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Effect of Placing Season on Fly Ash Concrete Exposed Outdoor for a Decade

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ABSTRACT

This study was investigated to the durability of concrete with "type third fly ash" in age of a decade by investigating of concrete strength, carbonated thickness and pore-size distribution. This measurement was done by taking core from exposed concrete specimens, which placed in three seasons (that are summer, autumn and winter) and exposed outdoor for ten years. The results of this study were summarized as that, the strength of fly ash concrete was lager than that of normal concrete without fly ash at the same age of concrete. The strength of fly ash concrete increased with an increase of fly ash replacement ratio and it was higher than normal concrete regardless of the placing season. The carbonated thickness of fly ash concrete was smaller than the normal concrete at different seasons in placing. The trend of pore-size distribution with different seasons in placing correlated to the trend of carbonated thickness and long-term strength.

INTRODUCTION

In Japan, Fly ash that is produced from the coal thermal power plants has been increasing drastically as the energy demand increases. Further more power plants it is getting extremely hard to produce the fine aggregate of high quality because the over-producing of sea sands, which influences environment of a sea. Fly ash particles are typical spherical and it can be replace sea sands in large volume. In our laboratory at the University of Tokushima, several papers [Kawaguchi et al. 1996; Kohno et al. 1997; Kohno et al. 1998; Yamaji et al. 1998; Heng et al. 2003] on fly ash concrete had been published for about the last dozen years. In this paper, the durability of concrete with "type third fly ash" in age of ten years, the concrete strength and the carbonated thickness were investigated [Yamaji et al. 1998]. It means, the examination by taking core from exposed specimens at deferent time of concrete as placed which exposing outdoor for ten years in a ready mixed concrete plant. We took three seasons for the placing of concrete like: summer, autumn and winter season to consider the influence of placing season on durability of concrete with “type third fly ash” in the age of ten years. In addition, core specimens in the age of ten years were also measured the pore-size distribution in order to investigate the relationship between the carbonation and the microstructure of hydration of cement paste exposed the outdoor for decade years.

EXPERIMENTAL INVESTIGATION

Materials

Characteristics of the materials for concrete except fly ash used are shown in Table 1. Cement was used normal portland cement. The river sand and the sea sand were used in the weight ratio of 7 to 3. The maximum size of coarse aggregate used was 25mm and 40mm. Normal air-entraining agent and water reducing agent were used in normal concrete without fly ash. Non ion type surface active air-entraining agent and superplasticizer were used for fly ash concrete.

The characteristics of fly ash used and classification of 4 kinds of fly ash according to JIS A 6201 is shown in Table 2. “Type third fly ash” was used instead of fine aggregate in this study. The specific surface area of “type third fly ash” is the same “type second fly ash”, but ignition loss of “type third fly ash” is over than 5% of “type second fly ash”.

Table 1. Materials properties

Materials	Kind or product's place	Gravity	Maximam size	Water absorption	Fineness modulus
		g/cm^3	mm	%	
Cement	High early portland cement	3.15	----	----	----
Fine Aggregate	Ochigun, hakatacho sea's sand	2.58	5	2.20	1.93
	Anan,ohono,nakagawa-river's sand	2.63		1.73	3.11
Coarse Aggragate	Anan, ohono, nakagawa-river's crashed ston	2.63	25	0.83	6.94
		2.63	40	0.75	7.98
Chemical admixture	Polycarboxylic acid-type superplasticizer for FA concrete	1.05	----	----	----
	Lignosulphonate-type water reducing admixture for normal cocnrete without FA	1.25	----	----	----
Air-entraining admixture	Anion type and non-ion type surface active agent for FA concrete	1.04	----	----	----
	Anion type surface active agent for normal cocnrete without FA	1.04	----	----	----

