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The Suppressing Effect of Fly Ash on ASR under Outdoor Exposure Conditions at the Seashore

Chikao Sannoh [1], Tohru Hashimoto [1], Kazuyuki Torii [2]

[1] *Hokuriku Electric Power Company Co. Ltd,15-1 Ushijima-machi, Toyama, 930-8686, Japan*
[2] *Kanazawa University, Kakuma-machi, Kanazawa, 920-1192, Japan*

ABSTRACT

This paper presents the updated information on the outdoor exposure test started in September 2004 at the seashore in the Hokuriku district, Japan, where the expansion behaviour of concrete was periodically measured. The previous paper on this topic was published for the 13th ICAAR in Trondheim, Norway. In this paper, it was apparent that the expansion of concrete with reactive river sand and reactive river gravel due to ASR could be controlled by the substitution of 15% fly ash which is categorized according to JIS A6201 as class Ⅱ. In addition, the cores were taken from the RC specimens at 6 years after exposure, microscopic features of thin core sections were observed with polarizing microscope to investigate the mechanism of the suppressing effect of fly ash on ASR. As a result, it was revealed that the progression of cracking was suppressed by a mixture of fly ash.

Keywords: ASR, Fly ash, Outdoor exposure test, Polarizing microscopic observation

1 INTRODUCTION

Fly ash has the suppressing effect on alkali-silica reaction (ASR),and the use of fly ash or fly ash cement, for which the effects on ASR as an admixture were previously confirmed, are stipulated in JIS A5308 (Appendix 2). Recently the methods to confirm the suppressing effect of fly ash on ASR were stipulated in JASS5 T-405 “Performance criteria of fly ash use in ASR suppressing measures” in which the mortar bar method stipulated in JIS A1146 was adopted. On the other hand, it is believed that the decision may not be a proper one in the case of some aggregates. Thus, it is necessary to investigate the suppressing effect of fly ash under real world conditions. The expansion behavior itself under real world conditions has not been profoundly studied, and the comparison between laboratory tests and field tests about the expansion behavior of ASR has not been clarified yet(Jason,H et. al, 2004). Therefore, it is important to examine the suppressing effect of fly ash under real world conditions and to study the mechanism of the suppressing effect due to the pozzolanic reaction over the long term. The authors exposed large-sized RC specimens, in which reactive aggregates were used, at the seashore, and have been measuring the expansion behavior of the concrete periodically in order to clarify the suppressing effect of fly ash on ASR(Sannoh et. al, 2008). This paper presents the updated information about the monitoring and microscopic features of thin core sections observed with a polarizing microscope to investigate the mechanism of the suppressing effect of fly ash on ASR(Gao Pei-wei et. al, 2004). In addition, the relationship between the expansion behavior of the mortars in the indoor accelerated test and the specimens in the outdoor conditions are examined(Sannoh et. al, 2004) .

2 MATERIALS AND METHODS

2.1 Materials

The mix proportion of concrete is shown in Table 1. Ordinary Portland cement (density: 3.16 g/cm^3, specific surface area: 3330 cm^2/g, alkali content: 0.68%) was used. The concrete was plain, without chemical admixtures, with 10 kg/m^3 Na_2Oeq since NaCl was added as alkali to promote ASR. As reactive aggregates, river sand and river gravel from Joganji River which are confirmed to have ASR deleterious effect in actual structures were used. The fly ash was produced at a coal-burning power plant in the Hokuriku District and its quality conformed to JIS A6201 type II ash. The physical properties and chemical components of fly ashes used in this study are shown in Table 2 and 3. The replacement ratio of fly ash was set at 15%, which is the lowest specified replacement ratio in the ASR suppression measures according to JIS A5308.

2.2 Methods

Indoor accelerated test
The mortar bar method in accordance to JIS A1146(specimens size:40mm×40mm×160mm) was adopted as an indoor accelerated test to confirm the suppressing effect of fly ash on ASR. The fly ash used is shown in Table 2. These laboratory trials preceded the outdoor exposure test.

