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Expanding the Use of Fly Ash as an Admixture in Concrete in Vietnam

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To bolster the drive for economic and social development in Vietnam, 31 coal-fired power plants were constructed to meet the demand for electricity. According to a survey by the Ministry of Natural Resources and Environment, approximately 20.5 million tons of coal ash will be generated in 2020. A part of the generated coal ash was recycled as landfill; however, the rest lies unused or discarded, causing serious environmental pollution. Since fly ash (FA) forms a major component of coal ash, it is necessary to establish methods for the safe, continuous, and effective use of FA. This study compared the Vietnamese National Standards with the Japanese Industrial Standards from the perspective of using FA as an admixture in concrete. Japanese FA was used in the experiments. Consequently, by using suitable amounts of chemical admixtures and adjusting the ratio of FA as a cement replacement and as a fine aggregate replacement, structural concrete can be manufactured, and the required quality can be assured.

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1 Introduction

Coal ash is primarily produced from the burning of coal in coal-fired power plants. The major components of coal ash are fly and bottom ashes. Presently, thermal power to is one of the essential sources of electricity production in the world. Consequently, a large amount of coal ash is discharged from thermal power plants every year. If coal ash can be reused as a recycled resource, it will create many economic benefits as well as reduce negative impacts on the environment. The reuse of coal ash can reduce greenhouse gas emissions and the amount of disposing in landfills, which causes the pollution of land and water. Moreover, the reuse of coal ash also reduces treatment costs, promote production, and create better quality products and materials that bring economic benefits. Recently, with the development of science and technology, the components of coal ash have been used as recycled resources in many applications such as cement production materials, and concrete admixtures.

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In Vietnam, 31 coal-fired power plants were constructed to meet the electricity demand, which in turn would boost the economic and social development of the country. In 2020, the amount of coal ash generation is expected to be approximately 20.5 million tons [1]. The disposal of this coal ash poses a challenge as only a part of the coal ash has been recycled as landfill; the rest lies unused or discarded, leading to serious environmental pollution. A major component of coal ash is fly ash (FA). In the future, it will be necessary to establish a safe, continuous, and effective method to use FA, thereby aiding in the safe disposal of coal ash.

Against this background, in this study, the Vietnamese National Standards were compared with the Japanese Industrial Standards for expanding the use of FA as an admixture in concrete by adopting the most suitable application method for FA. Experiments were conducted using Japanese FA.

2 Fly ash in Vietnam

2.1 Conditions of fly ash in Vietnam

In Vietnam, TCVN 10302:2014 [2] prescribes regulations for the use of FA as an admixture for manufacturing cement. Based on the calcium oxide content, FA is classified as two types, namely, alkaline (C) type and acidic (F) type. The application range of FA is divided into four: type a for concrete structures, type b for unreinforced concrete and mortar, type c for porous concrete, and type d for concrete and reinforced concrete under special conditions.

2.2 Properties of fly ash in Vietnam

As an example, Table 1 lists the properties of FA at the Uong Bi Thermal Power in Vietnam and the specified values of F-a in TCVN 10302:2014 [2]. Compared to FA type II (FAII) in the Japanese Industrial Standard JIS A 6201 (Fly ash for use in concrete), the values of the FA from the power plant are in the regulated range. Therefore, experiments were conducted for Japanese FAII.

3 Outline of experiment

3.1 Material

3.1.1 Cement and admixture

Table 2 lists the specifications of Japanese Portland cement (N, JIS R 5210) and FAII that were used in the experiments. Compared to Portland cement in Vietnam National Standard TCVN 2682:2009 (Portland cements - Specifications) [3], the qualities of N are in the regulated range of all of the three types in TCVN 2682:2009.

3.1.2 Aggregate

Table 3 lists the specifications of Japanese aggregate quality. River sand (NS1, NS2) and crushed sand (CS1) were used as fine aggregate, and crushed stone (CG1, NG1, NG2) was used as coarse aggregate.

