The Serious ASR Problems in Hokuriku District, Japan, and Its Mitigation Effect by Using Fly Ash Concretes

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1. Introduction

In the Hokuriku district in Japan, large numbers of bridges have been suffering from the combined damage caused by the chloride-induced corrosion of steel reinforcement and/or ASR (Torii, 2010). In order to produce highly durable concrete structures especially against ASR problem, the standard use of fly ash cement with the replacement of more than 15 % is recommended, which is proposed in all ready-mixed concrete mixtures from the economical and environmental point of view in this region (Sannoh et. al, 2008). For the achievement of this target, the research committee of a collaboration of industrial circles and universities on “the promotion of effective utilization of fly ash concretes in the Hokuriku district” was also founded in January 2011. On the approach of a promotive work, it can be pointed out that both the supply of good-quality fly ash from the electric power plant and its quality assurance are essential. In the Nanao-Ohta coal burning power plant, as shown in Figure 1, the production technique of very fine particles has successfully been established, where two processes are adopted; one the selection of original fly ash from the bituminous coal from mainly Australia, the other its mechanical separation of ultra-fine particles less than 10 μm by a centrifugal machine, as shown in Figure 2. The physical and chemical properties of fly ash produced are well satisfied with the quality standard of the highest level “Class I” according to JIS A6201. Furthermore, on the trial test in ready-mixed concrete plants, it has been confirmed that in the fly ash concretes with the replacement of 15 % by classified fine fly ash, the water content of concrete can be reduced by about 5 kg/m^3, and the compressive strength of concrete can be almost equal to the OPC concretes even at 28 days, which is greater than beyond 56 days.

In this paper, the quality assessment of classified fine ash, the effective utilization of highly durable fly ash concretes, the development undertaken and the extent of application in fly ash concretes are introduced along with the drawing from the current stage of serious ASR problem in the Hokuriku district (Torii et. al, 2016).

2. ASR Problem in Hokuriku District and its Countermeasures

In the Hokuriku district, due to the severity of both chloride attack and ASR, the development of economic and rational repair, retrofitting methods has become a top priority. In the whole, in the West Japan region, the chloride attack is related to the use of sea sand or sea gravel in concrete (internal salt attack), but in the Hokuriku district, which is rather linked to the use of river sand and river gravel in concrete, combined with the northwest monsoon from the Sea of Japan and the increased scattering of deicers on road surfaces, both in the winter season (external salt attack). On the other hand, this district is located within the huge volcanoes, such as the Hakusan and Tateyama mountains, in the upstream section of main rivers, prompting the outflow and spreading of volcanic rocks such as the andesite and rhyolite stones, which are the main reactive aggregates causing ASR damage in the entire area. Figure 3 shows the deteriorated ASR bridge map in the Hokuriku district. It is a common practice in the maintenance of

Figure 1. Photograph of an overview of centrifugal machine with fly ash silo.

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ASR-deteriorated bridge structures, the investigation of the relationship between the petrology of the reactive aggregates and the ASR degree of deterioration of concrete structures. However, this is a field that needs a considerable geology and petrology knowledge.

It is clarified that crushed andesite rocks from the Noto peninsula have been used in the Noto Expressway and National Road R249 and so on, which causes a severe type of ASR including the fracture of steel reinforcing bars (Torii et. al, 2009), (Minato et. al, 2010).

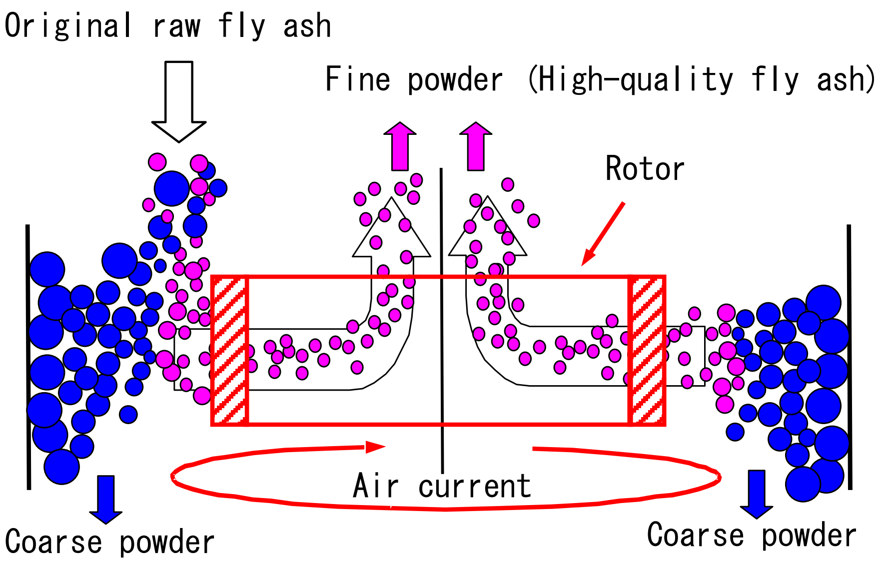

Figure 2. Schematic diagram of centrifugal machine in production of classified fine fly ash.