Outdoor exposure test
In September 2004 after two weeks of curing, the RC specimens(500 x 500 x 200 mm) were exposed on the quay of Shinminato harbor in Toyama Prefecture, where the effect of airborne salt water from sea was high, and the measurement of the expansion ratio in the concrete was periodically conducted. A diagram of the RC specimen is shown in Figure 1, and the fly ash used is shown in Table 3.

Mechanical properties
The cores(ϕ100mm×200mm) drilled from the specimens were tested for the compressive strength in accordance to JIS A1108 (Method of test for compressive strength of concrete) and the static modulus of elasticity in accordance to JIS A1149 (Method of test for static modulus of concrete) .

Microscopic features of thin core sections
Microscopic features of thin core sections(20mm×40mm,thickness:20μm) were observed with a polarizing microscope to investigate the mechanism of the suppressing effect of fly ash on ASR.

3 RESULTS AND DISCUSSION

3.1 Correlation between expansion behavior of mortar bars and the RC specimens

(1)Expansion Behavior of the mortar bars

The measurement results of expansion ratio in mortar bars conducted in accordance to JIS A1146 are shown in Figure 2. When compared to plain OPC mortar bars, the mortar bars blended with fly ash exhibited a suppressing behavior. The expansion ratio of FA-N(10%) and FA-T(10%) was under 0.1%, and the expansion ratio of FA-N(20%), FA-T(20%) and FA-S(20%) was almost zero. According to the criterion specified in JASS5 T-405, the limit of expansion ratio is 0.1%, therefore the lowest replacement ratio for FA-N and FA-T can be set at 10% and that of FA-S can be set at 20%.

(2)Expansion Behavior of RC specimens

The measurement results of expansion ratio in RC specimens are shown in Figure 3. The expansion in specimens with plain ordinary Portland cement (OPC) was large and reached about 0.9% in 6 years. When the specimens were blended with fly ash(FA-N and FA-T), the expansion was suppressed to about 0.2% and 0.3%. These results show the suppressing effects of fly ash under real environment conditions.

(3)Correlation between expansion behaviour of the mortar bars and the RC specimens

The correlation between the expansion ratio of mortar bars(182days,OPC and FA10%) and the RC specimens(68months,OPC and FA15%) is shown in Figure 4. Both are highly correlated. (R^2>0.8) These results show that the mortar bar methods we employed are valid for confirming the suppressing effects of fly ash on ASR. The main reason for the high correlation is believed to be that the river sand and river gravel had similar rock composition. The river sand and the river gravel were extracted in the same river, although the granulometry was different.

3.2 Mechanical properties of cores drilled from the RC specimens

(1)Relationship between compressive strength and static modulus in concrete cores

The relationship between the static modulus-compressive strength ratio and the compressive strength is shown in Figure 5. The curve in this figure shows the relationship between static modulus-compressive strength ratio and the compressive strength obtained from undamaged cores. In the case of the cores drilled from specimens with non-reactive aggregates, the relationship between those cores and undamaged cores was very similar. By comparison, in the case of the cores drilled from specimens with reactive aggregates, the ratio of static modulus to compressive strength is very low, in spite of using fly ash. It is well known that the ratio of static modulus to compressive strength decreases due to ASR when reactive aggregates are used. Thus, it was considered that there were many cracks inside the concrete due to ASR in the cores with reactive aggregates.

(2)Relationship between compressive strength and ultrasonic velocity in the cores

The relationship between the compressive strength and the ultrasonic velocity is shown in Figure 6. In the cases of the cores drilled from specimens with non-reactive aggregates, the compressive strengths and the ultrasonic velocities are high. By comparison, in the cases of the cores taken from specimens with reactive aggregates, they are low, particularly in cases where fly ash was not used. Thus, it was predicted that there would be many cracks inside the concrete due to ASR in the cores with reactive aggregates, particularly in the cases where fly ash was not used.

3.3 Microscopic features of concrete cores

(1)Visual observation of concrete cores

In the cases of the cores driled from specimens with reactive aggregates and without fly ash, cracks were observed inside many of the constituent pebbles in gravel, and the ASR gel was observed in various portions of the cement paste. By comparison, in the cases of the cores taken from specimens using reactive aggregates with fly ash, though cracks were not observed as much in the gravel, ASR gel was observed in some portions of the cement paste. Thus, we surmised that ASR occurs in both kinds of specimens, but only the degree of progression is different.

