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CPT as an evaluation method of concrete mixture for ASR expansion

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HIGHLIGHTS

- Compositional and size pessimum effects can be detected by CPT.
- CPT according to RILEM AAR-4 shows larger amount of alkali leaching from specimens.
- Wet paper wrapping for 100 × 100 × 400 mm specimens can reduce the alkali leaching.
- There are positive relations between mass gain of specimens and expansion.
- Paper wrapping with alkaline solution could be suitable for detecting ASR reactivity.

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ABSTRACT

Highly reactive andesite aggregates including opal or tridymite were evaluated by concrete prism test (CPT) in two ways and the suitable conditions of CPT were discussed. 18 concrete mixtures were used to examine the effect of the type and content of aggregate, the type of cementitious material. Two methods for detecting for ASR reactivity were used; RILEM AAR-4 and JASS 5N, and the latter one is of which authors revised few points. As the results, different performances of andesite depending on the size and the different required amounts of fly ash suppressing ASR depending on the mixture proportion were well demonstrated by CPT that is difficult for mortar bar test. As a curing method to avoid alkali leaching, wrapping with wet paper showed much less leaching than curing in a sealed box. From the viewpoint of easiness of operation, small size 75 × 75 × 250 mm is suitable than large size 100 × 100 × 400 mm.

1. Introduction

Alkali silica reaction (ASR) is one of durability problems even at present although detecting methods of alkali reactivity of aggregates and ASR countermeasures have been established in many countries. There are some reasons for imperfectness of these methodologies. It is sure that there are limitations of test methods for alkali reactivity of aggregate [1]. For highly reactive aggregate such as andesite containing opal or cristobalite/tridymite, or chert containing chalcedony, compositional pessimum phenomena [2] are the difficult point. Compositional pessimum phenomenon is characteristic behavior of highly reactive aggregate showing the most expansion at a lower mixing ration with non-reactive aggregate less than 100%. The pessimum composition depends on the reactivity of aggregate [3]. At the pessimum composition, more amounts of pozzolanic materials are required than in the case of 100% [4]. There is another pessimum effect, *i.e.* size pessimum effect that is typically found in argillaceous dolostone showing so-called alkali carbonate reaction (ACR) [2]. ACR type aggregate shows size pessimum effect and it does not expand when it is crashed into sand size. Therefore, mortar bar test can be misleading.

In order to overcome these kinds of disadvantage, more reliable test method is required for the mitigation of ASR. In this study, as an evaluation method of concrete mixture but not only aggregates against ASR expansion, concrete prism test (CPT) is proposed. Already, some types of CPT have been established as mentioned later. Therefore, some types are compared to check the appropriateness in this study from various points of view and this study is mainly aiming to find a suitable procedure of CPT. Various combinations of aggregates and cement types are examined and the expansion behaviors are compared by CPT.

Another characteristic point of this study is in the type of aggregates used. Majority of ASR studies have been carried out in

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advanced countries where late expansive aggregates including cryptocrystalline quartz causing late expansion and rapid expansive aggregates including chalcedony are the major alkali reactive aggregates. Even when volcanic rocks such as andesite is included, if it's geological age is older than Palaeogene, highly reactive minerals tend to be recrystallized as more stable quartz [5]. Contrary, in this study, extremely highly reactive aggregates in younger geological ages than Neogene containing cristobalite, tridymite or opal are examined. Andesite aggregate in this type is very popular in circum Pacific Rim countries having active volcanoes and has caused serious ASR damages including reinforcement breakages. In order to clarify the petrographic characteristics of aggregates, detailed characterization by polarizing optical microscope was also carried out.

2. Methods

2.1. Materials

Cement used was ordinary Portland cement (OPC) according to JIS A5211 that corresponds to CEM I 52.5 according to EN197-1. As supplemental cementitious materials (SCMs), siliceous fly ash and blast furnace slag were used. Physical characters are shown in Table 1 and chemical compositions are shown in Table 2.

As highly reactive aggregate, andesite containing opal in veins (A, B) from Tohoku area was used. "A" was used as coarse aggregate and "B" was used as fine aggregate in order to test the size pessimum phenomenon. A and B have the same source but only the sizes are different. Andesite containing tridymite (C) from Hokkaido and hornfels (D) containing microcrystalline quartz from Chubu area were used as coarse aggregates. As non-reactive aggregate, pure limestone (G, H) from Kyushu area was used. "G" was used as coarse aggregate and "H" was used as fine aggregate. G and H have the same source but only the sizes are different. Chemical composition and physical properties of these aggregate is shown in Tables 3 and 4, respectively. Microphotographs of aggregates are shown in Figs. 1–4 for aggregate A (B), C, D, and G (H) respectively.

