Study on the feasibility of FA-Sand premixed sand and fly-ash

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ABSTRACT

The authors propose blending of fly ash in fine aggregate beforehand as a method of adding fly ash to concrete. A supply of sand containing fly ash (hereafter referred to as FA sand) to concrete production plants eliminates the need for storage and batching equipment for fly ash.

The properties of FA sand and concrete containing FA sand were assessed by laboratory tests to confirm the feasibility of this method. Also, methods of measuring the proportion of fly ash in FA sand were investigated to explore quality control techniques for FA sand. The effect of fluctuations in the fly ash proportion on the measurement of the surface moisture content of FA sand and the qualities of resulting concrete were experimentally assessed as well. As a result, the fly ash proportion was found to be accurately measurable by the method of measuring the powder content. It was also found that fluctuations in the fly ash content scarcely affect the accuracy of surface moisture measurement and the qualities of concrete.

Keywords. fly ash, crushed sand, premixing, laboratory test, demonstration experiment

INTRODAUCTION

The percentage of crushed sand among other fine aggregate types has been increasing and is expected to increase, due to the recent depletion of good quality natural aggregate, including river sand and land sand, and the expansion of the area where sea sand extraction is prohibited. Crushed sand for concrete poses such problems as increases in the unit water content and reductions in the workability and pumpability of concrete due to its inadequate particle size and grading. To cope with these problems, methods of replacing part of crushed sand with fly ash have been proposed to improve the workability of concrete while fresh and its physical properties after hardening including strength. Nevertheless, the use of fly ash as a supplementary cementitious material (SCM) for concrete requires additional equipment investment, such as for special storage and batching equipment for fly ash. This is a major factor hampering the use of fly ash as a SCM for concrete.

This study intends to produce fine aggregate blended with fly ash beforehand (FA sand) and supply it to plants as premixed fine aggregate for concrete production. This method enables concrete plants to produce concrete containing fly ash as a SCM in a manner similar to normal concrete without the need to install special equipment for fly ash.

In this study, the authors produced FA sand and proportioned concrete containing FA sand, which was then subjected to tests to grasp its basic properties, to assess the applicability of FA sand. Methods of measuring the proportion of fly ash were also explored to investigate the quality control techniques for FA sand. The effect of fluctuations in the fly ash proportion on the qualities of concrete was experimentally assessed as well. The qualities of FA sand produced using actual equipment were then confirmed along with the qualities of concrete, demonstrating its high feasibility. This paper reports on the significance of this study and the results of laboratory tests and demonstration tests.

FEASIBILITY ASSESSMENT OF FA SAND

General. The feasibility of blending fly ash with crushed sand beforehand was to be confirmed by basic laboratory tests. The following items were checked:

(1)Check if FA sand can be treated in a manner similar to normal fine aggregate by examining the properties of crushed sand premixed with fly ash; (2)Check if premixing with fly ash adversely affects the qualities of concrete; (3)Check if the production conditions of FA sand adversely affect the qualities of concrete; (4)Examine the method of measuring the surface moisture content of FA sand; and (5)Examine the method of measuring the fly ash content of FA sand and grasp the effect of fluctuations in the fly ash content on the qualities of concrete.

Materials. Table 1. gives a list of the materials. Fly ash included classified and unclassified types produced at different power plants. The qualities of fly ash conform to Type II specified in JIS A 6201 (Fly ash). Aggregates were combinations of three types from different sources (aggregate 1 combining fine aggregate 1 and coarse aggregate 1, aggregate 2 combining fine aggregate 2 and coarse aggregate 2, and aggregate 3 combining fine aggregate 3 and coarse aggregate 3). Note that fine aggregate 3 was a blend of crushed sand and blast-furnace slag fine aggregate.

Production conditions of FA sand. A fly ash replacement ratio of 10% by mass of fine aggregate was adopted as a standard for FA sand, assuming the use of fly ash as a SCM in place of part of fine aggregate. FA sands with fly ash replacement ratios of 10% ±0, ± 1, ±2, and ± 3 percentage points were also selected to grasp the effect of fluctuations in the fly ash replacement ratio on the surface moisture measurement and concrete qualities.