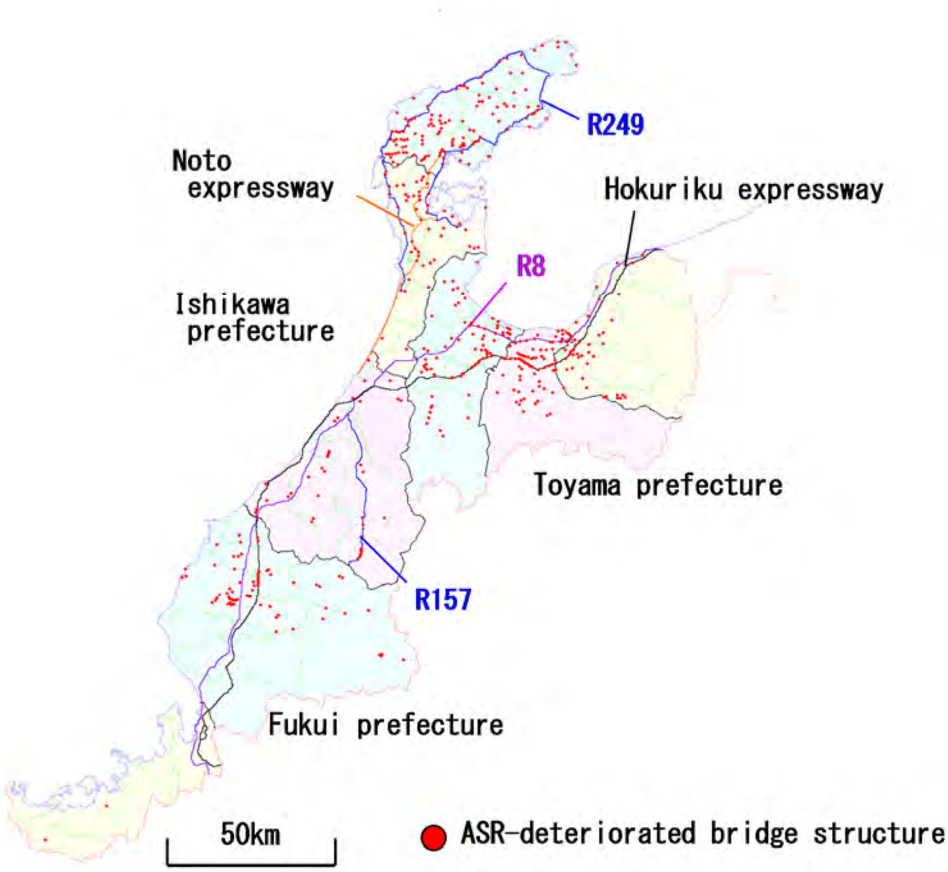

Figure 3. Distribution map of ASR deteriorated bridges in Hokuriku district.

Nowadays, some concrete plants in the Noto Peninsula are changing the aggregate to the limestone aggregates from the Niigata Prefecture. Furthermore, through a joint-collaborative effort with the Central Nippon Expressway Company, a lot of concrete cores were drilled from approximately 30 bridge piers or abutments in the Hokuriku Expressway, thus enabling the assessment of the degree of ASR deterioration of the structures in each area (Nomura et. al, 2012).

The results of ASR reactivity features of aggregates from river basins in the Hokuriku district has shown that particularly, the whole extension of the Joganji and Jinzu Rivers in Toyama Prefecture, the upstream of the Tedori River in the Ishikawa Prefecture and the Kuzuryu River in the Fukui Prefecture, all aggregates possess a very high ASR reactivity, and in some cases a pessimum content effect, because all these aggregates contain andesite particles with the opal and/or the cristobalite as a reactive component. As mentioned above, an excessive ASR expansion of concrete has led to a severe deterioration with the fracture of reinforcing steel bars and, particularly, in some bridges over the Jinzu River, the concrete bridge piers had to be completely demolished and rebuilt (Daidai et. al, 2008). In order to confront the widespread ASR deterioration of concrete structures in the Hokuriku district, the problem-solving approach have considered both, the repair and retrofitting of deteriorated structures in one hand, and the use of preventive countermeasures on the other hand.

3. Ineffectiveness of Japanese ASR Countermeasures (JIS A5308)

According to JIS A5308 for the ready-mixed concrete, the ASR countermeasures are as follows:

(1) Use the aggregate which are judged as "innocuous" based on the chemical method (JIS A1145) or the mortar bar method (JIS A1146)

(2) Set the total alkali content in concrete below 3kg/m^3

(3) Use the blended cements with the ASR suppression effect

However, the order of countermeasures proposed by both the Japan Society of Civil Engineers and the Architectural Institute of Japan slightly differs. In the recent case of RC building hall in Toyama city, the fine and coarse aggregates from the Jinzu River have been assessed as "Innocuous" and also the total alkali content of concrete has been kept below 3kg/m^3, presumably around 2.4kg/m^3, however the severe ASR occurs.