3.2 Mix proportion

Table 4 lists the mix proportion of concrete. The water-binder ratios (W/B) were set to 45%, 55%, and 65%. Furthermore, FAII was used as a cement replacement in two ways as type B (FB in JIS R 5213) with a replacement ratio of 15% and as type C (FC in JIS R 5213) with a replacement ratio of 30% [4]. When FAII was used as fine aggregate replacement, the replacement ratio was (N + FAII) × 20%. In addition, the specimen groups containing FAII as both cement replacement and fine aggregate replacement were also used. In all, 11 specimen groups were prepared. In all mix proportions, the target slump was 18.0 ± 2.5 cm, and the target air content was 4.5 ± 1.5%. Experiment items and experiment methods are listed in Table 5.

Table 1 – Comparison of fly ash in Vietnam with the standards of Vietnam and Japan.

<table>
<tr><th colspan="2">Item</th><th>Properties of FA from Uong Bi Thermal Power</th><th>Fly ash type F-a (TCVN10302:2014) [2]</th><th>Fly ash type II (JIS A 6201)</th></tr>
<tr><td colspan="2">Silicon dioxide content (%)</td><td>55.6</td><td>≥ 45</td><td>≥45</td></tr>
<tr><td colspan="2">Moisture content (%)</td><td>0.13</td><td>3≥</td><td>1≥</td></tr>
<tr><td colspan="2">Loss on ignition (%)</td><td>4.68</td><td>5≥</td><td>5≥</td></tr>
<tr><td colspan="2">Density (g/cm^3)</td><td>2.35~2.69</td><td>-</td><td>≥1.95</td></tr>
<tr><td colspan="2">Specific surface area (cm^2/g)</td><td>-</td><td>-</td><td>≥2500</td></tr>
<tr><td colspan="2">Fineness (45μm sieve retention, %)</td><td>29.8</td><td>25≥</td><td>40≥</td></tr>
<tr><td colspan="2">Mortar flow ratio (%)</td><td>95.7</td><td>105≥</td><td>≥95</td></tr>
<tr><td colspan="2">Activity index at 28 days (%)</td><td>85.3</td><td>-</td><td>≥80</td></tr>
<tr><td colspan="2">Activity index at 91 days (%)</td><td>-</td><td>-</td><td>≥90</td></tr>
<tr><td colspan="2">Harmful alkali content (%)</td><td>-</td><td>1.5≥</td><td>-</td></tr>
<tr><td colspan="2">Cl^- (%)</td><td>-</td><td>0.1≥</td><td>-</td></tr>
<tr><td colspan="2">SO_3 (%)</td><td>0.17</td><td>5≥</td><td>-</td></tr>
<tr><td colspan="2">CaO (%)</td><td>-</td><td>2≥</td><td>-</td></tr>
<tr><td rowspan="2">Natural radioactivity *Aeff* (*Bq/kg*)</td><td>For private house and public construction</td><td>-</td><td>370≥</td><td>-</td></tr>
<tr><td>Industrial construction, urban road, urban area</td><td>-</td><td>740≥</td><td>-</td></tr>
</table>

4 Experimental results

The experimental results of fresh concrete are listed in Table 6.

4.1 Fresh concrete

4.1.1 Slump and air content

For FA30-FS20CG1CS1-55, when FAII was used as the largest weight value, the slump and air content satisfied the target values.

4.1.2 Density

Compared with the specimen groups which used only N, the specimen groups with FAII had lower density.

4.1.3 Temperature

In general, when FAII was used as the cement replacement, the temperature of the concrete at the time of placing was lower [5]. In this study, a similar trend was observed for the specimen groups in which FAII was used, and it was in contrast to the behavior observed for specimen groups with only N.

4.1.4 Chloride ion content

For FAII, the chloride ion content did not have any observable effect.

Table 2 – Quality of N and FAII.