Two kinds of andesite (A (B) and C) are known to show compositional pessimum effect at 30 mass% [4]. From field experiences, A, C and D caused ASR damages in real structures. However, in the case of late expansive D, the construction of damaged structures were several ten years ago and it was difficult to identify the same source of aggregate and similar aggregate was sampled in a near aggregate mine.

Table 1
Physical characters of cement and SCMs used.

	Density (g/cm^3)	Specific surface area (cm^2/g)
OPC	3.16	3110
FA	2.30	4190
BS	2.89	4400

2.2. Petrographic observation of aggregates

In order to clarify the petrographic characters of aggregates used, thin sections having around 20 μm were prepared and observed optical microscope.

A (B) shows a porphyry texture composed of phenocrysts and grandmas. Phenocrysts are plagioclase, ortho-pyroxene, clino-pyroxene, opaque minerals as shown black particles under an optical microscope and minor apatite. Grandmas are composed of plagioclase, cristobalite, pyroxene, and opaque minerals. Most of contained pyroxenes are altered to smectite, opal, and carbonates. There are many fine cracks filled with opal veins accompanying cristobalite as round grains on the surface of veins and dolomite. Original glass in matrix is estimated to be decomposed to smectite, cristobalite, and opal. These textures indicate that A (B) is altered andesite. Opal and cristobalite is highly alkali reactive minerals.

C shows porphyry texture also. Phenocrysts are plagioclase, ortho-pyroxene, clino-pyroxene, olivine, hornblende, opaque minerals and minor apatite. There are also quartz phenocrysts as xenoliths those are the mineral fragments brought from other rocks during eruption of andesite magma. Grandmas are composed of plagioclase, tridymite, pyroxene, and opaque minerals. These textures indicate that this C is relatively slowly cooled holocrystalline andesite without glass. Tridymite is highly alkali reactive mineral.

D shows mosaic like granoblastic texture composed of quartz and plagioclase accompanying biotite and muscovite and minor apatite, tourmaline, opaque minerals and zircon. These textures indicate that D is argillaceous hornfels. Microcrystalline quartz crystals are included as late expansive minerals.

G (H) are composed of micro/cryptocrystalline calcite whose texture is called as micrite and occasionally recrystallized calcite in veins. There textures indicate that G is pure limestone without alkali reactive minerals.

In Table 5, the results of chemical method according to ASTM C 289 are shown. A (B) were judged as potentially deleterious suggesting compositional pessimum phenomenon. C was judged as deleterious. D is judged as innocuous because

Table 2
Chemical composition of cement used (mass%).

	insol.	ig.loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	P_2O_5	MnO	Cl	Total
OPC	0.22	1.87	20.89	5.29	3.09	64.25	0.92	2.02	0.35	0.36	0.30	0.51	0.12	0.016	99.99
FA	0.12	2.37	54.96	28.10	4.76	3.18	1.30	0.49	1.07	1.30	1.58	0.51	0.03	0.000	99.65
BS	84.22	0.87	33.26	13.12	0.39	44.12	4.78	4.08	0.18	0.38	0.45	0.00	0.16	0.001	101.79

Table 3
Chemical composition of aggregate used (mass%).

	ig.loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	P_2O_5	MnO	Cl	Total
A, B	4.92	63.31	14.06	5.38	4.58	0.98	0.06	3.94	1.39	0.64	0.19	0.20	0.000	99.65
C	0.39	59.43	16.40	7.49	7.24	3.75	0.00	2.71	1.67	0.70	0.12	0.15	0.001	100.1
D	2.72	69.43	13.82	3.36	2.06	1.30	0.40	3.23	2.80	0.46	0.11	0.07	0.000	99.76
G, H	43.57	0.35	0.14	0.11	54.66	0.44	0.00	0.00	0.01	0.02	0.02	0.00	0.000	99.32

Table 4
Physical characters of aggregate used.

Aggregate	SSD density (g/cm^3)	Dry density (g/cm^3)	Absorption (%)	Unit weight (kg/L)	Solid content (%)	FM	Fines (%)
A	2.52	2.46	2.33	1.41	57.2	6.60	4.2
B	2.63	2.49	5.78	1.46	58.7	2.87	4.4
C	2.69	2.63	2.06	1.56	59.5	6.56	1.2
D	2.66	2.65	0.71	1.52	57.4	6.63	1.0
G	2.70	2.68	0.55	1.54	57.3	6.59	1.7
H	2.70	2.68	0.61	1.85	68.9	3.04	8.2