To ensure uniform blending of fly ash, FA sand should be produced using batch-type blending equipment having a sufficient blending capacity, and the plant should have appropriate material storage facilities. From this aspect, the production facilities of FA sand are required as a rule to conform to JIS A 5308 (Ready-mixed concrete). A forced mixing-type concrete pan mixer with a capacity of 50 liters was therefore used for producing FA sand in this study. A mixing time equivalent to the case of mixing concrete was adopted from the aspect of ensuring the time required for achieving uniform blending of fly ash. Fine aggregate and fly ash were simultaneously fed into the mixer and mixed for 3 min. The surface moisture content of fine aggregate at the time of blending and the storage period after blending were set at around 3% and 1 - 3 days, respectively, except when these are varied as test factors. FA sand was stored in hermetic containers and handled in the same manner as unblended fine aggregate.

Table 1. Materials

Materials		Type	Specification
Cement C		Ordinary Portland Cement	density3.16g/cm^3
Fly-Ash F		FA1（Classified）	Density 2.30g/cm^3,ig.loss1.60%,$SiO_2$60.1% Blain specific surface area:3,800cm^2/g
		FA2（un-Classified）	Density 2.28g/cm^3,ig.loss0.90%,$SiO_2$56.6% Blain specific surface area:3,570cm^2/g
Sand S	①	Crushed Sand, Ibuki Shiga	density 2.65g/cm^3,absoption:0.88%
	②	Crushed Sand, Iejima Hyogo	Density 2.58g/cm^3,absorption:1.86%
	③	Crushed Sand, Iejima Hyogo	density 2.57g/cm^3,absorption:2.02%
		Blast Furnace Slag Sand	density 2.74g/cm^3,absorption:0.79%
Gravel G	①	Crushed Stone, Ibuki Shiga	maximum size 20mm, density 2.70g/cm^3
	②	crushed Stone, Iejima Hyogo	maximum size 20mm, density 2.63g/cm^3
Admixture		Super Plasticizer	Polycarboxylate Based

Applicability assessment. The slump and compressive strength of concrete were compared to confirm that premixing of fly ash does not adversely affect the performance of the resulting concrete. The test cases include (1) no fly ash; (2) simultaneous addition of sand and fly ash; and (3) FA sand. Table 2. gives the mixture proportions of concrete. W/C, slump, and air content (non-air-entrained) of 40%, 12 ± 2 cm, and 2 ± 1%, respectively, were adopted in consideration of application to concrete products. Concrete was basically proportioned under conditions excluding fly ash. When fly ash was to be added, the sand-aggregate ratio was reduced by 2 percentage points, with the other proportions left unchanged, in consideration of the increase in the powder content. All the materials were simultaneously fed into a 50-liter forced mixing-type pan mixer and mixed for 3 min.

Figure 1. shows the results of slump and compressive strength tests. Though the slump tendencies varied depending on the types of fine aggregate and fly ash, these are adjustable by the dosage of the air-entraining and high-range water-reducing admixture. On the other hand, the compressive strength of concrete containing FA sand turned out to be 3 to 8% higher than concrete in which fly ash was added at the time of mixing, regardless of the types of aggregate and fly ash. Therefore, instead of an adverse effect, premixing of fly ash with fine aggregate was found to have an effect of enhancing the strength of concrete.

Investigation into production conditions of FA sand. Tests were conducted to check if changes in the production conditions of FA sand adversely affect the qualities of the resulting concrete. In this study, the effects of the storage period after the production of FA sand (1 day to 1 month) and the surface moisture ratio (1 to 7%) on the slump and compressive strength were investigated. FA 1 and aggregate 3 were used as the fly ash and aggregate for test concrete, which was proportioned similarly to Table 1.

Table 2. Mixture Proportions

Sand	Addition method of fly-ash	Water Cement Ratio W/C,%	Sand-aggregate ratio s/a,%	Unit content , kg/m³					SP *C%
				Water W	Cement C	Fly Ash F	Sand S	Gravel G	
Sand ①	Without	40	38	155	388	—	707	1176	1.0
	at mixing		36			66	590	1213	
	Premixed					656 (FA sand)			
Sand ②	Without		40	170	425	—	697	1066	1.5
	at mixing		38			65	586	1101	
	Premixed					651 (FA sand)			
Sand ③	Without		40	170	425	—	717	1066	1.8
	at mixing		38			67	600	1101	
	Premixed					667 (FA sand)			