Table 2. Characteristics of fly ash used and classifications of JIS A 6201

Fly ash		Properties			
		Density (g/cm^3)	Specific surface area (cm^2/g)	Ignition loss (%)	Flow value ratio (%)
Type third fly ash used		2.19	4490	6.45	99
Classification of fly ash by JIS A 6201	Type first fly ash	Above 1.95	Above 5000	Below 3.0	Above 105
	Type second fly ash	Above 1.95	Above 2500	Below 5.0	Above 95
	Type third fly ash	Above 1.95	Above 2500	Below 8.0	Above 85
	Type fourth fly ash	Above 1.95	Above 1500	Below 5.0	Above 75

Mix proportions of concrete

In order to have 21N/mm^2 of required average strength in age 28days, 8±2.5cm of required slump, 4.5±1.5% of required air content and 40mm, 25mm of maximum size of coarse aggregate were used in this mixture as shown in Table 3. Fine aggregate was replaced to fly ash in the ratio 0%, 10% and 20% of the whole volume of fine aggregate. This ratio, which means the unit content of fly ash divided by the sum of unit content of fine aggregate and fly ash, is called as fly ash replacement ratio in this paper. The meaning of the symbol of sort of mixture's name shown in Table 3 is that, the first of two numbers means required average strength and the next number means required slump and next two numbers means maximum size of coarse aggregate, and the last numbers are fly ash replacement ratio. The dosage of superplasticizer or water reducing agent was set to have the required slump with estimation of slump loss caused by the traveling time from ready mixed concrete plant to site.

Table 3. Mix proportions of concrete

Mixture's name	W/C (%)	s /a (%)	Unit content (kg/m^3)							SP / WRA (× C)	AE agent
			W	C	FA	Fine aggregate		Coarse aggregate			
						River sand	Sea sand	25-5mm	40-20mm		
18-8-40(0)	62.0	42.7	146	235	0	573	246	775	332	1.0％*	4.5A
18-8-40(10)	66.4	40.7	154	232	65	487	209	794	340	1.60%	13A
18-8-40(20)	66.5	38.7	151	227	124	414	177	826	354	**	15A
21-8-25(0)	56.0	43.2	153	273	0	565	242	1069	0	1.0％*	3.5A
21-8-25(10)	59.8	40.2	158	264	63	473	203	1122	0	1.50%	15A
21-8-25(20)	59.7	40.2	160	268	125	419	179	1177	0	2.00%	15A

Note, *is WRA .** are C×2.1％ for Summer and C×1.9％ for Autum and Winter.

Specimens and items of examination

Fig. 1. Overview of specimens exposed outdoor

The size of specimen was slab type of 900×600×200(mm). In one mix proportion, 5 specimens were made and exposed outdoor for 10years in the ready mixed concrete plant. The ready mixed concrete plant was placed at Anan city of Tokushima prefecture in Sikoku Island at Japan. This

Table 4. Dates and the range of concrete temperature of making specimens

Mixture's name	Season	Date of making specimen Date, Month, Year	Concrete Temperature minimum - maximum (°C)
18-8-40(0)	Summer	17th, Sep., 1998	26.0 - 26.0
18-8-40(10)		9th, Sep., 1998	26.5--26.5
18-8-40(20)		11th, Sep., 1998	27.5--29.0
21-8-25(0)		14th, Sep. 1998	28.0 - 28.0
21-8-25(10)		3rd, Sep., 1998	28.5 - 29.0
21-8-25(20)		7th, Sep., 1998	26.5 - 27.0
18-8-40(0)	Autum	25th, Nov., 1998	13.0 - 15.0
18-8-40(10)		13th, Nov., 1998	15.5 - 17.0
18-8-40(20)		17th, Nov., 1998	19.5 - 21.0
21-8-25(0)		19th, Nov., 1998	12.0 - 13.0
21-8-25(10)		9th, Nov., 1998	18.0 - 19.0
21-8-25(20)		11th, Nov., 1998	16.0 - 17.0
18-8-40(0)	Winter	18th, Feb., 1999	9.5 - 11.0
18-8-40(10)		10th, Feb., 1999	9.0 - 11.0
18-8-40(20)		12th, Feb., 1999	7.0 - 9.0
21-8-25(0)		15th, Feb., 1999	6.5 - 9.0
21-8-25(10)		2nd, Feb., 1999	9.0 - 11.0
21-8-25(20)		8th, Feb., 1999	7.0 - 9.5

area is the south-western area of Japan and this area belongs the Temperate Zone. Fig. 1 shows the state of specimens exposed outdoor. The date of making specimen and the range of concrete temperature of making specimen are shown in Table 4.