Similarly, based on the survey of ASR cases in East Japan Railways, there is an evidence of ineffective countermeasures against ASR, thereby they have adopted a new standard in the assessment of aggregates used in concrete. On the other hand, if ASR occurs in aggregate stones and rocks, and naturally, "if the place changes, the quality required also changes", then the regional deterioration phenomenon will be quite high. In terms of magnitude, the ASR problem is similar to the chloride attack, but in Japan it seems to persist a lack of awareness about this matter. It should be noted that JIS A 5308 standards and countermeasures cannot uniformly be applicable nationwide. When looking into the ASR countermeasures, especially in relation to (1), there are certain details that are overemphasized regarding the chemical method (JIS A1145), but the fact that the aggregate is merely judged as "innocuous" or "not innocuous", offers little meaning in terms of engineering. In the case of ASTM C289, it is clearly stated the rocks types such as the lime stone and the stone which contain clay mineral that cannot be appropriately assessed with the chemical method, but why this is done, we forget to inquire. In relation to (2), not only the influence of alkalis from the external environment and within the aggregates is not considered, but also the appropriateness of the regulation on the total alkali content has not been reexamined. Even in the Hokuriku district, where has been confirmed that differences on the rock types, the degree of ASR reactivity varies depending on the riverbeds, naturally, it is difficult to accurately assess ASR reactivity of these aggregates only with the resort of the chemical method (JIS A1145). Especially, with such a highly reactive aggregates from the Jouganji River and Jinzu River which contain the andesite particle with the opal and/or the cristobalite as a reactive component, even if the maximum alkali content of concrete is observed, there is a strong possibility that

ASR will occur. Therefore, the countermeasures (1) and (2) should be considered for revision, while the countermeasure (3) seems to be the most effective one in the Hokuriku District. That is to say, when the reliability of the ASR test method and the variation of rock types in the aggregate mixture are considered, a countermeasure which supposes the possible presence of highly reactive rocks in the mixture is necessary. In the Hokuriku district, it translates into anything less than "Standardizing" the use of blended cements in concrete.

4. Necessities for Using Fly Ash in Concrete

With the introduction of a green purchase system by the Ministry of Land, Infrastructure, Transport and Tourism and other organizations, the blast furnace cement type B, which is one of most available blended cements, has increased up to 23 % of the whole share of cement materials. However, the production of blast furnace slug powder is limited to the national capital suburban areas, Tokyo, Osaka, Nagoya, Kitakyushu etc., but its production is completely non-existent in the Sea of Japan region. In addition, as for silica fume cement, from the results of ASR countermeasures in Iceland, it is reported that only the 5% replacement ratio is required for ASR suppression effect, but from the relationship of supply and cost, as the entire quantity would have to be imported, the use of this cement is limited to the high strength concrete of more than 100 N/mm^2. In this regard, from the viewpoint of effective utilization of available resources in the Sea of Japan region, the use of fly ash should be strongly encouraged.

Actually, even in the Akita prefecture, the northeast district of the Sea of Japan region, the ongoing application of locally produced fly ash has been reported. The common catch phrases used are "Local Production for Local Consumption" and "Reduction of Environmental Impact".

In the 2011 Tohoku Great Earthquake and Tsunami disaster, there was a lot of the human life loss, together with bridges and buildings near the seashore being destroyed and washed away by giant tsunami waves. Until now, a feeling of "Resentment" has held us back about the limits of civil engineering works and disaster prevention technology. Afterwards, most of nuclear power plants have been shut down, and there is no plan in sight for their immediate operation. In the Hokuriku district, in the summer of this year, approximately half of the electricity supplied was generated by coal burning power plants. Setting apart the argument of natural renewable energy, for the time being, it is reasonable to consider that we will rely on the abundant coal reserves to meet our energy needs. In this case, also the topic of processing and the effective utilization of coal ash in cement production becomes an impending subject. Simultaneously, based on the prevailing social situation, where the reduction of general public construction works is negatively affecting the production output of cements containing coal ashes in raw materials, right now, the ability and intention of using fly ash in concrete is called into question. Until recently, the use of fly ash in concrete has been kept at a very low level, around 2 %. On the other hand, in Europe, as shown in the Figure 4, fly ash is used as a

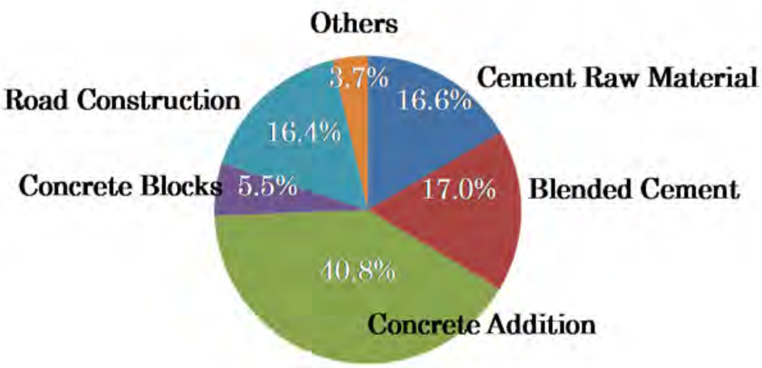

Figure 4. Utilisation of fly ash in the construction industry and underground mining in Europe (EU 15) in 2016.

cement binder and a concrete admixture with a proportion of about 60%. "Why has fly ash been so sparingly used in Japanese concrete?" The answer is very clear, if we look into the large quality variation of fly ash in chemical compositions and fineness, largely due to the influence of the type of raw coal material, the type of boiler, its burning temperature, etc. Concrete manufacturers mentioned especially, the day-to-day fluctuations of residual carbon quantity as the major cause of the instability of the air content in concrete, thus refraining from using the fly ash concrete. In order to solve this problem, first, it is necessary to eliminate the "Trauma" for the concrete manufacturer and then restore the reliability and credibility of the fly ash in concrete. This is the confidence of the first author based on the experience of concrete engineers over the last 40 years.

