the other hand, OC was determined to be "harmless." These results show the same tendency as the ASR characteristics of the raw aggregate on the accelerated mortar bar test as ASTM.

Table.2 Mix proportion, fresh properties and compressive strength of concrete at 28 days

	Kinds of Coarse agg.	W/C (%)	Unit weight (kg/m^3)				Fresh concrete properties			Compressive strength (N/mm^2)
			C	W	S	G	Slump (cm)	Air (%)	Temp. (℃)	
OC	OG	50	350	165	823	981	11.0	4.7	25.0	29.4
KC	KG					1021	6.5	4.3	24.0	28.7
SC	SG					962	16.0	4.1	23.0	27.9

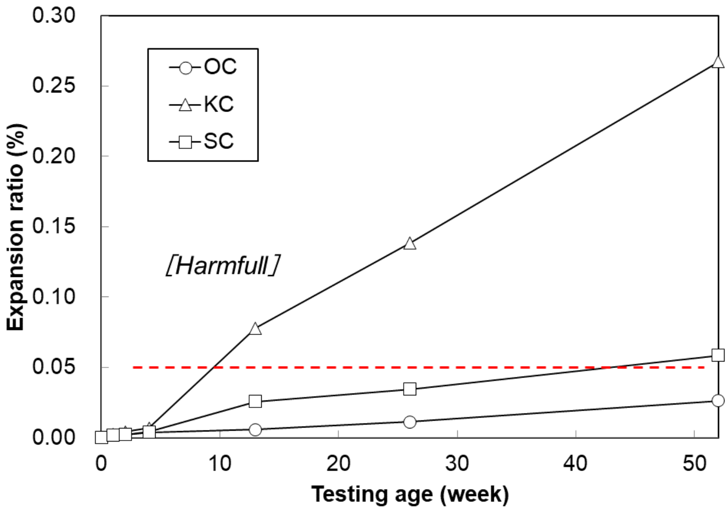

Figure. 3 ASR expansion test on RILEM

In order to prepare recycled coarse aggregate, cylindrical specimens of φ100 × 200mm were prepared. The raw concrete specimens were stored in an outdoor environment for one to three weeks to further promote ASR, and then cured in water at 40 ° C. To check the amount of expansion of the raw concrete specimen, a 100 × 100 × 400 mm prismatic sample was prepared. Figure 4 shows the amount of expansion of the monitored specimens. The swelling behaviour of these samples were slower when compared with RILEM AAR-3 test. This is because the monitoring specimens were cured under the same conditions as the concrete specimens. However, the amount of expansion of KC increased rapidly from the age of 13 weeks, showing a similar tendency to the raw aggregate and raw concrete. At 20 weeks of age, cracks were confirmed in the test specimen. On the other hand, in SC, although the amount of expansion was slightly small, there was no significant difference from the expansion behaviour in the RILEM AAR-3 test. Recycling of the original concrete specimens was performed at about 20 weeks for KC and 26 weeks for OC and SC at the age of the monitoring specimens.