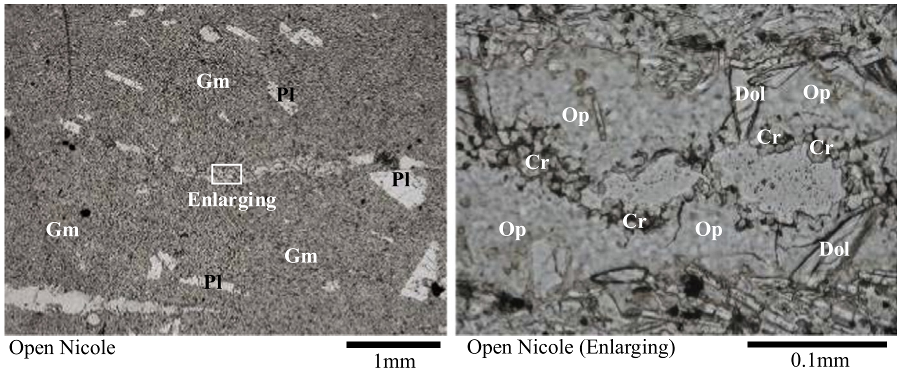

Fig. 1. Microphotos of A, B. Gm: groundmass, Pl: plagioclase, Cr: cristobalite, Dol: dolomite, Op: opaque minerals.

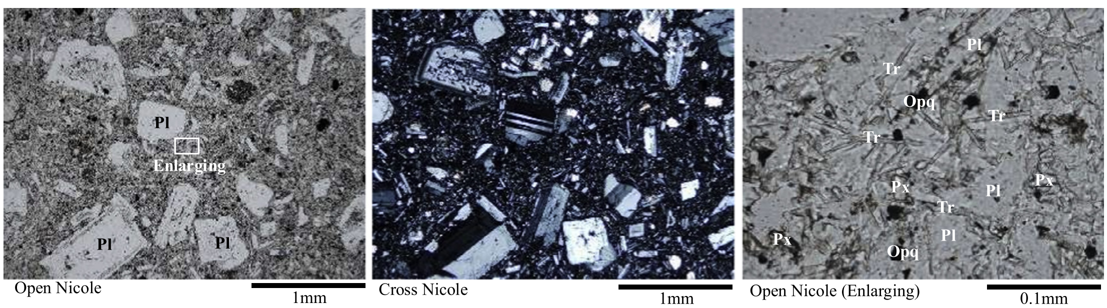

Fig. 2. Microphotos of C. Gm: groundmass, Pl: plagioclase, Px: pyroxene, Tr: tridymite, Opq: opaque minerals.

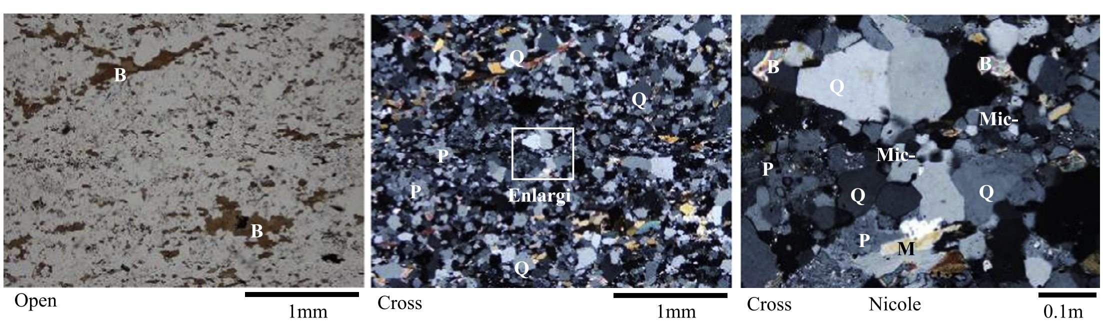

Fig. 3. Microphotos of D. Qz: quartz, Pl: plagioclase, Bt: biotite, Mic: micrite.

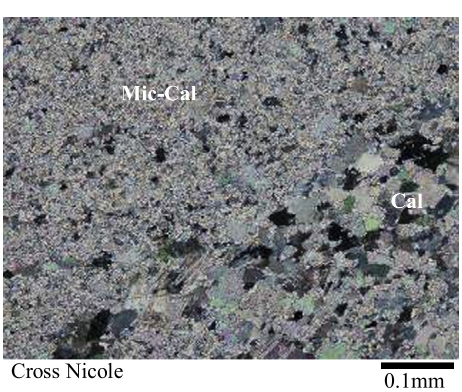

Fig. 4. Microphotos of G, H. Cal: calcite, Mic: micrite.

chemical method is insensitive for late expansive aggregate containing micro/cryptocrystalline quartz. G (H) are innocuous because of the absence of alkali reactive minerals.

2.3. Mixture proportions of concrete

In Table 6, the designed levels of CPT experiments are shown. In order to detect the pessimum phenomena, aggregate A was mixed with aggregate G as coarse aggregate (No. 1) and compared with 100% aggregate A (No. 5). In order to detect the size effect, aggregate B was mixed with aggregate H as fine aggregate (No. 7). Another kind of andesite was also examined by using aggregate C (No. 10).