5. Supply System and Quality Assurance of Fly Ash

In January 2011, a joint-collaborative industry-academia-government research committee on the "promotion of effective utilization of fly ash concrete in the Hokuriku district" was set up. It has started the standardization of the use of fly ash concrete and consultations on the definition of a sustainable and effective supply system in the Hokuriku district. The location map of coal burning power plants currently operational in the Hokuriku district is shown in Figure 5. In Toyama, Ishikawa and Fukui prefectures, there is a coal burning power plant respectively, but those from where good quality fly ashes can be steadily supplied, judged from relationship between the type of boiler and its burning temperature, are the Nanao-Ohta thermal power plant in Ishikawa prefecture and the Tsuruga thermal power plant in Fukui prefecture. For this reason, it has been decided that both Toyama and Ishikawa prefectures have been supplied from the Nanao-Ota thermal power plant, while the Fukui prefecture will be supplied from the Tsuruga thermal power plant in September 2012, thus covering all the entire Hokuriku district area, through the distribution terminals suitably located. Furthermore, at the following stage, the fly ash will be directly transported to the cement factories at the Niigata prefecture, Itoigawa city and the Fukui prefecture, Tsuruga city, for the production of fly ash type B cement, as the supplying system is being taken under consideration. When this system becomes operational, it is expected that cement transportation costs within the designated area can be largely reduced, including other advantages.

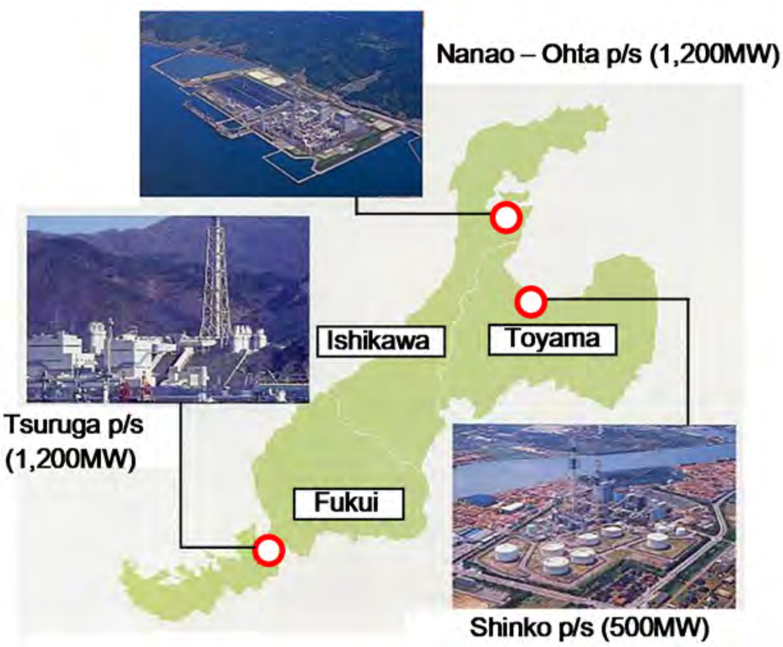

Figure 5. Location map of coal burning power plants currently operational in Hokuriku district.

On the other hand, in regard to the quality assurance of fly ash, the small variations in the physical and chemical properties can significantly improve the pozzolanic activity of fly ash itself. As shown in Figure 6, two determinant factors for this achievement at Nanao-Ohta thermal power plant in the Ishikawa prefecture, have been the use of only bituminous coal as raw materials imported from mainly Australia, and the introduction of grading and collection process in the cyclone, pulverized coal separator, perfected by a technology that leads to a very high-quality fly ash production. About 30,000 tons of fly ash can be produced per year in the Nanao-Ohta thermal power plants. Figure 7 shows the size and shape of fly ash particles. As can be seen, this high quality fly ash consists mainly of spherical and uniform particles with the average particle size of about 8 μm, where those deformed, ill-shaped particles containing many voids are not observed. In addition, the mineral compositions of this type fly ash can also be significantly improved in the process of production of fine particles: the glassy phases of fly ash are increased since the crystal phases such as quartz, hematite and mullite are reduced compared with the original raw fly ash, as presented in Table 1. Concerning the quality improvement of the fly ash, amongst other properties, the ignition loss is almost

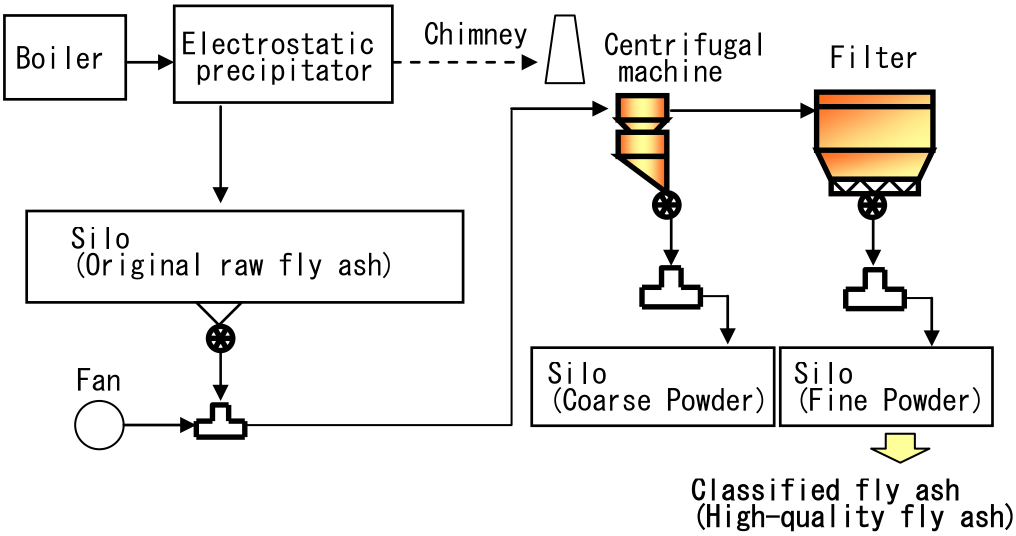

Figure 6. Production process of classified fly ash in Nanao-Ohta coal burning power plant in Ishikawa Prefecture.