(2)Observation of thin core sections with a polarizing microscope

Polarizing microscope observations of thin core sections are shown in Photographs 1-8. Photographs 1-4 show composite pictures of entire thin core sections viewed under low magnification. The pebbles with cracks are marked with red circles. Photographs 5-8 show typical parts of thin core sections in which cracks due to ASR were observed inside the gravel and the sand particles. Table 4 shows the occurrence of cracks inside gravel, sand, and some portions of the cement paste.

In the cases of the thin core sections taken from the surface of a core without fly ash, cracks were observed inside small andesite particles and in a few portions of cement paste. The crack width was relatively large (about 0.2mm). By comparison, in the cases of the thin core sections sliced from the interior of concrete cores without fly ash, cracks were observed inside many andesite gravel particles, many andesite sand particles and in many portions of cement paste. Though the widths of the cracks inside the aggregates were relatively large (about 0.1-0.2mm), the crack widths inside the portions of cement paste were a little different than those from core surface. It is well known that the expansion of concrete due to ASR is affected by the restriction of the re-bar. Thus, the difference of crack widths between the surface portions and the interior portions may arise from the differences in the restrictive conditions in both places. In the cases of thin core sections taken from the surface of concrete cores with fly ash, few cracks were observed inside the andesite aggregate, and only in a few portions of cement paste. The width of the cracks was relatively large (about 0.2mm) as in the cases without fly ash. On the other hand, in the cases of the thin core sections taken from the interiors of cores with fly ash, cracks were not observed except inside a few andesite sand granules. The width of the cracks was very small (about 0.03mm width), which was different from the cases without fly ash. Thus, we surmised that ASR was suppressed by the use of fly ash, and cracks did not occur, except inside a few andesite sand granules, whose particles were small and in which ASR was easily promoted. Through the observations of thin core sections with a polarizing microscope, it has been confirmed that the degree of ASR progression is much different between cases with and without fly ash, and the use of fly ash effectively suppressed ASR in spite of severe conditions.

4 CONCLUSIONS

The correlation between the expansion ratios of mortar bars and the expansion ratios of RC specimens was high.

Concerning the suppression using river-made aggregate including reactive andesite stone, it has been demonstrated that the use of good quality fly ash at the replacement ratio of 15% can effectively suppress ASR.

Through the observations of thin core sections with a polarizing microscope, it has been confirmed that the degree of ASR progression is reduced by the use of fly ash.

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Table 1. Concrete mix proportions

Gmax (mm)	W/C (%)	s/a (%)	Unit content (kg/m^3)				
			W	C	S	G	NaCl
20	50	40	175	350	749	1106	11.5

Table 2. Physical properties and chemical components of different types of fly ash used in mortar bars

	Density (g/cm^3)	Blaine fineness (cm^2/g)	Chemical compositions（Wt%）						
			Ig.loss	SiO_2	Al_2O_3	CaO	Fe_2O_3	Na_2O	K_2O
FA-N	2.32	4070	1.8	62.16	23.45	0.80	4.28	0.23	1.10
FA-T	2.16	4310	4.2	67.40	19.50	1.00	3.50	0.38	1.08
FA-S	2.05	2950	3.2	46.80	32.00	3.40	7.60	0.23	0.63

Table 3. Physical properties and chemical components of different types of fly ash used in RC specimens

	Density (g/cm^3)	Blaine fineness (cm^2/g)	Chemical compositions（Wt%）						
			Ig.loss	SiO_2	Al_2O_3	CaO	Fe_2O_3	Na_2O	K_2O
FA-N	2.33	3550	1.5	59.64	26.50	0.80	4.89	0.24	1.39
FA-T	2.21	3990	2.8	70.41	18.43	1.07	4.62	0.47	0.76
FA-S	2.15	2920	3.2	48.45	31.83	3.93	6.27	0.25	0.59