In order to investigate the strength development of hardened concrete with age, the drilled cores (ϕ 100mm) were used to examine the compressive strength by the method of sampling and testing for compressive strength of drilled cores of concrete which is established by JIS A 1107-2002 published by Japanese Standards Association. On the other hand, drilled cores also were used to examine tensile strength by the method of test for splitting tensile strength of concrete (JIS A 1113-2006). When the specimen exposed outdoor was drilled to get core specimens were at 91days, one year, three years, five years and ten years. Drilling cores of specimens exposed

Fig. 2. Overview of drilling cores from specimens exposed outdoor

outdoor was shown in Fig. 2.

Due to the process of pozzolanic reaction of fly ash in fly ash concrete, the consumption of $Ca(OH)_2$ has occurred in fly ash concrete. Then the concentration of OH^- in pore solution of fly ash concrete tends to decrease with the age increment. The carbonation of cover concrete tends to increase according to the lower concentration of OH^-. In order to investigate the carbonation of cover concrete, 1% solution of phenolphthalein was performed to measure carbonation depth by spaying onto semi cylinder surface after finishing the test for splitting tensile strength of concrete. In case of core test, top and bottom surface of semi cylinder (ϕ 100mm) were measured total more over 10 places in 0.1mm unite as a carbonated thickness. This test is established by the method for measuring carbonation depth of concrete (JIS A 1152-2002).

Moreover it was measured the pore-size distribution and pore volume of the exposure outdoor of specimens for a decade using a mercury porosimetry method in order to investigate the relationship between carbonation depth and microstructure of cover concrete.

RESULTS AND DISCUSSIONS

Compressive strength

The relationship between the compressive strength and the age of concrete which placed in summer, autumn and winter season are shown in Fig. 3, Fig. 4 and Fig. 5, respectively. Generally the compressive strength of fly ash concrete was larger than that of normal concrete without fly ash at the same age of concrete in long term. As the fly ash replacement ratio was larger, the compressive strength was larger at the same age of concrete and the same placing season.

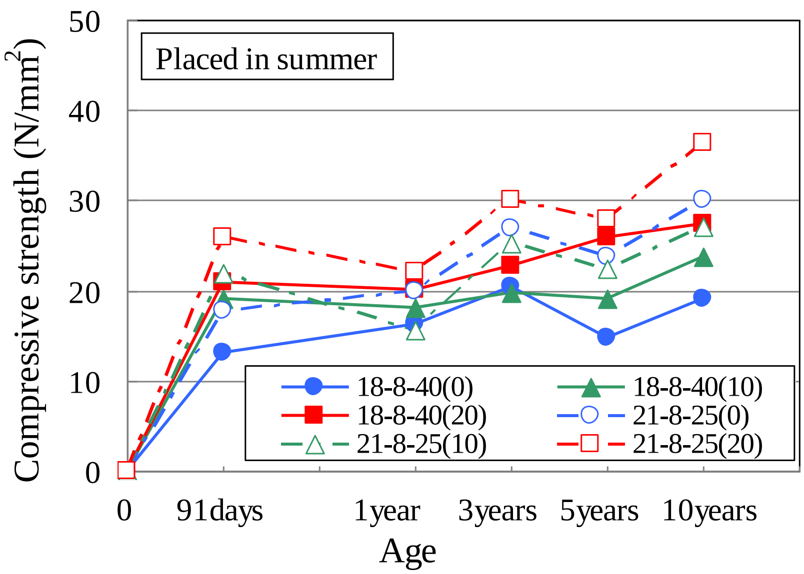

Fig. 3. Development of compressive strength with age of concrete placed in summer