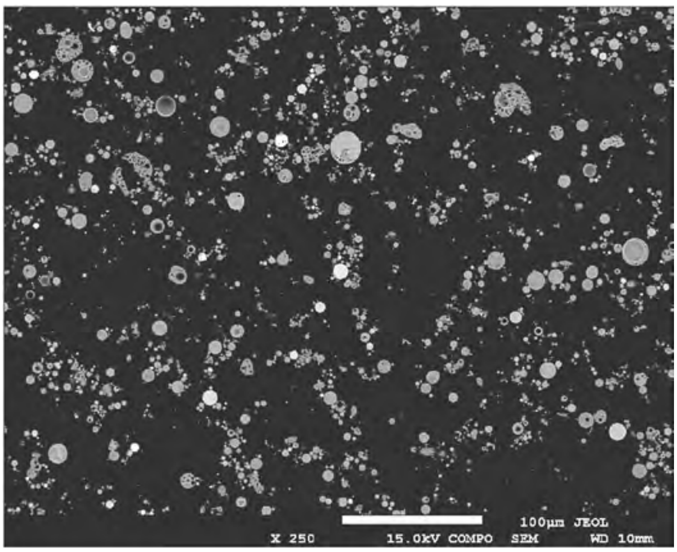

Figure 7. Microscopic photograph of the clsssified fly ash particles. (Scale:100μm)

Table 1. Physical and mineralogical properties of classified fly ash.

Fly ash type	Physical properties		Mineralogical properties(%)				
	Density (g/cm^3)	Blaine fineness (cm^2/g)	Quartz	Mullite	Magnetite	Lime	Glass
Original	2.36	3390	5.4	26.7	2.0	0.8	65.1
High-quality	2.43	4780	5.0	20.6	1.0	0.2	73.2

constant below 2 %, the activity index of fly ash mortar is increased to over 90 % at 28 days and over 100% at 91 days aged, thus fulfilling the requirement of the JIS A6201 type I requirement. Furthermore, the same equipment for the production of similar high-quality type of fly ash is scheduled for installation at the summer 2012, at the Tsuruga thermal power plant in Fukui prefecture. Therefore, it has been possible to supply the entire Fukui prefecture with additional 30,000 tons of this high-quality fly ash per year.

6. Advantages of Fly Ash Concrete

The fly ash concrete is certified for a service life that can span from 50 years to over 100 years, and the local area communities can be supplied with a highly durable concrete structure. First of all, aiming at the popularization of fly ash concrete, four representative concrete plants from the Toyama and Ishikawa prefectures were selected for the production of 27N/mm^2 class concrete using their standard mix proportion. Crushed aggregates, chemical admixtures and 15% fly ash replacement from the Nanao-Ohta thermal power plant were used in the preparation of the trial mixes for subsequent laboratory tests. The results showed that: (1) the unit water content of concrete could be reduced by about 5 kg/m^3, thus the little bleeding and segregation, (2) at 28 days, the compressive strength of fly ash concrete is almost similar to those of OPC and BFS concretes, but at 56 days, the strength of fly ash concrete exceeded them. Based on these trial mix results from JIS certified ready-mix concrete factories, the construction tests for retaining wall have begun in collaboration with local construction companies. At the same time, various experiments were simultaneously carried out at Kanazawa University and Kanazawa Institute of Technology, namely, the ASR suppression effect, chloride penetration and steel corrosion reduction effects, cracking resistance due to heat of hydration and dry shrinkage etc., leading to the establishment of a fundamental engineering database. Concerning the ASR suppression effect by fly ash, Figures 8 and 9 show the results of the accelerated mortar tests of specimens using the river gravel from Jouganji River in Toyama prefecture, which is considered to be the most reactive one in our country. In JIS A1146 mortar bar test, OPC and BFS 42 % mortars expanded with the curing time to a significant extent since FA 15 % mortar did not expand at all. Furthermore, in Danish test immersed in saturated NaCl solution at 50°C, the mortar bars without fly ash expanded considerably, but little in FA15% mortar, it became clear that the ASR expansion of mortars was controlled over a long term by using the high-quality fly ash. Figure 10 shows the thin section of mortars after JIS A1146 mortar bar test.

In addition, there are a lot of PC bridge girders and PCa element production companies in the Hokuriku district. Accordingly, it has become a new widespread problem, the occurrence of ASR-related cracking in PC girder beams and PCa elements (Torii et. al, 2011). Because in the PC bridges and PCa elements, high strength concrete of 40 N/mm^2 or 50 N/mm^2 with the steam or autoclave curing is executed, a different set of ASR countermeasures should be adopted, to those related to the ready-mixed concrete factories. Currently, a collaborative research work among the local companies has just started the investigation on the manufacturing technology and the performance evaluation of PC beams and PCa elements made with fly ash concrete. Therefore, the creativity and enthusiasm of all parts involved, raises no doubt that the prospects of engineering development in the field of fly ash concrete and the activation of the local concrete industry in the Hokuriku district are good.