Table 4. Occurrence of cracks inside the gravel, sand, and some portions of the cement paste

	portion	Gravel	Sand	Cement paste
OPC	Surface (0～20mm)	few cracks width:large (about 0.2mm)	few cracks width:large (about 0.2mm)	few cracks width:large (about 0.2mm)
	Interior (80～120mm)	many cracks width:large (about 0.1mm)	many cracks width:large (about 0.2mm)	many cracks width:small (about 0.02mm)
FA 15%	Surface (0～20mm)	few cracks width:large (about 0.2mm)	no cracks	few cracks width:large (about 0.1mm)
	Interior (80～120mm)	no cracks	few cracks width:about 0.03mm	few cracks width:small (about 0.02mm)

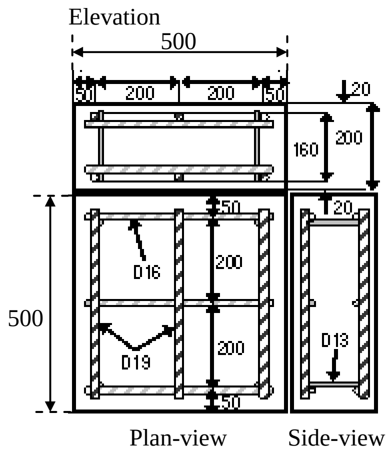


Figure 1. Diagram of RC specimen

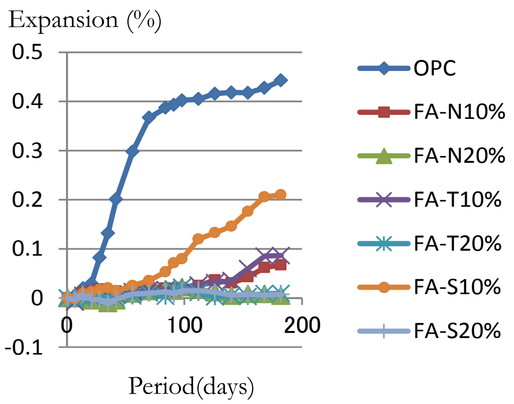


Figure 2. Expansion behavior of mortar bars with and without fly ash

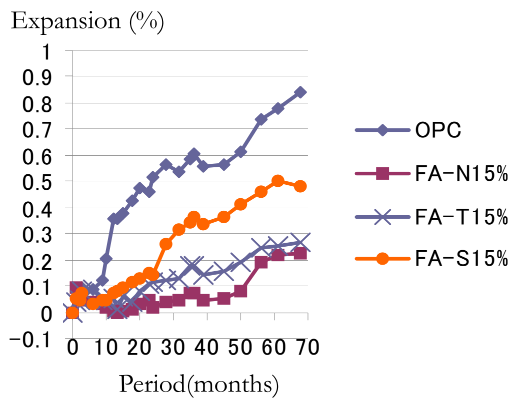


Figure 3. Expansion behavior of RC specimens with and without fly ash

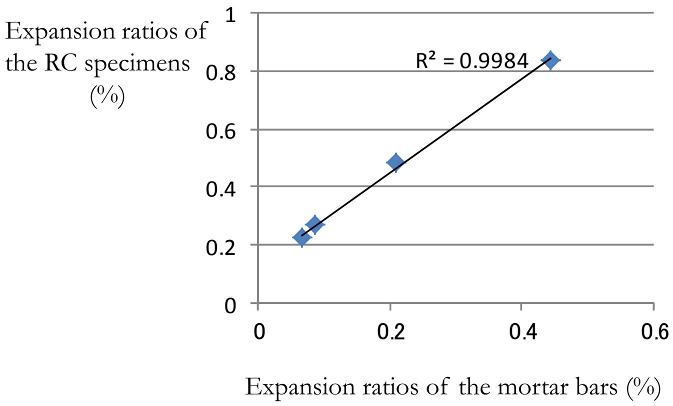


Figure 4. Correlation between the expansion ratios of mortar bars and the expansion ratios of RC specimens