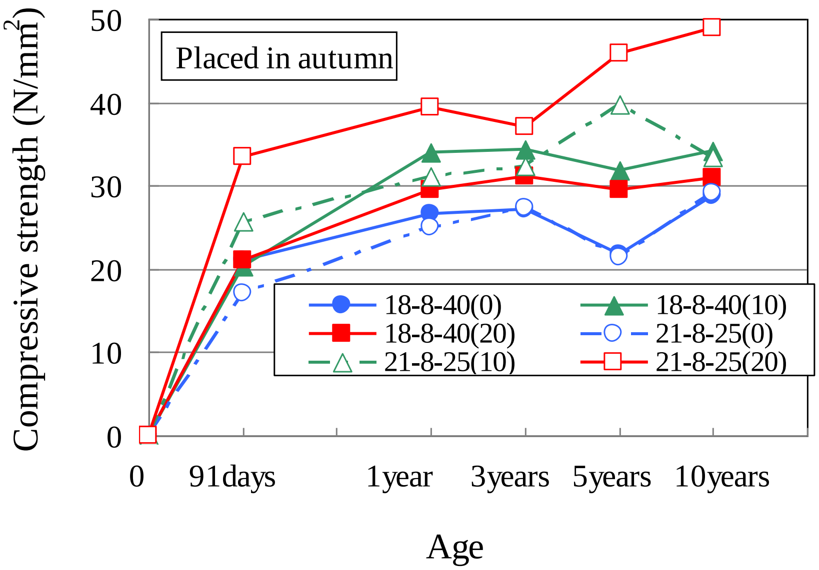

Fig. 4. Development of compressive strength with age of concrete placed in autumn

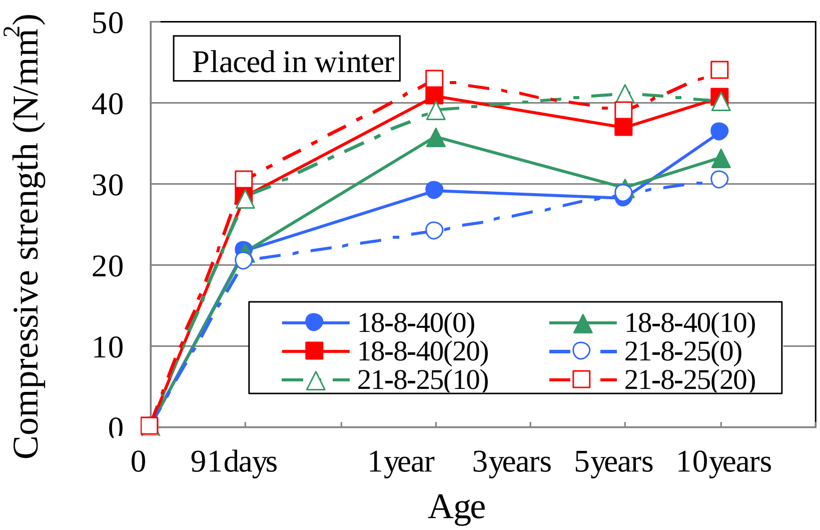

Fig. 5. Development of compressive strength with age of concrete placed in winter

In the case of placing in the summer season as shown in Fig..3, the compressive strength of mixture' name of 18-8-40(0) at the age of 91 days and five years is smaller than 18N/mm^2 of required average strength. Also the compressive strength of mixture's name of 21-8-25(0) at the age of 91 days is smaller than 21N/mm^2 of required average strength. The reason is that there were cracks inside while core specimens were drilled. On the other hand, in the case of placing in the autumn and wither as shown in Fig. 4 and Fig. 5, the compressive strength of normal concrete without fly ash was exceeded the required average strength. It was considered that the long-term strength is affected by the placing seasons and the concrete temperature of casting.