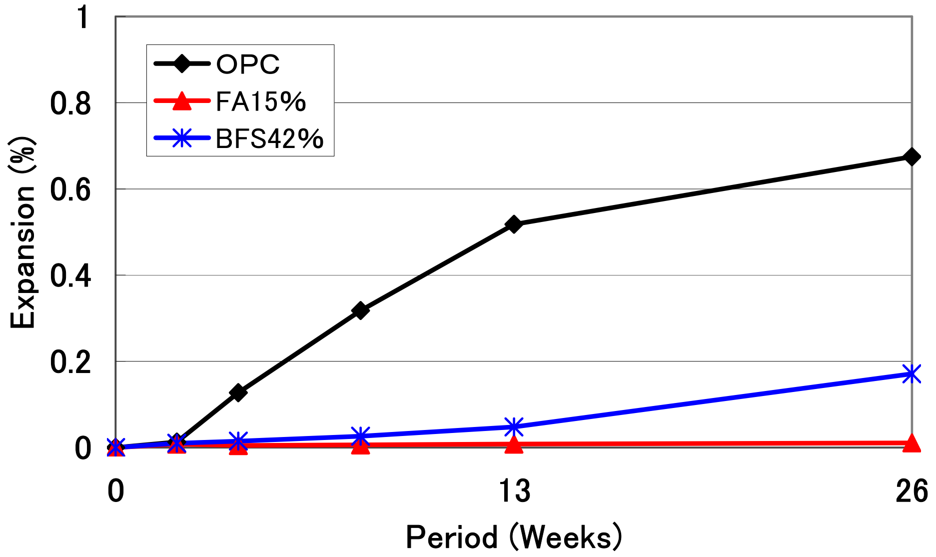

Figure 8. Expansion behaviors of OPC, BFS 42% and FA 15 % mortars in JIS A1146 method.

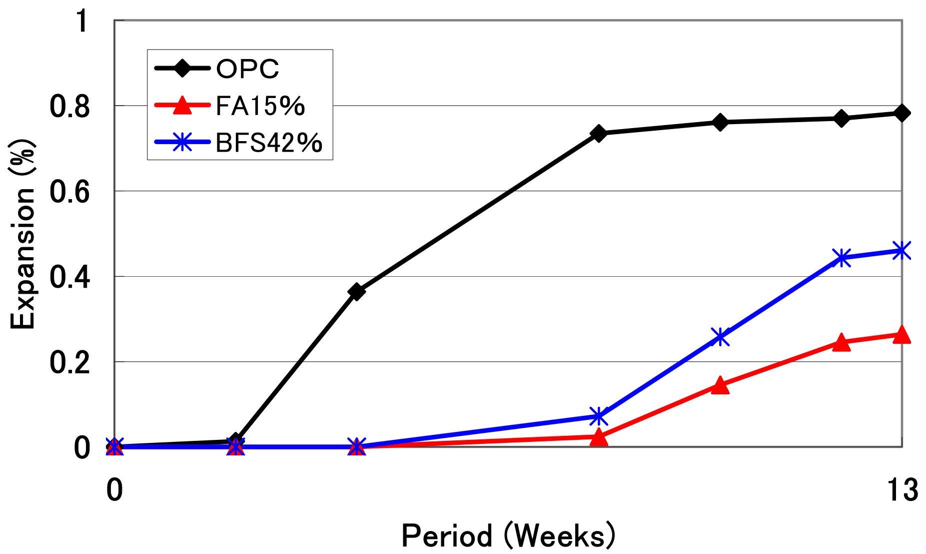

Figure 9. Expansion behaviors of OPC, BFS 42% and FA 15 % mortars in Danish method.

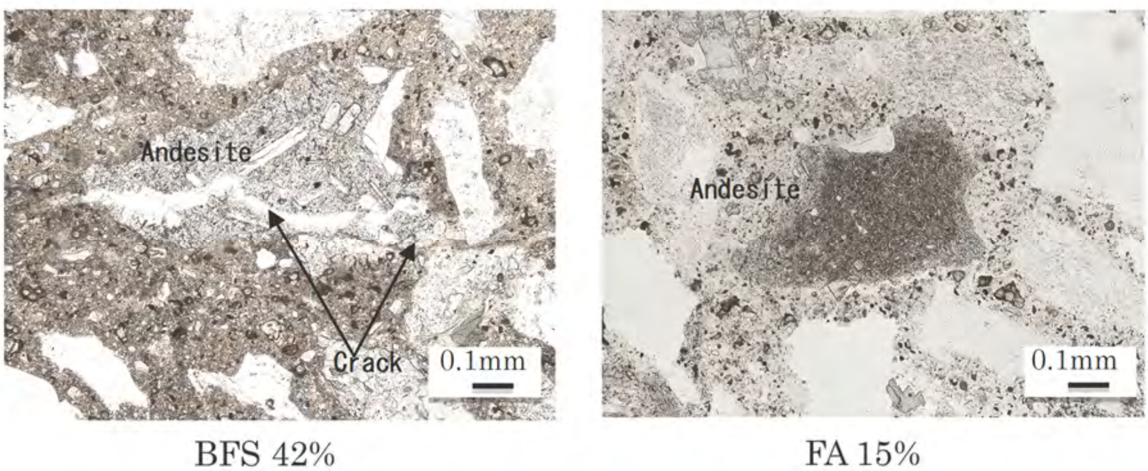

Figure 10. Petrographic observations of thin sections of mortars after JIS A1146 mortar bar test. (Polarizing microscope in plane-polarized light)