In order to detect the difference in ASR suppressing effect of fly ash (FA) and ground granulated blast furnace slag (BS), different amounts were added in the pessimum composition of aggregates A (B) and C (Nos. 2, 3, 4, 8, 9, 11, 12) and 100% of aggregate A (No. 6).

Table 5
Test results of aggregate used by chemical method.

Aggregate	Rc (mmol/L)	Sc (mmol/L)	Reactivity
A, B	207	672	Potentially deleterious
C	112	592	Deleterious
D	109	16	Innocuous
G, H	8	1	Innocuous

Table 6
Designed levels of CPT.

	Concrete material			CPT	
	Aggregates		Binder[b]	RILEM AAR-4	MJASS5Nm
	Coarse[a]	Fine			
No. 1	A:G = 3:7	H	OPC	○	○
No. 2	A:G = 3:7	H	FA25%	○	○
No. 3	A:G = 3:7	H	FA35%	–	○
No. 4	A:G = 3:7	H	BS55%	–	○
No. 5	A	H	OPC	–	○
No. 6	A	H	FA25%	–	○
No. 7	G	B:H = 3:7	OPC	○	○
No. 8	G	B:H = 3:7	FA25%	○	○
No. 9	G	B:H = 3:7	FA35%	–	○
No. 10	C:G = 3:7	H	OPC	–	○
No. 11	C:G = 3:7	H	FA25%	–	○
No. 12	C:G = 3:7	H	FA35%	–	○
No. 14	D	H	OPC	○	○
No. 15	D	H	FA25%	–	○
No. 16	D	H	FA35%	–	○
No. 18	G	H	OPC	–	○

FA: fly ash, BS: ground granulated blast furnace slag.
[a] Mixed by mass ratio.
[b] Number indicates mass replacement ratio.

Applicability for late expansive aggregate, aggregate D (No. 14) was used as coarse aggregate and suppression effect of fly ash was checked (Nos. 15, 16). In order to confirm the non-reactivity of aggregate G and H, one concrete was made of aggregate G and H (No. 18) for coarse and fine aggregates, respectively.

The comparison between two CPT methods was carried out by selected levels of concrete by two methods (Nos. 1, 2, 7, 8, 14).

In Table 7, the mixture proportions of concrete are shown. Water content was kept constant as 160 kg/m^3. In some mixtures, OPC was replaced with FA as much as 15, 25, or 35 mass% or 55 mass% of BS. Slump flow was adjusted 12 ± 4 cm by changing AE water reducer dosage. Air content was controlled 4.5 ± 1.5% by changing AE agent dosage. Reagent grade NaOH was added to adjust alkali amount as 5.5 kg/m^3 by dissolving in mixing water.

2.4. CPT

There are several kinds of CPT. CSA A23.2 27A-09 or RILEM AAR-3 are considered as the most popular and reliable methods. In order to accelerate ASR expansion, alkali amount is increased to 5.5 kg/m^3 and temperature is increased at 38 °C. In order to obtain the results in shorter time, ultra-accelerated CPT RILEM AAR-4 is now under preparation [6]. The accelerating temperature is 60 °C. In this study, in order to obtain results in shorter time, basic condition of AAR-4 [7] was adopted. Of course the effect of temperature is important and another test is now under preparation.

These methods use concrete specimen having a size of 75 × 75 × 250 mm. This relatively small size has a possibility of alkali leaching [8]. Contrary, large concrete prism having a size of 100 × 100 × 400 mm is very popular in Japan. One who consider the application of CPT in his society, he will think about the infrastructure. When different size of specimen is introduced, everyone has to prepare new molds. Therefore, in this study in Japan, majority of CPT was carried out according to existing standard JASS5N-T603 [9] and used a specimen of 100 × 100 × 400 mm but curing temperature was changed (mJASS5N) and compared with the smaller specimen of AAR-4.

Moisture control is another important issue for CPT. For the specimens of mJASS5N in this study, according to JASS5N-T603, concrete prism is wrapped with wet paper by water where the size and amount of water for wetting are specified. In this study, two pieces of unwoven A3 size paper (Kim wipe) were used. For one piece of paper, 50 g of water was added. The procedure of wrapping of a specimen and placement in a curing chamber are shown in Fig. 5. After wrapping with wet paper, the each specimen was covered by thin plastic film and was contained in a thick plastic bag in order to prevent moisture movement between a specimen and surrounding environment. Then, four specimens for each experiment level are placed vertically in a container that temperature is controlled with a heater in water in the bottom of container surrounded by heat insulator of foamed polyurethane board. Small AAR-4 size specimens were prepared and cured according to RILEM AAR-4 temporary version [7]. Four concrete specimens for one experimental level were placed vertically in a stainless steel container without wrapping. The specimens were not immersed in water but cured above water.