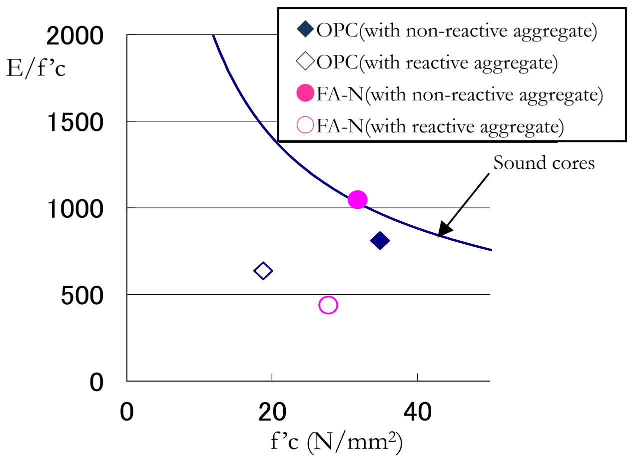


Figure 5. Relationship between the static modulus(E)-compressive strength(f'c) ratio and the compressive strength(f'c)

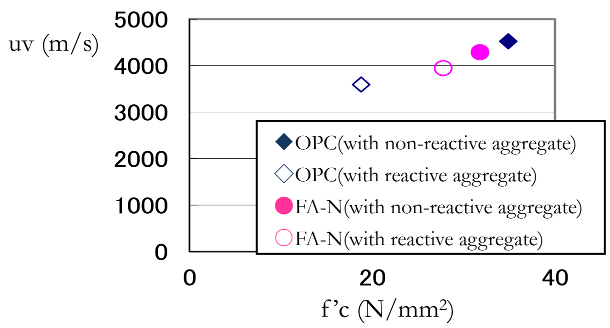
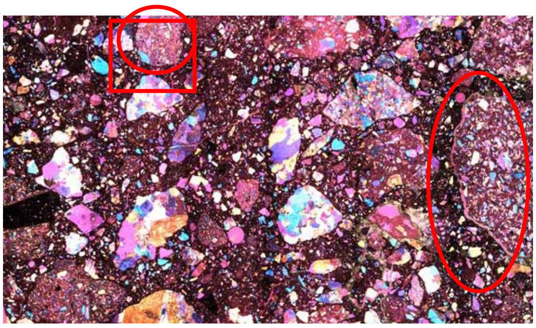
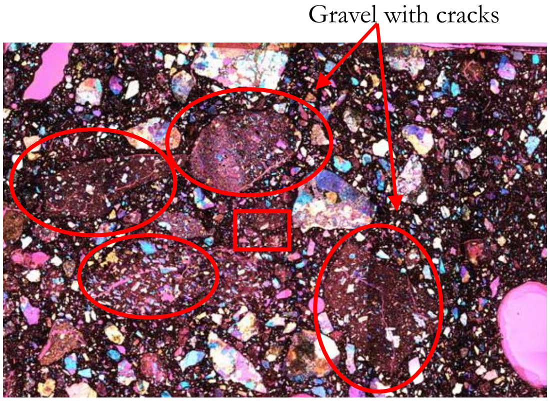


Figure 6. Relationship between the compressive strength(f'c) and the ultrasonic velocity(uv)



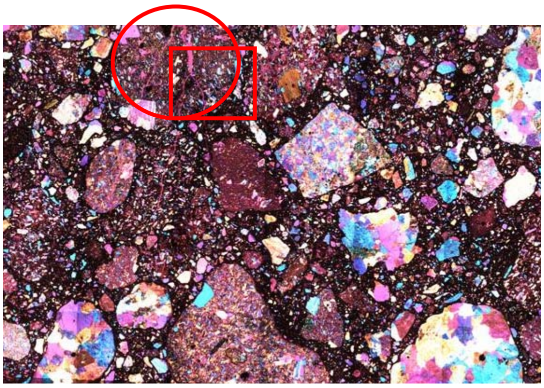
(▭ : The area of photograph 5) 10mm

Photograph 1. Composite pictures of entire thin core sections
(OPC, surface of the core, Optical microscope image under crossed nicols)