7. Successful Use of Fly Ash Concretes in Precast PC Electrical Poles in Hokuriku Electric Power Company

Electrical concrete poles are prestressed concrete (PC) manufactured using centrifugal moulding in precast concrete (PCa) factories. These poles are normally circularly shaped PC with strength of more than 70 N/mm^2. Recently it has been found throughout Japan that large vertical cracks may occur on the surfaces of these poles near the ground within 10 years after installation. Figure 11 shows examples of vertical cracks generated in a tension-type PC electric pole. Crack widths varied from about 0.2 mm to several mm, and the cracks progress upward from near the base of the utility pole. Furthermore, these vertical cracks tend to occur in pairs on opposite sides of the circumference. These cracks reach to the interior prestressing steel wires leaving them severely corroded. The cause of these cracks was investigated in sample segments cut from the poles. Figure 12 shows the results of the ASR gel fluorescence test (Sannoh et. al, 2013) using concrete fragments collected from electrical PC poles exhibiting vertical cracks. From the photograph, it was found that the fine aggregates of some volcanic rock types were intensely generating ASR especially in the interior of PC pole columns in the hollow cross sections. In addition, 20μm thick sections incluing fine aggregates showing a strong reaction to the gel fluorescence method were observed with a polarized light microscope. One example is shown in Figure 13. As a result of the observation of large numbers of concrete slices, it was determined that the andesite and rhyolitic welded tuffs contained in the fine aggregate which contained andesitic river sands and gravels generated ASR.

Furthermore, as an effective mitigation

Figure 11. Photograph of an external appearance of vertical cracks.

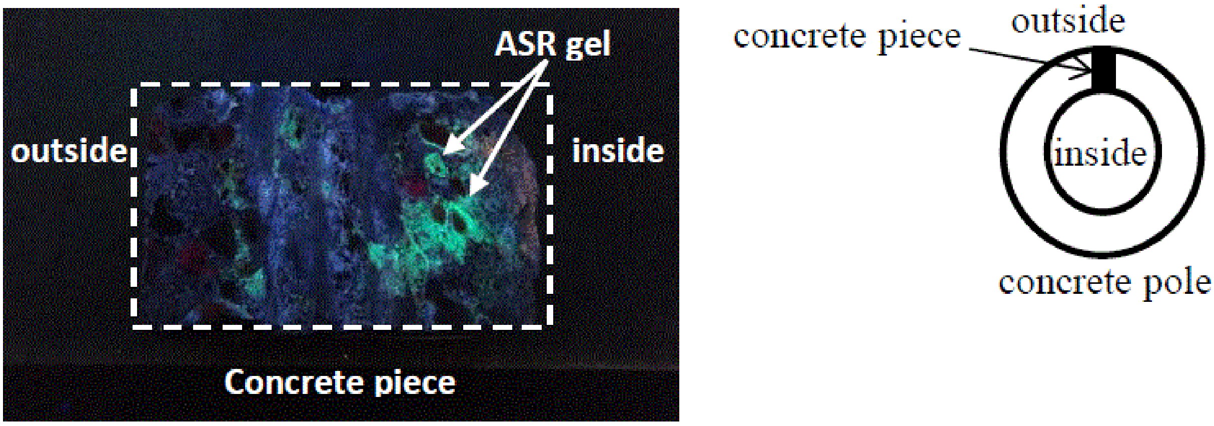

Figure 12. Results of Gel Fluorescence Method.

countermeasure to control ASR expansion, 15% replacement of high early-strength OPC with fine fly ash was tested. The accelerated mortar bar test results are shown in Figure 14. From this figure, in the cases in which fine fly ash was not mixed, it was judged that the aggregate from the Jinzu River is not unaffected, whereas the aggregate from the Kurobe River was "unclear." However, when 15% fine fly ash was used it was found that sufficient ASR mitigation was obtained. The accelerated concrete prism test results are shown in Figure 15. As can be seen from the figure, even in the concrete mixtures utilizing 15% fine fly ash for the tension type PC electric poles, sufficient ASR mitigation was obtained. Therefore, it has been confirmed that utilizing fine fly ash as a measure against ASR is effective for improving the durability of the PC pole column itself when new PC poles are produced. In response to these results, about 6,000 electrical concrete poles have been manufactured annually using fly ash concrete in the Hokuriku district from April 2016. Figures 16 show the part of the manufacturing process of the Precast PC Electrical Poles.

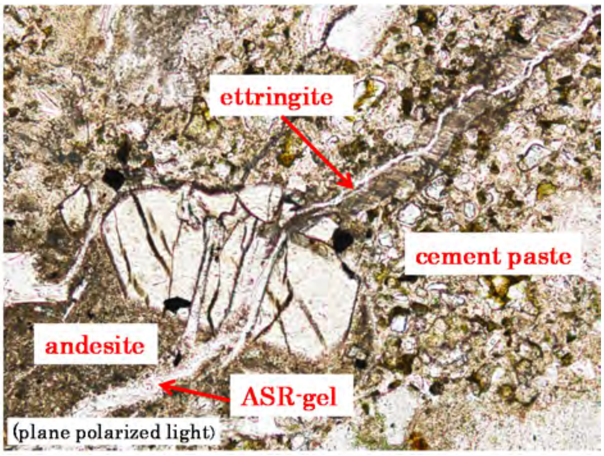

Figure 13. Observation results of concrete pieces.