Before 24 h of length measurement, specimens were moved to a room of 20 °C. For the specimens of mJASS5N, plastic bag and film was removed and paper was unwrapped. Then, the length was measured. The mass of wet paper was measured. When going to the next step, water was added to the same paper up to the mass of initial value. After whole test period, water content and alkali content in the paper were measured and alkali leaching was evaluated.

For the specimens of AAR-4, just length and weight changes were measured and returned into stainless steel container directly and the height of water in the bottom of container was adjusted to a constant level by adding water if necessary. After whole test period, water sample was taken form the bottom of the container and the alkali concentration was measured and alkali leaching was evaluated.

1st line left: wetting process of paper. Middle: wrapping with the 1st paper. Right: wrapping with 2nd paper.
2nd line left: fixing the paper with adhesive tape. Middle: overwrapping by thin plastic film for foods covering. Right: covering by a thick plastic bag.
3rd line left: fixing of plastic bag with adhesive tape. Right: appearance of completed wrapped specimens.
4th line left: a stainless container for AAR-4. Middle: heat bath to keep atmosphere at 60 °C and 100%RH. Right: outer appearances of heat bathes.

3. Results and discussions

3.1. Evaluation of various mixtures

The expansion behaviors of specimens of mJASS5N are shown in Fig. 6 and the suppression effects of pozzolans are summarized in Table 8. The highest expansion ratio 0.51% was obtained from No. 7, the pessimum composition of andesite B used as fine aggregate. Compared to No. 1's expansion ratio 0.21% where andesite A is used as coarse aggregate in the pessimum composition, ASR expansion ratio was significantly high when the same andesite

Table 7
Mixture proportion of concrete.

	Unit content (kg/m^3)						Admixtures		
	OPC	FA	BS	W	S	G	AE WR (kg)	AE agent (g)	NaOH (kg/m^3)
No. 1	320	–	–	160	842	1011	1.00	6.4	4.702
No. 2	240	80	–	160	832	995	1.00	52.8	3.319
No. 3	208	112	–	160	826	990	1.00	91.5	2.765
No. 4	114	–	176	160	837	1000	0.88	20.5	5.043
No. 5	320	–	–	160	842	963	0.88	57.6	4.702
No. 6	240	80	–	160	832	948	0.88	28.8	3.319
No. 7	320	–	–	160	836	1030	1.00	140	4.702
No. 8	240	80	–	160	825	1015	1.00	288[a]	3.319
No. 9	208	112	–	160	819	1010	1.00	332[a]	2.765
No. 10	320	–	–	160	842	1030	1.00	12.8	4.702
No. 11	240	80	–	160	832	1013	1.00	105	3.319
No. 12	208	112	–	160	826	1009	1.00	91.5	2.765
No. 14	320	–	–	160	842	1016	1.00	6.4	4.702
No. 15	272	48	–	160	837	1005	1.00	16.3[a]	3.872
No. 16	240	80	–	160	832	1000	1.00	28.8[a]	3.319
No. 18	320	–	–	160	842	1032	1.00	6.4	4.702

[a] Alkyl carboxylic acid-based.

Fig. 5. Testing sequence of mJASS5N.

was used as fine aggregate. And suppressing effect of fly ash is less in the case of No. 7. With the addition of 25 mass% of FA as replacement of OPC, although the expansion ratio of No. 1 was reduced to 0.03% (No. 2), that of No. 7 was reduced to only 0.05% (No. 8) that exceeds threshold value 0.04%. 0.04% is the threshold value of expansion ratio by CSA A23-27A for deleterious and is the value to start cracking [10]. This is an example of the size pessimum effect. Not only the expansion level but also the effectiveness of fly ash can be different depending on the size of aggregate. This kind of phenomenon can be detected only by CPT but is difficult to know by mortar bar test.

By comparing the expansions of Nos. 2, 3, and 4, it is possible to compare the effectiveness of SCMs. In the case of andesite A at the pessimum composition, 15 mass% of BS replacement (No. 4) was not enough to suppress ASR. In the case of No. 10 where andesite C was used, expanding speed was less than No. 1 but the saturated expansion was more. For the No. 10, 25 mass% of FA was more effective than in the case of No. 1. The reason is not clear but there seem to be complicated cross effects by the combination of aggregate and pozzolanic materials. A test method for the evaluation of effectiveness of pozzolans preventing ASR is already described in ASTM C441. However, this standard can judge the effectiveness of pozzolans by using Pyrex glass but cannot evaluate how much pozzolans are required to suppress expansion for specific type of aggregates.