Item		Portland cement					Admixture
		N	TCVN 2682:2009 [3]			JIS R 5210	FAII
			PC30	PC40	PC50		
Compressive strength (*MPa*)	3days±45min	32.3	≥16	≥21	≥25	≥12.5	-
	28days±8hours	63.2	≥30	≥40	≥50	≥42.5	-
Silicon dioxide content (%)		-		-		-	60.1
Moisture content (%)		-		-		-	0.5 ≥
Loss on ignition (%)		2.29		3≥		5≥	1.8
Density (g/cm^3)		3.16		-		-	2.29
Specific surface area (cm^2/g)		3300		≥2800		≥2500	3570
Fineness (45μm sieve retention, %)		-		-		-	9
Mortar flow ratio (%)		-		-		-	104
Activity index at 28 days (%)		-		-		-	85
Activity index at 91 days (%)		-		-		-	97
Hardening process (minute)	Start	146		≥45		≥60	-
	Finish	228		375≥		600≥	-
Fineness (0.09 mm sieve retention, %)		-		10≥		-	-
Volumetric stability (Le Chatelier method) (*mm*)		-		10≥		-	-
Na_2O_{qd} (%) ($\%Na_2O_{qd}=\%Na_2O+0.658\%K_2O$)		-		0.6≥		-	-
Insoluble matter (%)		-		1.5≥		-	-
SO_3 (%)		2.13		3.5≥		3.5≥	-
CaO (%)		-		-		-	1.62
MgO (%)		1.49		5≥		5≥	1.69

Table 3 – Quality of aggregate.

Item	Test method	NS1*1	NS2*1	CS1*2	CG1*3	NG1*4	NG2*4
Density in oven-dry condition (g/cm^3)	JIS A 1109 JIS A 1110	2.56	2.60	2.52	2.61	2.65	2.61
Absorption (%)		1.67	1.44	1.60	1.21	0.65	1.17
Fineness modulus (F.M.)	JIS A 1102	2.42	2.74	2.63	6.64	6.67	6.60
Materials finer than 75-μm sieve (%)	JIS A 1103	2.90	1.60	4.50	1.70	0.80	1.10
Solid content (%)	JIS A 1104	65.3	64.8	67.1	58.6	60.8	60.6
Solid content in aggregate (%)	JIS A 5005	-	-	58.2	58.3	59.8	59.8

*1：Sand from Ibi River, *2：Crushed sand from Shinshiro, *3: Crushed stone from Shinshiro, *4：Crushed stone from Kasugai.

Table 4 – Mix proportion of concrete.

Specimen*1	Mix proportion condition					Quantity of material per unit volume (kg/m³)						Chemical admixture (B×%)		
	Bin-der	Replacement ratio (%)*2		W/B (%)	s/a (%)	W	C	FAII		S	G	Ad. 1*4	Ad. 2*5	Ad. 3*6
		FA	FS					FA	FS					
N-NG2NS2-45	N	-	-	45	43.5	183	407	-	-	736	960	1.0	0.0	0.0
N-NG1NS1-55	N	-	-	55	46.3	175	318	-	-	824	974	1.0	0.002	0.0
N-NG2NS2-55	N	-	-	55	45.8	180	327	-	-	810	960	1.0	0.0	0.0
N-CG1CS1-55	N	-	-	55	47.6	180	327	-	-	819	928	1.0	0.0	0.0
N-NG2NS2-65	N	-	-	65	47.4	177	272	-	-	863	960	1.0	0.0	0.0
FA30-NG2NS2-45	N, FAII	30	-	45	42.1	183	285	122	-	697	960	1.0	0.0	0.2
FA30-NG2NS2-55	N, FAII	30	-	55	44.9	180	229	98	-	779	960	1.0	0.0	0.2
N-FS20NG1NS1-55	N, FAII	-	10*3	55	43.4	175	318	-	80	733	974	1.0	0.002	0.0
FA15-FS20CG1CS1-55	N, FAII	15	10*3	55	44.2	180	278	49	82	712	928	1.5	0.0	0.8
FA30-FS20CG1CS1-55	N, FAII	30	11*3	55	43.6	180	229	98	82	697	928	1.5	0.0	0.8
FA30-NG2NS2-65	N, FAII	30	-	65	46.7	177	191	82	-	837	960	1.0	0.0	0.2