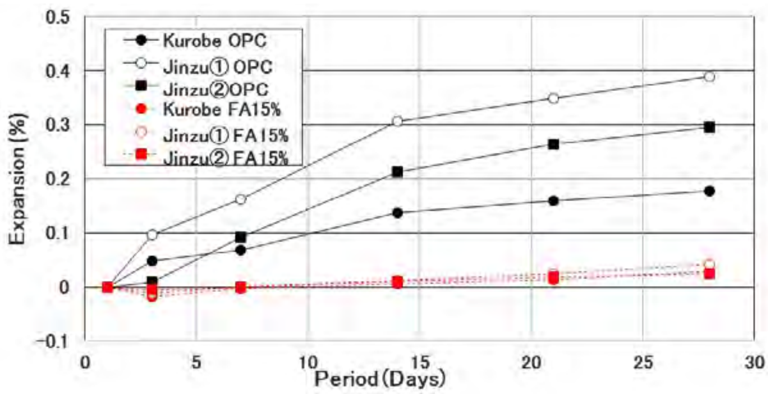

Figure 14. Accelerated mortar bar test result.

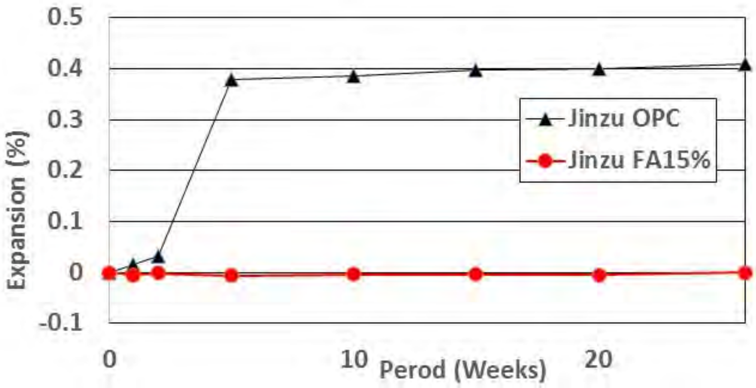

Figure 15. Result of accelerated concrete prism test.

8. CONCLUSIONS

In the Hokuriku district, the efforts toward the production of highly durable concrete mixture using classified fine fly ash from the Nanao-Ohta and Tsuruga coal-burning power plant has been continued. At a present time when ASR deterioration phenomena are still progressing in some areas in the Toyama and Ishikawa Prefecture after the JIS A5308 ASR countermeasures in 1989, the use of fly ash concrete is the most recommended in order to solve the ASR or chloride attack problem. Fortunately, in January 2011, a joint-collaborative committee was set up. At present, a lot of trials for the target of actual use of fly ash concrete in bridges, buildings, and dam structures, etc., are actively ongoing. Figure 17 shows the concrete volume of structures using fly ash concrete in public works in the Hokuriku district. Furthermore, some examples of the structures are shown in Figures 18. As shown in the photograph, the use of fly ash is also expanding in construction such as the ongoing Hokuriku Shinkansen construction. We would like to propose the know-how for a further effective utilization of fly ash concrete in the Hokuriku District and other districts, based on the strong faith of “Local Production for Local Consumption” and “Reduction of Environmental Impact”.

16-1 Rebar preparation

16-2 Concrete insertion

16-3 Centrifugal molding

16-4 Formwork removal (upper side)

Figures 16-1 to 16-4. Part of the manufacturing process of the Precast PC Electrical Poles.

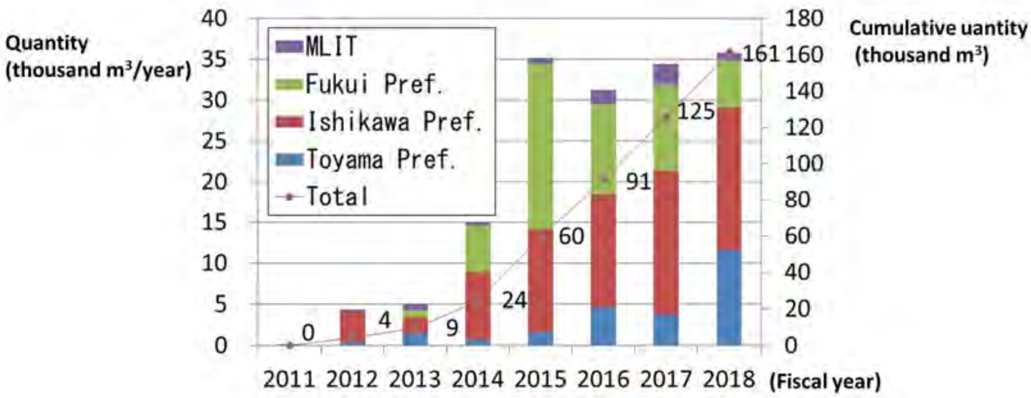

Figure 17. Concrete volume of structures using fly ash concrete in public works in the Hokuriku district.

18-1 Photograph of a box culvert in the public works

18-2 Photograph of an abutment in the public works

18-3 Photograph of the blocks in the public works

18-4 Photograph of a viaduct in the Hokuriku Shinkansen construction

Figures 18-1 to 18-4. The examples of the structures used fly ash concrete in the construction.

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