The concrete No. 14 containing aggregate D showed 0.07% of expansion ratio and judged as deleterious although chemical method resulted in innocuous. Compared with other rapid expansion showing relatively saturated behaviors after 10 weeks, No. 14 showed continuous expanding behavior even at 26 weeks. The expansion was successfully suppressed by the addition of FA. However, it is curious that the expansion was not suppressed by FA completely but only the expansion speed decreased. This is different from the case of aggregate A with 25 mass% of FA (No. 6) where expansion was completely suppressed.

3.2. Comparison between AAR-4 and mJASS5N

The correlation between the expansion behaviors by AAR-4 and mJASS5N is shown in Fig. 7. In a wide range as shown in the left, both methods showed a linear correlation of one by one. However, looking at details at limited expansion range as shown in the right,

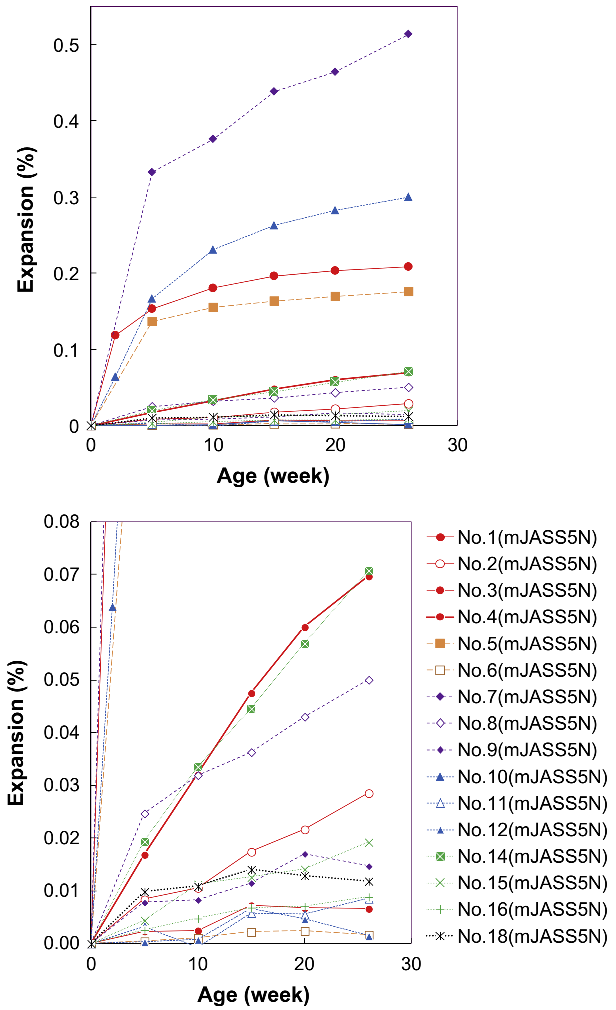

Fig. 6. Expansion behaviors of concrete. *Legend:* Mixture No. in Table 6 (testing method).

there is a discrepancy. AAR-4 showed lower values than mJASS5N. Also as shown in the case of No. 1, at the early ages the discrepancy was limited but in the later ages it increases. The difficult point is in the range of less than 0.10%. If threshold value to judge deleterious is set as 0.04%, AAR-4 gives different conclusions for No. 8 and No. 14 from mJASS5N.

As a possible reason, the difference in moisture controlling method is considered because by mJASS5N specimens were wrapped by wet papers but by AAR-4 specimens were just kept over water in a container even it contained water in the bottom and sealed. In Fig. 8, the relationship between mass change and expansion is shown. There are two trends regardless of test methods, *i.e.* one is the specimens of andesite A and B without FA and the other is the specimens of andesite A and B with FA and that of hornfels D. In the case of significant expansion, mass gain meaning water absorption resulted in expansion. But in the case of limited expansion, water tends to be absorbed but the expansion was limited. This may be caused by the difference in the water absorbing reactions. In the case of more expansion, water might be consumed in the formation reaction of expansive ASR gel. On the other hand, in the case of less expansion, water might be consumed in the non-expansive pozzolanic reaction. Further detailed analysis is required.