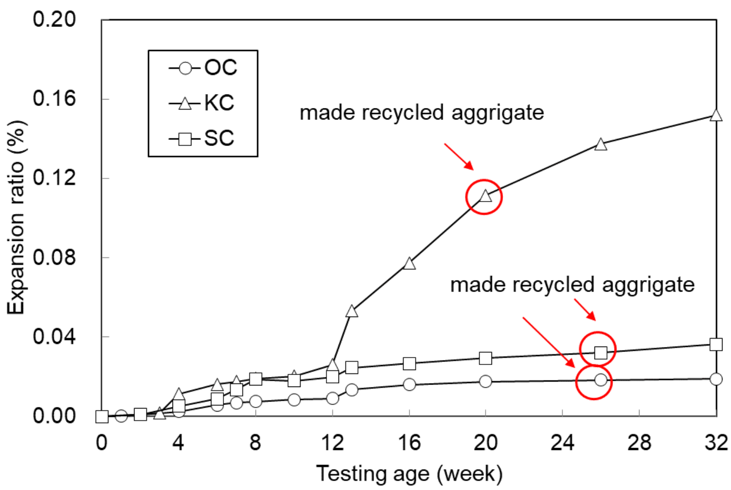

Figure. 4 Expansion test on monitoring specimens

2.2. Production of recycled coarse aggregate

Recycled coarse aggregates L and H and modified recycled aggregate LC were produced from OC, KC and SC raw concrete specimens. At this point, KC has confirmed expansion and cracking due to ASR. Recycled coarse aggregate L was produced only by crushing treatment (jaw crusher / impact crusher). Recycled coarse aggregate H was produced by further grinding (ball milling) the recycled coarse aggregate L. In the modified recycled aggregate, the coarse aggregate L was carbonated. The forced carbonation condition was 1 week long under the of temperature of 20 degrees Celsius and relative humidity of 60% in the accelerated carbonation chamber, as in the previous study [1]. All the produced recycled coarse aggregates were washed with water to remove fine particles. Figure 5 shows the density and water absorption of the recycled coarse aggregate. In all types of modified recycled aggregate, the density and water absorption properties had improved. There are also improvements for the quality of recycled coarse aggregate M. Although the alkali content was separately measured, no significant difference was found in the total alkali content of the recycled coarse aggregates L and H in this study.

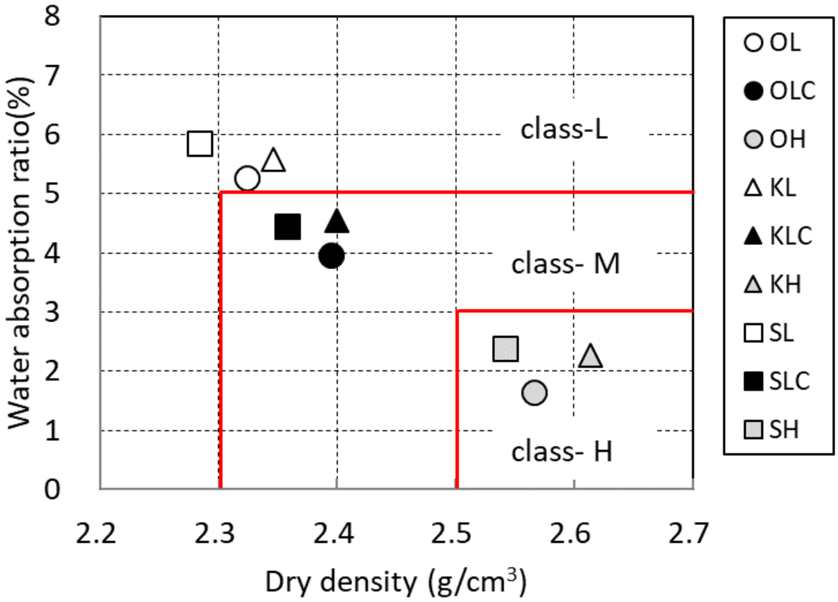

Figure. 5 Density and water absorption ratio on recycled aggregates

3. ASR characteristics of recycled aggregate concrete

3.1. Outline of the experiment

Concrete was prepared using the recycled coarse aggregate shown in Table 3 and the ASR characteristics were confirmed. The materials used the same as preparing recycled aggregate concrete. The composition of recycled aggregate concrete was W/C=0.5, s/a=0.46, and unit water volume of 165kg/m^3. For the purpose of promoting ASR, two types were prepared, one with NaOH added and one without NaOH, so that the total alkali content in recycled aggregate concrete including alkali from cement was 7 kg/m^3. In addition, the calculation of the total alkali content of the sample to which NaOH was added did not include the alkali content from the aggregate. A 100 × 100 × 400 mm prism was prepared, and after demolding, it was cured for 1 week in an environment at a temperature of 20 degrees Celsius and humidity of 60%. Table 3 shows also the compressive strength on recycled concrete. The compressive strength tends to be larger for H class aggregate. It can be said that the amount of attached mortar affects the strength development. Also, the modified recycled aggregate has increased compressive strength compared to L, as in previous studies [2]. When NaOH was added, the compressive strength was reduced.