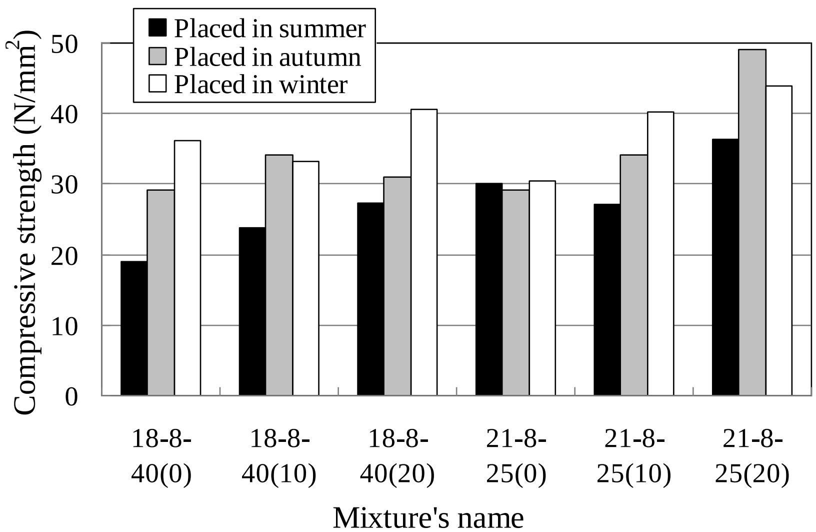

Fig. 6. Compressive strength at the age of 10 years in placed three seasons

Fig. 6 shows the compressive strength at the age of 10 years in placing three seasons. When the strength of fly ash concrete was compared with that of normal concrete without fly ash, it can be seen that the compressive strength of fly ash concrete increases with an increase of fly ash replacement ratio and the age of concrete, and it is higher than that of normal concrete without fly ash regardless of the placing season. It is due to pulverized effect of fly ash and pozzolanic reaction increase compressive strength which do not depend on placing season. The compressive strength of fly ash concrete placing in summer was smaller in comparison with that placing in autumn or winter. As mentioned before, the long-term strength of normal concrete which placed in a high concrete temperature is generally lower than that of placing concrete in low temperature. It also shows a similar result in fly ash concrete. Therefore we need enough attention for concrete curing condition which means casting temperature and method for casting and curing when fly ash is replaced for a part of fine aggregate in summer season.

Tensile strength

The tensile strength of core specimen at the age of 10 years in placing three seasons is shown in Fig. 7. It was evident that the trend of tensile strength development is similar to compressive strength. Tensile strength placing in autumn and winter is larger than that placing in summer without relationship of fly ash replacement ratio and required average strength. Usually early time strength of high temperature of casting and curing is larger compared with the low temperature of casting and curing. Then it was considered that, early time strength placing in winter is lower that cause to increase long-term strength by pozzolanic reaction. In general, high curing temperature promotes pozzolanic reaction of fly ash, but this result shows that the promotion of long-term pozzolanic reaction does not depend on early of high temperature of casting and curing.

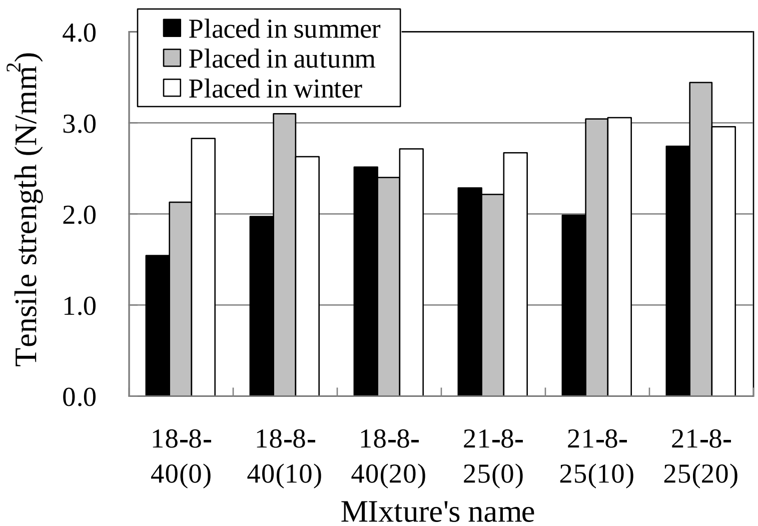

Fig. 7. Tensile strength at the age of 10 years in placed three seasons

Carbonated thickness

The result of carbonated thickness at the age of 10 years is shown in Fig. 8. It was seen that the carbonated thickness of fly ash concrete is smaller than that of normal concrete without fly ash regardless of placing seasons. If a quantity of cement is constant and fine aggregate is replaced to FA, the resistance of carbonation of fly ash concrete is longer than that of normal concrete.