When the difference in two methods are compared, as expected in the condition of AAR-4, mass gain was limited than that of mJASS5N. However, the expansion of AAR-4 was more than mJASS5N at the same mass gain and the moisture seems not to be the direct reason of discrepancy. Another possible reason will be the differences in alkali leaching. Measured amount of leached alkalis were shown in Table 9. Alkali amounts leached were 2% or 3% of original 5.5 kg/m^3 for mJASS5N and 16% or 30% of that for AAR-4. The reason why limited amount of alkali leaching in mJASS5N may be in the use of the same paper and just water was added in a sealed condition that means no alkali leaching out to environment but kept in the plastic film at least. In this condition, alkali cannot go out from the system and can exist only in the paper at the same concentration with pore solution in limited solution volume. More alkali leaching in AAR-4 may be caused by the water drops when the container is cooled for the measurement even though the inclined inner roof is prepared, or moisture condensation in the container on the specimens when the container, especially the water in the bottom is heated after measurement during the specimens are cold. Therefore, because of the more amount of alkali leaching, AAR-4 resulted in the less expansion. For rapid expansion, the effect of alkali leaching was limited because the most of expansion was happened before the first measurement. There is another possibility of the reason for limited alkali leaching of mJASS5N in its large specimen size.

There is one more difficult point in AAR-4. Drying during cooling may happen because the stainless steel container cooled faster than concrete prisms inside. Water in concrete prisms can move on the inside surface of container by condensation. When alkali amount is much, the equilibrium vapor pressure is low and vapor tends to be absorbed by concrete prisms. However, once the alkali content becomes less, the vapor absorbing tendency decreases and water may move from concrete prisms to the container. In real condition of concrete structure, the severest condition for ASR excepting alkali supply from de-icing salt or sea salt is continuous supply of water. Therefore, wrapping with wet paper is considered as reasonably safe side.

The alkali leaching in the case of wrapping by wet paper is caused by the alkali movement from concrete specimen to wet paper. Therefore, if appropriate amount of alkalis are included in wet paper in advance, the movement of alkalis are expected to be limited less. CPT is an accelerated test in order to reproduce the worst case in field. Therefore, keeping alkalis and moisture is an essential point. Further investigations are required.

Table 8
ASR suppressing effect of SCMs in various concrete mixtures (26 weeks, mJASS5N).

Aggregate/proportion	OPC	FA			BS
		15%	25%	35%	55%
A/30%	0.208 (No. 1)	–	0.029 (No. 2)	0.007 (No. 3)	0.076 (No. 4)
A/100%	0.176 (No. 5)	–	0.002 (No. 6)	–	–
B/30%	0.513 (No. 7)	–	0.050 (No. 8)	0.015 (No. 9)	–
C/30%	0.300 (No. 10)	–	0.009 (No. 11)	0.002 (No. 12)	–
D/100%	0.071 (No. 14)	0.019 (No. 15)	0.009 (No. 16)	–	–

(): Mixture No. in Table 6.

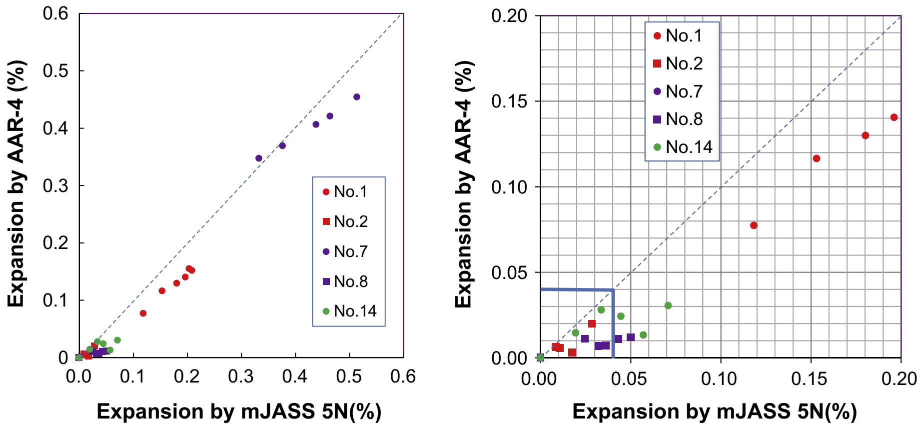

Fig. 7. Correlation between the expansion behaviors by AAR-4 and mJASS5N.

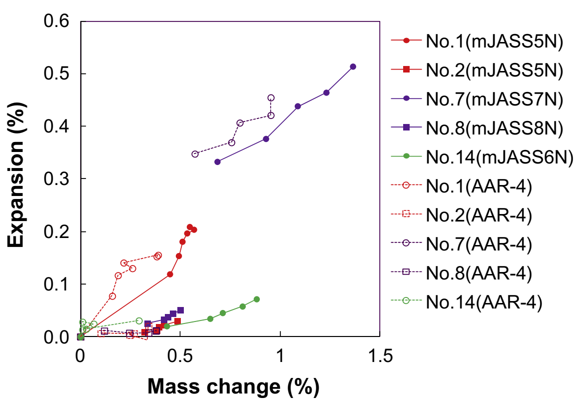

Fig. 8. Mass change of specimens during CPT and expansion.

Table 9
Alkali leaching from concrete specimens.