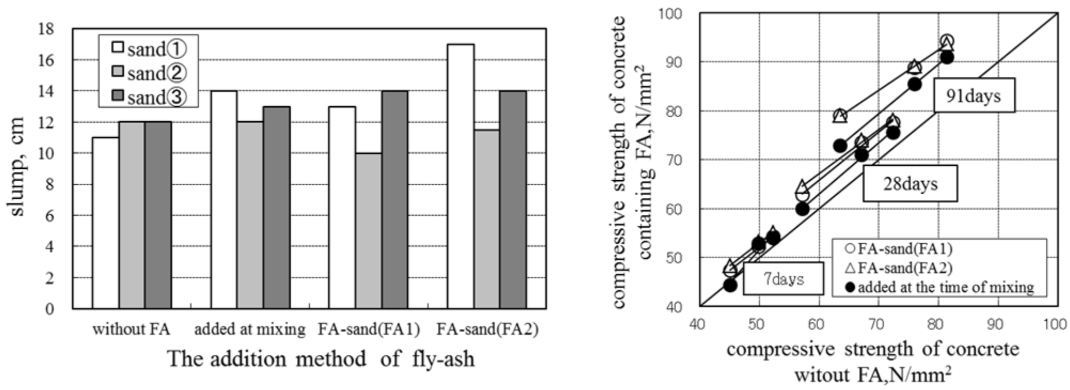

Figure 1. The results of slump tests and compressive strength tests

Figure 2. shows the effect of the storage terms and the surface moisture content of FA sand on the compressive strength. "Blending immediately before mixing" in this figure refers to a method with a change in the mixing sequence, in which fly ash is blended with fine aggregate immediately before adding the other materials. Though a slight difference in the compressive strength is observed at 7 days, FA sand leads to uniformly higher strength at 28 days than the case of simultaneous addition, being scarcely affected by the storage period. Meanwhile, "blending immediately before mixing" and "simultaneous addition" led to nearly the same strength.

FA sand generally leads to higher compressive strength than the case of "simultaneous addition" regardless of the surface moisture content, though with a slight scatter. It is therefore inferred that the normal surface moisture content in the range of 1 to 7% scarcely affects the compressive strength.

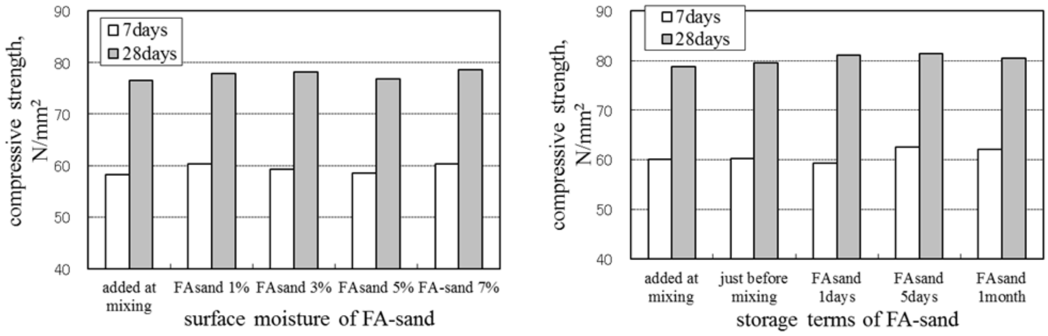

Figure 2. Influence of storage term and surface moisture on compressive strength

Investigation into the production control method for FA sand

(1) Investigation into the method of measuring surface moisture content

The applicability of the oven drying method and volumetric method (JIS A 1210), which are generally used for measuring the surface moisture content of fine aggregate, was examined. Judgment of the saturated surface dry condition using a flow cone was expected to be difficult, due to the high powder content of FA sand containing fly ash when compared with general fine aggregate. For this reason, it was decided to calculate the surface moisture content and water absorption from the water absorption of fine aggregate and the proportion of fly ash. Tests were conducted using fine aggregate 3.

Figure 3. shows the results of comparison between the surface moisture measurements by the oven drying method and volumetric method. Measurements by both methods nearly agreed, though the tests were conducted on single samples.