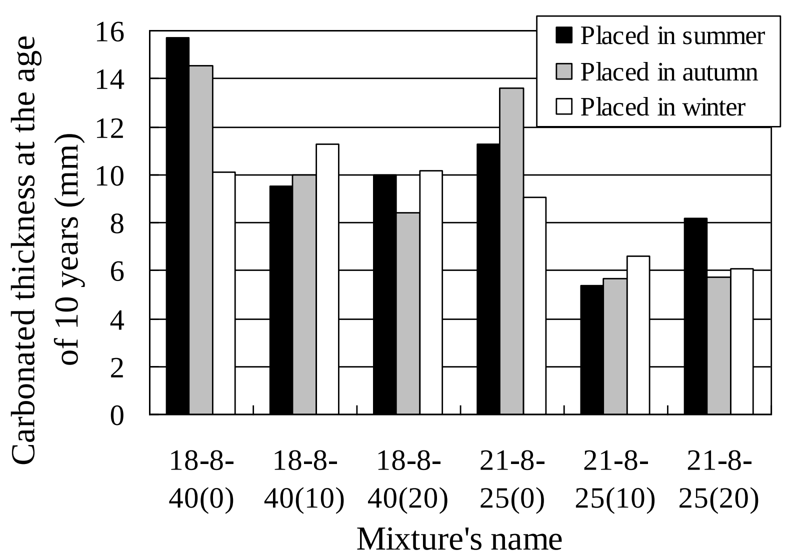

Fig. 8. Carbonated thickness at the age of 10 years in placed three seasons

Usually it is said that the carbonated thickness of normal concrete is 1mm/year in Japan. Then the carbonated thickness at the age of 10 years will be about 10mm. However the value was larger than the 10mm regardless of required average strength. Especially, the carbonated

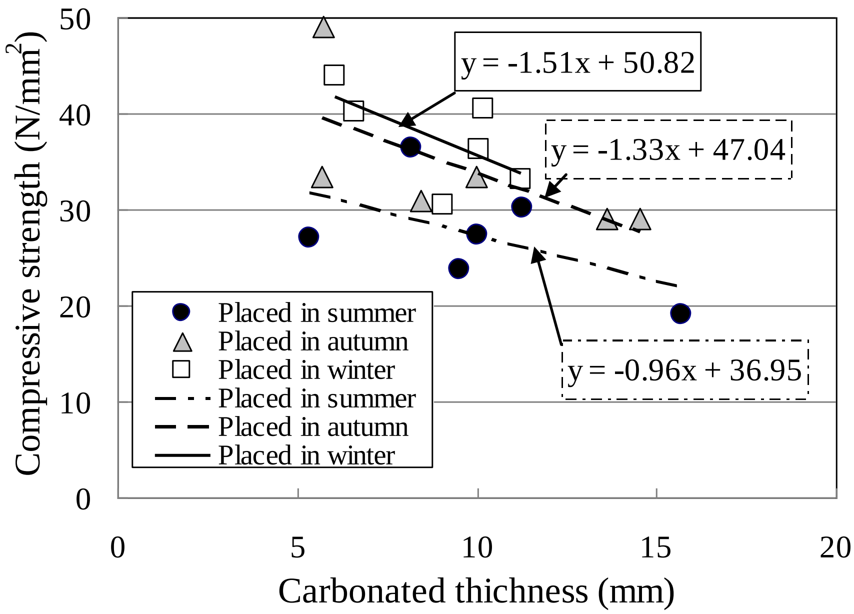

Fig. 9. Relationship between carbonated thickness and compressive strength at the age of 10 years in placed three seasons

thickness of concrete (18-8-40(0)) placing in summer was more than 15mm. This area where the specimens were exposed outdoor, located near several factories for production of paper mill which outbreak of photochemical smog in summer. Then it was thought that the large carbonated thickness had influence of the problem of acid rain strongly.