*1: Binder-fly ash (FS)/coarse aggregate (G)/fine aggregate (S)-W/B, *2: FA: Cement replacement, FS: fine aggregate replacement, *3: (N + FAII) × 20%, *4: AE water reducing admixture (high performance type): modified lignin sulfonic acid compound, poly-carboxylic acid-based, *5: Air entraining (AE) admixture: resin-based anionic surfactant, *6: FA AE admixture: high fatty acid salt and non-ionic surfactant.

Table 5 – Experiments and methods.

Type	Experiment	Test method	Remark
Fresh concrete	Slump	JIS A1101	–
	Air content	JIS A 1128	
	Density	JIS A 1116	
	Temperature	JIS A 1156	
	Chloride ion content	JASS 5 T-502	Electrode current method
Hardened concrete	Compressive strength	JIS A 1108	Standard curing method 4 weeks, 13 weeks
	Static modulus of elasticity	JIS A 1149	
	Drying shrinkage	JIS A 1129-3	–
	Accelerated carbonation depth	JIS A 1153	–
	Durability factor	JIS A 1148	Experiment method A

Table 6 – Experimental results for fresh concrete.

Specimen	Slump *(cm)*	Air content *(%)*[*1]	Density *(kg/m³)*	Temperature *(°C)*	Chloride ion content *(kg/m³)*[*2]
N-NG2NS2-45	19.5	4.4 (0.2)	2299	28.0	0.03
N-NG1NS1-55	18.5	4.0 (0.0)	2304	28.6	0.03
N-NG2NS2-55	18.0	4.1 (0.2)	2336	28.4	0.02
N-CG1CS1-55	18.5	4.4 (0.0)	2318	26.0	0.04
N-NG2NS2-65	18.0	4.6 (0.2)	2288	24.6	0.02
FA30-NG2NS2-45	20.5	4.2 (0.2)	2283	19.5	0.03
FA30-NG2NS2-55	19.0	5.0 (0.2)	2285	27.0	0.02
N-FS20NG1NS1-55	18.0	5.7 (0.0)	2270	25.6	0.02
FA15-FS20CG1CS1-55	20.5	4.7 (0.3)	2262	22.4	0.02
FA30-FS20CG1CS1-55	19.5	4.9 (0.3)	2224	20.2	0.02
FA30-NG2NS2-65	19.5	4.7 (0.3)	2245	23.5	0.05

*1: In ( ) is the aggregate correction factor. *2: Refer to electrode current method. For normal-weight concrete, refer to JISA 5308.

4.2 Hardened concrete

4.2.1 Compressive strength and static modulus of elasticity

As shown in Figure 1, when FAII was used as the cement replacement, the development of compressive strength was observed from 4 weeks to 13 weeks. When FAII was used as the fine aggregate replacement, N-FS20NG1NS1-55 had a compressive strength at 13 weeks greater than 50 *N/mm²*. Compared with specimen groups in which only N was used, the increased trend was observed. Furthermore, the static modulus of elasticity also showed the same trend.