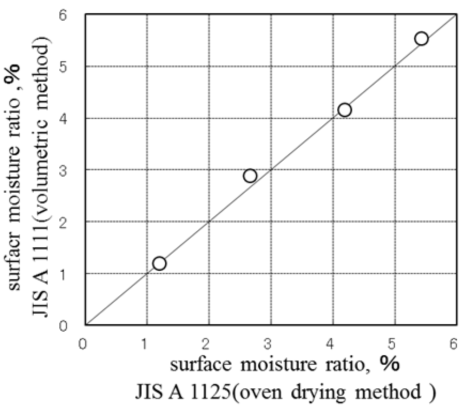

Figure 3. Comparison between the surface moisture measurements by the oven drying method and volumetric method

(2) Investigation into the method of measuring the proportion of fly ash

The surface moisture content and the proportion of fly ash were measured as quality assessment tests on FA sand. The proportion of fly ash was determined by measuring the powder content of FA sand by the method of measuring the powder content of aggregate in accordance with JIS A 1103 and subtracting the powder contents of crushed sand and blast-furnace slag fine aggregate.

Figure 4. shows the results of comparison between the specified and measured proportions of fly ash in FA sand. As shown in the figure, their difference is around 0.5% at the maximum. It can therefore be said that the proportion of fly ash is accurately measurable by the method of measuring the powder content of aggregate specified in JIS A 1103. These results also suggest that FA sand retains its uniform condition without segregation between fly ash and fine aggregate during handling. Due to the above-mentioned difficulty of measuring the physical properties of FA sand as a whole, the quality control of FA sand should be basically carried out by quality control of fine aggregate and fly ash as the materials and batching control of the materials at the time of production. However, confirmation of the retention of the specified fly ash proportion is sufficiently feasible after the production of FA sand by measurement of the powder content.

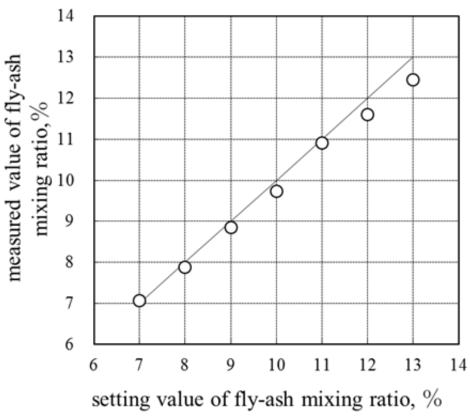

Figure 4. Setting value versus measured value of fly-ash mixing ratio of FASand

(3) Effect of fluctuations in the proportion of fly ash on the performance of concrete

The slump and compressive strength of concretes with the specified fly ash proportion ±0, ±1, ±2, and ±3 percentage points were compared to grasp the effect of fluctuations in the fly ash proportion on the measurement of surface moisture content and the qualities of concrete.

Figure 5. shows the effects of fluctuations in the fly ash proportion on the slump and air content.

The slump tends to increase as the fly ash proportion decreases and decrease as the fly ash proportion increases. However, the variation range of the slump is as small as 1 cm at the maximum, posing no practical problem. As to air-entrained concrete proportioned for ready-mixed concrete (RMC), the air content tends to decrease as the fly ash proportion increases, but the differences are small. As to concrete proportioned for concrete products, fluctuations in the fly ash proportion scarcely affect the air content. It can therefore be said that changes in the fly ash proportion to ±3 percentage points scarcely affect the properties of the resulting fresh concrete.

Figure 6. shows the effects of fluctuations in the fly ash proportion on the compressive strength of concretes proportioned for RMC and concrete products. As seen from the figures, the compressive strength tends to increase as the fly ash proportion increases, but the

differences are marginal. This is because a higher fly ash proportion increases the powder content and binder content, but this effect is not significantly large, presumably because the cement content is kept constant.

Note that no appreciable differences were observed between FA sand and conventional simultaneous addition of fly ash and fine aggregate, in regard to both the fresh concrete properties and compressive strength. Therefore, the use of FA sand has no adverse effects on the qualities of concrete