		Alkali amount leached (%, $Na_2O_{eq.}$)
mJASS5N: 100 × 100 × 400 mm	No. 1	3.4
Wrapped with wet 2 pc of paper	No. 14	2.1
RILEM AAR-4: 75 × 75 × 250 mm	No. 1	16.3
Stored in a sealed box containing water in the bottom	No. 14	30.3

Table 10
Accuracy of measurements.

	mJASS5N	AAR-4
Standard deviation		
Total	0.006	0.015
<0.04%	0.002	0.006
<0.04%	0.011	0.029
Coefficient of variation		
Total	0.346	0.380
<0.04%	0.547	0.560
<0.04%	0.094	0.111

3.3. Accuracy and repeatability

Accuracy of measurements was evaluated by calculating standard deviation and coefficient of variation of each measurement of four specimens in one level. The results are shown in Table 10. In limited expansion, because absolute values are limited and standard deviation was relatively low. For mJASS5N, the accuracy is 0.002% and for AAR-4 that is 0.006. In larger expansion exceeding 0.04%, absolute values of expansion ratio become diverse compared to less expansion ratios. However, the coefficient of variation is limited. For mJASS5N, the accuracy is 9% and for AAR-4, that is 11%.

Repeatability in one laboratory is analyzed from the correlation between FA amount and expansion ratios. There are exponential correlations between them. By fitting data to exponential curve, the differences between measured data and regression analysis were compared. The difference between them is 0.0048 ± 0.0064% of expansion ratio in average.

Repeatability inter laboratories are now under investigation in a technical committee of Japan concrete Institute.

3.4. Easiness of operation

The detailed test procedure of mJASS5N is already shown in Fig. 5. It is worthy to mention the easiness of operation. The wrapping sequence takes long time and is hard work because of the weight of specimen. The weight of 75 × 75 × 250 mm specimen is 3 kg but the weight of 100 × 100 × 400 mm specimen is 9.5 kg. This is a significant difference considering the human ability for operation. In the experiences of this study, the most difficult point is in the heavy weight. There is another disadvantage for large specimen. As shown in the last two photos in Fig. 5, large specimens occupy almost three times more space. This fact increases testing cost significantly.

Significant alkali leaching had been expected before the experiment but the result was limited. This suggests if appropriate cares are paid, smaller size specimen can be acceptable without significant alkali leaching.

Based on the experiences in this study, it is possible to propose appropriate CPT procedures for performance testing of real concrete mix in order to overcome the disadvantages of various mortar bar tests.

(1) 75 × 75 × 250 mm size is preferable from the view point of human friendliness.
(2) Alkali leaching is probably reduced by using alkali solution with appropriate concentration for wetting paper or appropriate cloth.
(3) Total alkali of 5.5 kg/m^3 from cement and SCMs are adjusted by adding NaOH. Alkali boosting has a meaning of acceleration.

(4) Specimens are wrapped by one piece of paper wetted by 50 g of alkali solution at first and then they are overwrapped by thin plastic film in order to prevent moisture movement.
(5) Addition of extra water is required if the weight of wet paper was reduced at the timing of length measurement. The same paper should be used. The specimen should be over wrapped by new thin plastic film.
(6) Curing condition is set at 60 °C.
(7) Temporary judgment threshold of 0.04% expansion at the age of 20 weeks is proposed.

4. Conclusions

In order to evaluate the ASR possibility of aggregate in concrete mixture and suppressing effect of ASR by SCMs, ultra accelerated concrete prism tests CPT were carried out at 60 °C by using two different specimen size, *i.e.* $75 \times 75 \times 250$ mm or $100 \times 100 \times 400$ mm, and different curing conditions, *i.e.* wrapping with wet paper or curing in a stainless container. From the experiments, following conclusions are obtained.

(1) Compositional and size pessimum effects can be detected by CPT.
(2) Alkali leaching by wet wrapping was limited from the specimen of $100 \times 100 \times 400$ mm compared to the specimen of $75 \times 75 \times 250$ mm without wrapping contained in a sealed stainless steel container.
(3) There are positive relations between mass gain of specimens and expansion for each mix and each type of CPT. However, the tendencies are different depending on type of aggregate and combination with SCMs.
(4) Based on the experiences of both types of CPT, smaller size is significantly human friendly and easy to operate.
(5) There is a possibility of less expansion in CPT according to RILEM AAR-4 and there is a possibility to improve by wrapping with paper wetted by alkaline solution.

As a study in the next step, the calibration of expanding behavior of CPT as an accelerated test to the expansion of real concrete containing less alkali amount in real environments being lower temperature should be investigated in order to obtain the axis of time scale in the acceleration test proposed in this study. If this becomes possible, it will be able to design the service life of concrete also from the viewpoint of ASR.

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