4.2.2 Drying shrinkage

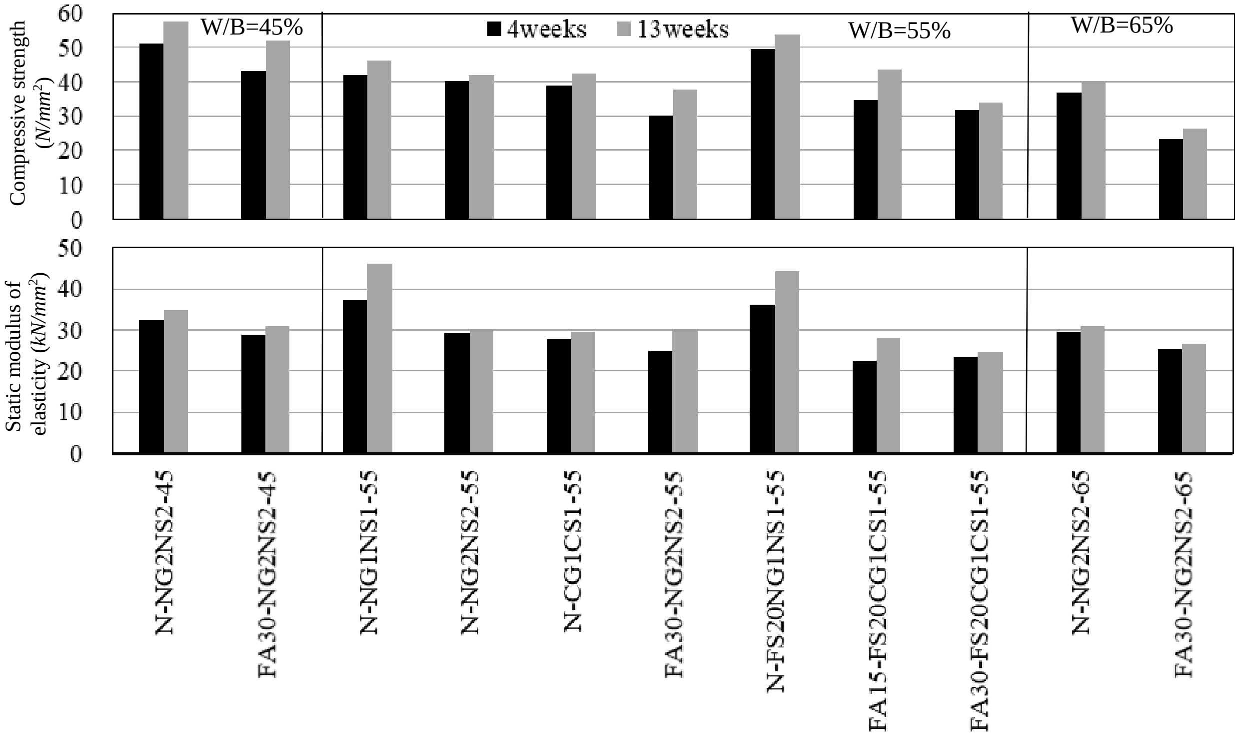

Fig. 1 – Compressive strength and static modulus of elasticity.

Vietnamese standard regulates that the shrinkage of normal-weight concrete be limited to the range from 1 to 15 × 10^{-4} [6]. In JASS 5 (2018) [7], for long-term and very-long-term planned service period, the drying shrinkage should not exceed 8 × 10^{-4}. In this study, the threshold set as 8 × 10^{-4} because it is the central value of the range as per the Vietnamese standard for drying shrinkage. As shown in Figure 2, for all the specimen groups with FAII, drying shrinkage ≤8 × 10^{-4}.

4.2.3 Accelerated carbonation

According to TCVN 9343:2012 Clause 6.4.4 "Determination of downgraded level and rehabilitation measures" [8], the carbonation depth of concrete should be at a minimum distance of 10 *mm* from a reinforced bar. Therefore, assuming a specimen of size 100 × 100 × 400 *mm* and a rebar diameter of D19, the threshold for the carbonation depth from the specimen surface was set as about 30 *mm*. In Japan, the Architectural Institute of Japan "Recommendations for Design and Construction Practice of High Durable Concrete" [9] regulates that the carbonation depth should not exceed 25 *mm*. As a conservative setting, the target quality threshold set as 25 *mm*. As shown in Figure 2, when FAII was used as the cement replacement, the accelerated carbonation increased with the replacement ratio; when FAII was used as the FC type, the threshold was exceeded for all specimens. On the other hand, when FAII was used as the fine aggregate replacement, because of the higher compressive strength, the accelerated carbonation was smaller than that in specimen groups with only N.