Table 3 Results of compressive strength on different concrete

Kinds of coarse agg	*Concrete*	*Coarse agg*	*Compressive strength (N/mm^2)*	
			Non-NaOH	Adding NaOH
OL	OC	OG	37.1	24.2
OLC			38.5	27.5
OH			39.5	29.0
KL	KC	KG	39.3	25.5
KLC			40.3	30.7
KH			40.1	27.3
SL	SC	SG	35.8	24.5
SLC			38.5	26.7
SH			39.9	27.8

3.2. Experimental result

Figure 6 shows the expansion of recycled aggregate concrete. Comparing the types of raw aggregates, those using the non-reactive raw aggregate OG showed almost no expansion regardless of whether NaOH was added or not. It is clear that there is no danger of ASR occurring again when recycled coarse aggregate made from non-reactive raw aggregate is used. In the case of using highly reactive KG, the amount of expansion was significantly increased with the addition of NaOH. Silica remains at the time of production of recycled coarse aggregate, and it is considered that ASR occurred when recycled aggregate concrete was used. In addition, those without addition of NaOH showed almost no swelling. This is probably because the total alkali content of recycled aggregate concrete using KG and not containing NaOH was 2.9 kg/m^3, indicating that the alkali content did not reach ASR. On the other hand, when SG was used, the aggregate had low to moderate reactivity as the ASR characteristics of the original aggregate, but almost no expansion was observed as in OG.

Comparing L and H, H increased the rate of expansion when NaOH was added and using reactive aggregate. This is considered to be due to the fact that the amount of attached mortar with H was small, so that the elution of silica and the penetration of alkali were easily performed. On the other hand, in the case of using KG with high reactivity without addition of NaOH, L slightly expanded. It is possible that the alkali in the attached mortar affects ASR. In addition, the amount of expansion is greatly suppressed by using the modified recycled aggregate. In particular, those using highly reactive KG as the raw aggregate were very remarkable, showing a high suppression effect on ASR. Figure 7 shows an image of this ASR suppression mechanism. In addition to the presence of attached mortar, the modified recycled aggregate become denser by carbonation, which suppresses the penetration of alkali and further dissolution of silica in the raw aggregate. It is thought that ASR is reduced by suppressing it. However, in this experiment, the expansion of the original concrete due to ASR was considered to have calmed down to a certain extent, and the scope of the experiment was limited. In the future, it is necessary to continue studying the raw concrete before ASR progresses, and also to confirm the suppression mechanism by the modified recycled aggregate.