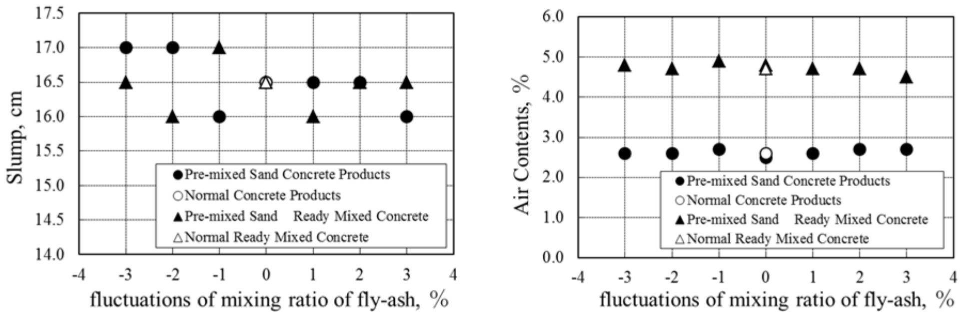

Figure 5. Relationship between fluctuation of mixing ratio of fly-ash and slump, air contents

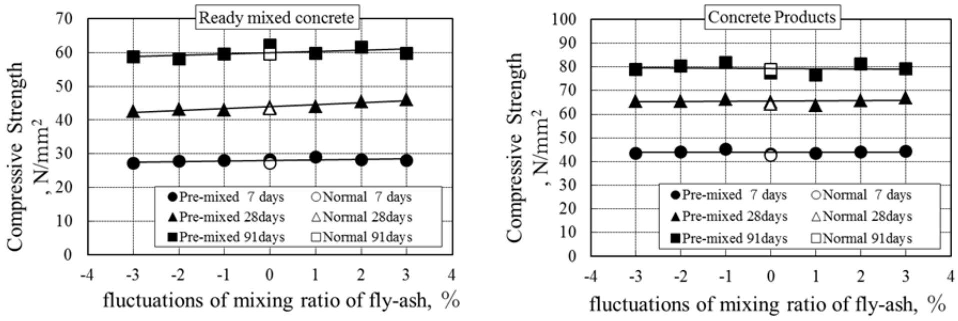

Figure 6. Relationship between fluctuation of mixing ratio of fly-ash and compressive strength

DEMONSTRATION EXPERIMENT

General. Tests were conducted using actual equipment to check the feasibility of production on a practical basis, while extracting problems to be solved for putting FA sand into practical use. The following points were checked:

(1) Check if fine aggregate and fly ash can be uniformly blended and if FA sand having the required qualities can be produced using an actual plant. (2) Check the degree of segregation, scatter, etc. during transportation by dump truck. (3) Check if it is possible to handle FA in the same manner as normal fine aggregate and produce concrete using an actual plant.

Investigation into production facilities for FA sand. A concrete mixer was used to achieve uniform blending of fly ash in the laboratory tests. While FA sand is intended to be handled as fine aggregate, fly ash blended in FA sand is normally regarded as a supplementary cementitious material. For this reason, batching errors for fly ash content are required to be within the specified range, and uniform blending of fly ash at the specified proportion is important. From this aspect, the authors considered it necessary to blend FA sand batch by batch instead of performing continuous blending and use high-capacity blending equipment. Based on the investigation, it was decided to produce FA sand using a concrete production plant (Plant).

Experiment overview.

(1) Materials

Tables 3. gives a list of materials. The fly ash, which was an unclassified type, was generated from the same power plant as fly ash FA2 used in the laboratory tests. The other materials were those normally used at the plant.

Table 3. Materials

Materials		Type	Specification
Cement C		Ordinary Portland Cement	density3.16g/cm^3
Fly-Ash F		FA2（un-Classification）	density 2.34g/cm^3 Ig.loss0.50%,$SiO_2$51.4% Blain specific surface area:4,130cm^2/g
Sand S	S1	Crushed Sand, Iejima Hyogo	density 2.58g/cm^3,bsorption:1.95%
	S2	Blast Furnance Slag Sand	density 2.78g/cm^3,absorption:1.86%
Gravel G		Crushed Stone Iejima Hyogo	maximum size 20mm, density 2.63g/cm^3
Admixture		Super Plasticizer	Polycarboxylate Based

(2) Description of the Plant

The experiment was carried out at a JIS-accredited RMC plant located in Kishiwada City, Osaka Prefecture. The concrete mixer was a 2.25 m^3 forced mixing-type pan mixer with a capacity of 135 m^3/h.