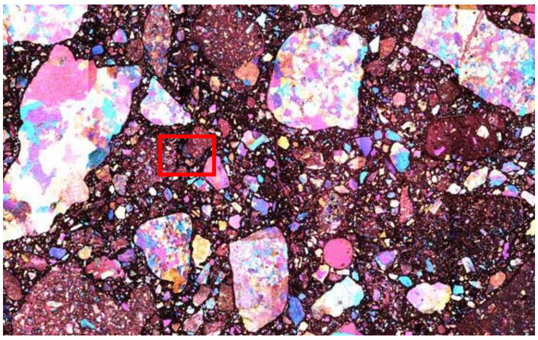
(▭ : The area of photograph 6) 10mm

Photograph 2. Composite pictures of entire thin core sections
(OPC, interior of the core, Optical microscope image under crossed nicols)



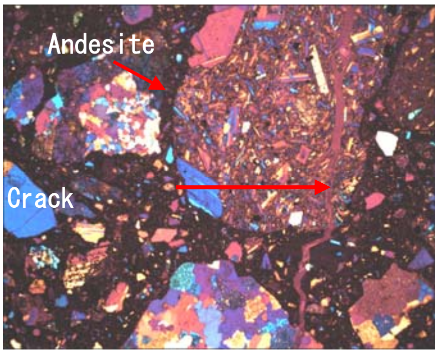
(▭ : The area of photograph 7) 10mm

Photograph 3. Composite pictures of entire thin core sections
(FA, surface of the core, Optical microscope image under crossed nicols)



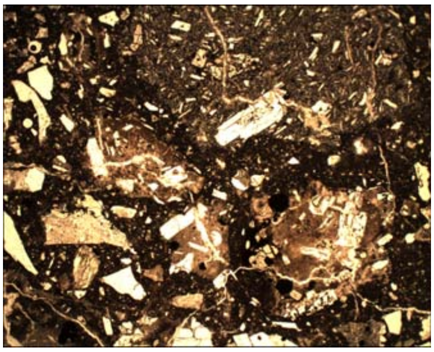
(☐ : The area of photograph 8) 10mm

Photograph 4. Composite pictures of entire thin core sections
(FA, interior of the core, Optical microscope image under crossed nicols)



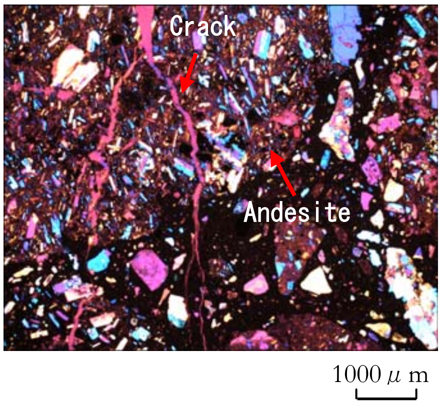
1000 μ m

Photograph 5. Cracks inside aggregate
(OPC, surface of the core, Optical microscope image under crossed nicols, Magnified portion of Photograph 1)

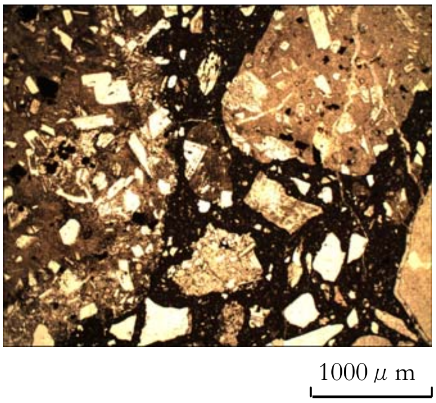


1000 μ m

Photograph 6. Cracks inside sands
(OPC, interior of the core, Optical microscope image under parallel nicols, Magnified portion of Photograph 2)



Photograph 7. Cracks inside aggregate
(FA, surface of the core, Optical microscope image under crossed nicols, Magnified portion of Photograph 3)



Photograph 8. Cracks inside sands
(FA, interior of the core, Optical microscope image under parallel nicols, Magnified portion of Photograph 4)