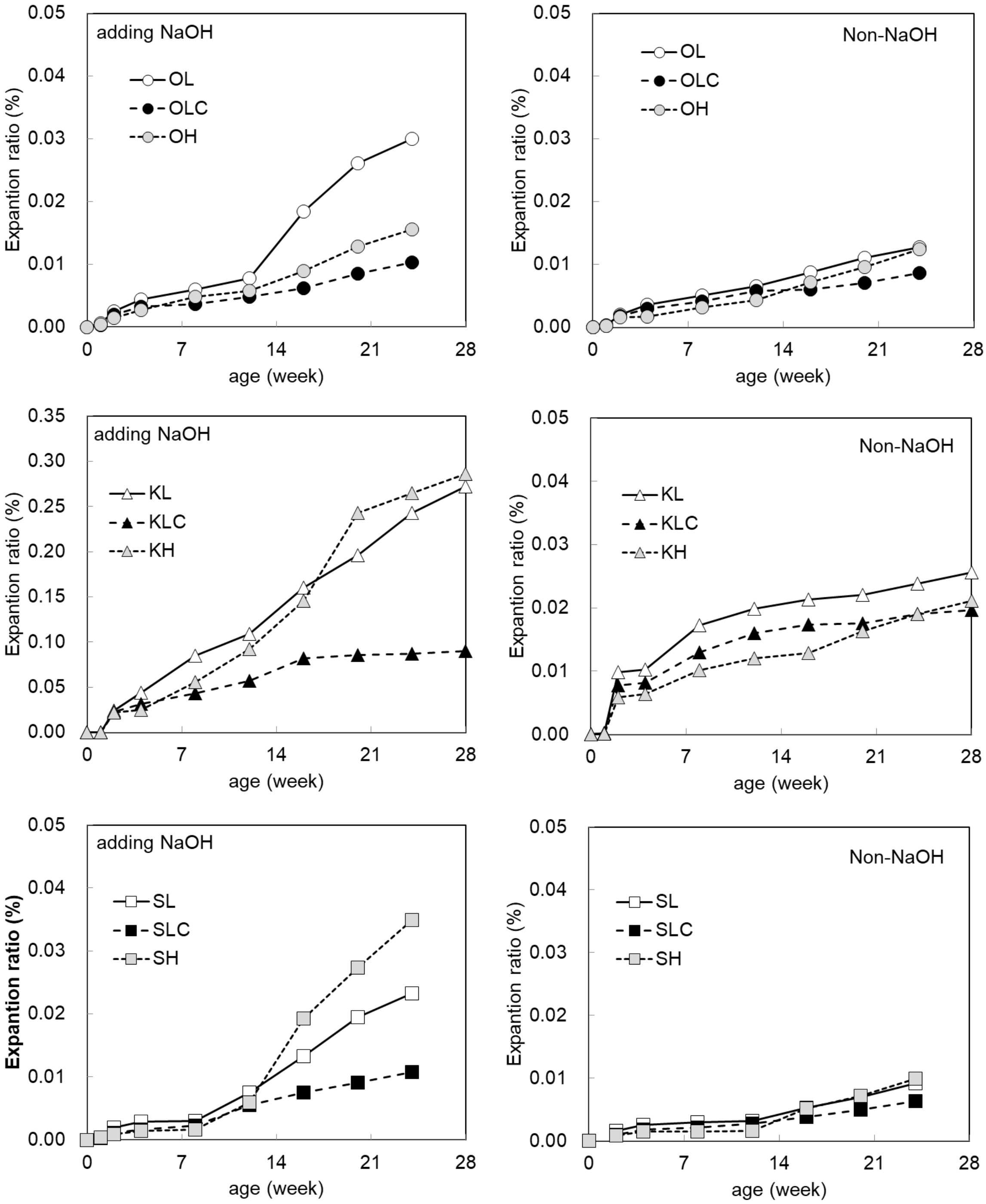

Figure.6 Results of re-ASR on recycled concrete

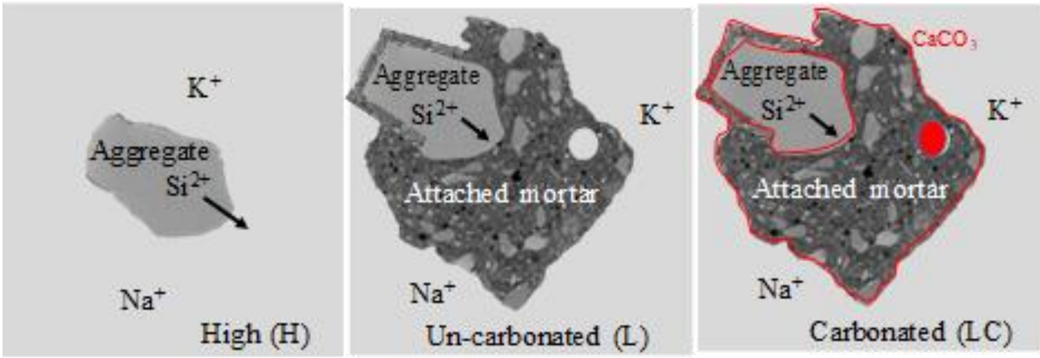

Figure.7 The mechanism of prevented ASR on using carbonated recycled aggregate

4. Summary

The following findings were obtained in this study.

(1) The ASR characteristics by the accelerated mortar bar method in raw aggregate and RILEM AAR-3 in raw concrete showed the same tendency.

(2) It was found that there was no danger of ASR occurring again when recycled coarse aggregate made from non-reactive raw aggregate was used. In the case of using highly reactive KG, the amount of expansion significantly increased with the addition of NaOH. This suggests that even when the ASR of the raw aggregate has progressed to some extent, the silica remains when the recycled coarse aggregate is made, and when the recycled aggregate concrete is used, the ASR occurs again.

(3) When L and H quality recycled aggregate were compared, the expansion was higher for H with the addition of NaOH and using reactive aggregate.

(4) The swelling behaviour was greatly suppressed by using the recycled aggregate modified by carbonation, and for the one using highly reactive KG as the original aggregate the decrease was very remarkable, showing a high inhibitory effect on ASR.

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