(3) Production conditions for FA sand

Two types of fine aggregates are blended for concrete production in many plants, including the present Plant, to adjust the grading. In such a case, FA sand is supposed to replace one of the two fine aggregates. It is therefore necessary to set the fly ash proportion of FA sand at a higher level in consideration of the fly ash replacement ratio to the total amount of fine aggregate. From this aspect, fly ash was blended only with crushed sand S1 at a ratio of 20%, which is slightly higher than in the laboratory tests. The batch size was 2 tons, and 6 tons of FA sand was produced in 3 batches. The blending time was 60 sec, referring to the concrete mixing time of 45 sec in this Plant. A target surface moisture content of 5% was adopted for crushed sand at the time of blending fly ash based on the laboratory test results. According to measurements, the surface moisture content was adjusted by adding water to achieve the target. FA sand was produced one day before the production of concrete.

(4) Proportioning of concrete

Table 4. gives the mixture proportions of concrete. Concrete was produced in three ways: (1) with no fly ash; (2) by simultaneous addition of fly ash and fine aggregate; and (3) with FA sand. In consideration of application to concrete products, the concretes were proportioned with a W/C of 45% and target slump and air content of 15 ± 2 cm and 2 ± 1 %, respectively (non-air-entrained concrete). The unit water content and sand-aggregate ratio were kept constant regardless of the inclusion of fly ash, and the dosage of the air-entraining and high-range water-reducing admixture was adjusted to attain the required slump.

Table 4. Mixture Proportions

Addition method of fly-ash	Water Cement Ratio W/C, %	Sand-aggregate ratio s/a, %	Unit content , kg/m^3						SP *C%
			Water W	Cement C	Fly Ash F	Sand S1	Sand S2	Gravel G	
Without	45	45.2	175	389	—	556	257	984	1.8
at mixing					108	433			1.2
Premixed					667 (FA sand)				

(5) Mixing of concrete

All the materials were fed into the mixer at a time and then mixed for 45 sec. The batch size was 0.75 m^3. Two batches of each mixture of concrete, 1.5 m^3, were produced. As-mixed concrete was loaded into an agitating truck, sampled by a normal method, and subjected to tests to confirm its fresh properties (slump and air content) and compressive strength.

Test results.

(1) Production, Transportation and conveyance of FA sand

Photograph 1. shows the state of loading FA sand onto a dump truck. No lump of fly ash was found by visual observation, demonstrating uniform blending of fly ash. Discharge from the mixer and hopper was also carried out without any problem.

In order to examine the degree of segregation and scatter during transportation by dump truck, FA sand was conveyed on an ordinary road for around 1 hour with simple sheet covering. Photograph 1. shows the state of FA sand after transportation. Drying was limited to the surface, while no scatter or segregation was observed. The FA sand was then conveyed into an aggregate storage facility (Photograph 1.) and transferred into a storage bin of the Plant. This was done by a belt conveyer without any problem.

(loading) **(after conveyance)** **(dumping)**

Photograph 1. Loading, conveyance and dumping of FAsand

(2) Production of concrete and its qualities

The FA sand, which had been sent to a storage bin on the day before concrete production, was conveyed into a batching tank, batched, and fed into the mixer without any problem. Table 5. gives a list of the results of tests on the resulting concrete. Its properties and qualities were proven to be satisfactory, though the test items were limited to basic qualities..

Table 5. The results of tests

Addition Method of fly-ash	Concrete Temperature ,℃	Slump ,cm	Air Content ,%	Compressive Strength, N/mm^2	
				7days	28days
Without	26.5	15.0	2.5	41.4	56.1
at mixing	26.0	13.0	2.6	43.0	60.0
Premixed	27.0	17.0	2.8	43.2	58.4

SUMMARY

The authors proposed premixing of fly ash with fine aggregate to enable concrete production plants to produce concrete containing fly ash as a supplementary cementitious material without the need to install special equipment for fly ash. Laboratory tests and demonstration tests were conducted to establish methods of producing FA sand and concrete made using FA sand, and confirmed the qualities of concrete made using FA sand. These tests demonstrated that this approach is highly feasible from the technical aspect.

Since premixing of fly ash with fine aggregate is unconventional, it naturally does not conform to existing standards, which are premised on batching and mixing of fly ash at the time of concrete production. In order to put the present method into practical use, sufficient data accumulation is essential. Assessment tests are underway on the physical properties and long-term durability of concrete made using FA sand, as well as on the scatters of the fly ash proportion and quality of FA sand. The results of these tests are to be reported later.

The authors intend to continue data accumulation to make this technique promote the effective use of fly ash and contribute to enhancement of the performance of concrete structures.

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