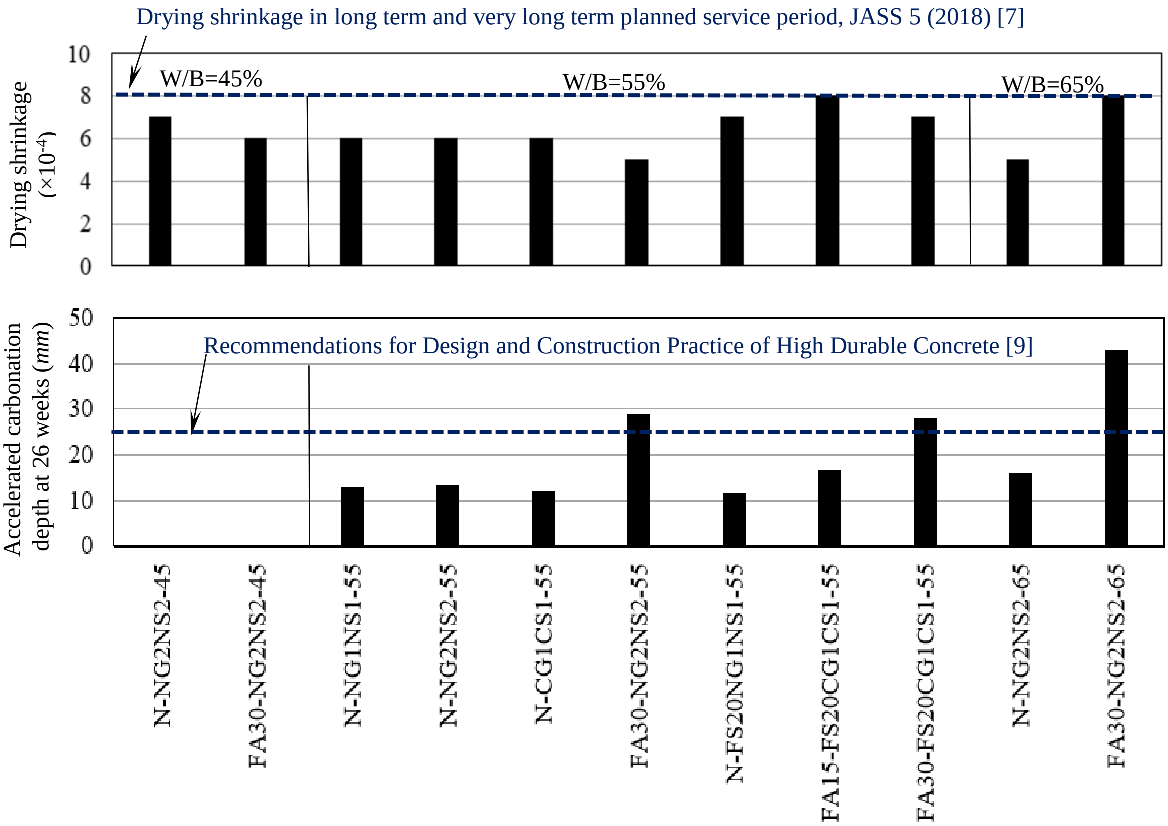

Fig. 2 – Drying shrinkage and accelerated carbonation depth.

4.2.4 Freezing and thawing

In Vietnam, no regulations have been prescribed for freezing damage to architectural structures. Therefore, JASS5(2018) [7] was applied for evaluating the concrete under freezing and thawing conditions. If under the freezing and thawing conditions, concrete had a target as-mixed air content ranging from 4.0% to 6.0% (4.5 ± 1.5% with a lower limit of 4.0%), regardless the application method and replacement ratio of FAII, the durability factor was almost ≥85, and frost damage resistance was assured.

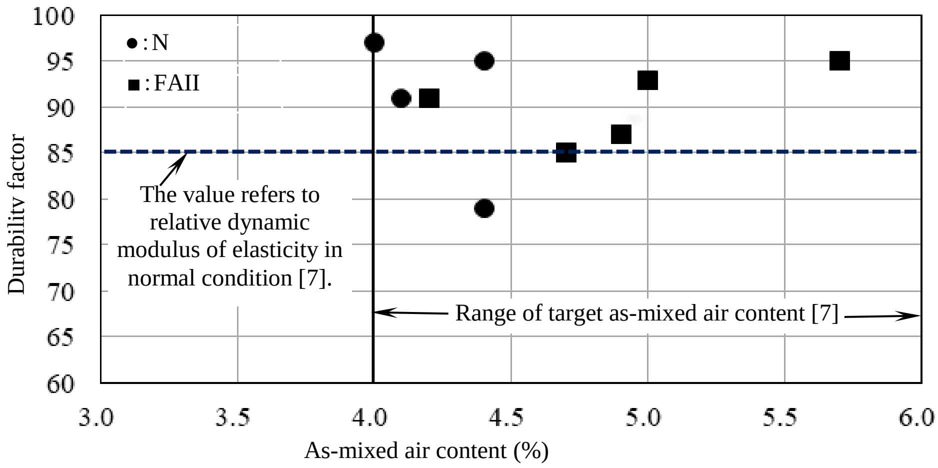

Fig. 3 – Correlation of as-mixed air content and durability factor.

5 Conclusion

- Even though a large amount of FAII was used in the mix proportion, by suitable application of the chemical admixture, both slump and air content satisfied the target values.
- When FAII was used as the cement replacement, the compressive strength and static modulus of elasticity showed an increasing trend from 4 to 13 weeks. However, when FAII was used as a fine aggregate replacement, because of the increasing binder weight, the compressive strength tended to increase.
- All of the specimen groups with FAII underwent drying shrinkage under the threshold value of 8×10^{-4}. On the other hand, for the accelerated carbonation, the specimen groups in which FAII was used as the FC type exceeded the threshold value. However, when FAII was used as the fine aggregate replacement, carbonation decreased.
- With regard to the durability factor, if the specimen groups were in the suitable as-mixed air content range, the durability factor was ≥85 regardless of the application method and FAII replacement ratio.

Thus, it was shown that by using Japanese Portland cement, Japanese aggregate, and a suitable amount of chemical admixtures, and adjusting the ratio of FA as the cement replacement and fine aggregate replacement, the manufacturing of structure concrete of the desired quality can be assured.

References

[1]- MNRE, Explanation on the coal ash and treatment of coal-fired power plants, Ministry of Natural Resources and Environment: Vietnam, 2019.
[2]- MST, TCVN 10306:2014 High strength concrete − Proportional design with cylinder sample, Vietnam: Ministry of Science and Technology, 2014.
[3]- MST, TCVN 2682:2009 Portland cement - Specifications., Ministry of Science and Technology: Vietnam, 2009.
[4]- AIJ, Recommendations for practice of concrete with fly ash, Architectural Institute of Japan: Japan, 2007.
[5]- AIJ, Recommendations for practice of hot weather concreting, Architectural Institute of Japan: Japan, 2019.
[6]- VMC, 22TCN 60-84, Testing procedure of cement concrete, Vietnam Ministry of Construction, Sector standard: Vietnam. 1st Publish, 1984.
[7]- AIJ, JASS 5 Reinforced Concrete Work, Architectural Institute of Japan, Japanese Architectural Standard Specification, 2018.
[8]- MST, TCVN 9491:2012, Concrete and reinforced concrete structure - Guide to maintenance, Ministry of Science and Technology: Vietnam. 1st Publish, 2012.
[9]- AIJ, Recommendations for design and construction practice of high durable concrete, Architectural Institute of Japan: Japan, 1991.