The relationship between the carbonated thickness and the compressive strength of core specimen placing three seasons at the age of 10 years is presented in Fig. 9. The carbonated thickness and the compressive strength had strong correlation. The carbonated thickness increased while strength was small. However the progress of carbonation placing in autumn or winter was earlier than that in summer at the same strength. In other words the compressive strength placing in summer was smaller than that in autumn or winter at same carbonated thickness. The development of early-age strength placing in autumn or winter was smaller than that on summer so that the curing temperature after casting was low. It was thought that surface characteristics of concrete have the influence on velocity of carbonation. In general, resistance of carbonation increases with an increasing of strength. Then it was considered that the carbonated thickness placing in summer is smaller than that in autumn or winter. However long-term strength placing in autumn or winter was larger than that in summer. The resistance of carbonation has influence of long-term strength rather than early-age strength. Hence the carbonated thickness of fly ash concrete was no problem for casting in low concrete temperature and placing in winter or autumn in Japan. On the contrary, it is considered that the construction condition for fly ash concrete prefers placing in winter or autumn to placing in summer.

Pore-size distribution of concrete exposed outdoor for a decade

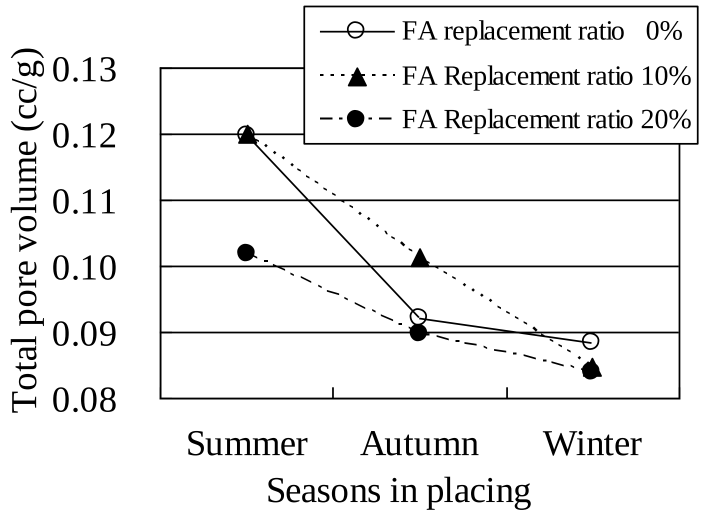

Fig. 10. Relationship between total pore volume of core specimens and placing seasons at the age of 10 years

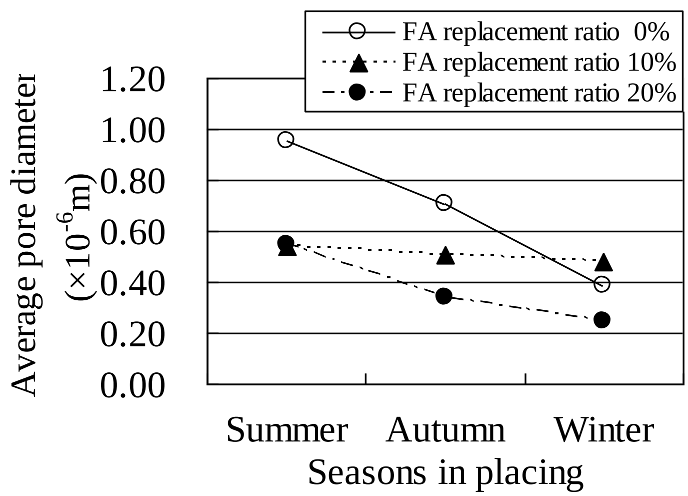

Fig. 11. Relationship between average pore diameter of core specimens and placing seasons at the age of 10 years

The results of total pore volume and average pore diameter of concrete exposed outdoor for a decade are shown in Fig. 10 and Fig. 11, respectively. Total pore volume and average pore diameter were calculated by the pore-size distribution using the mercury porosimetry method. As shown in Fig. 10 and Fig. 11, the total pore volume and average pore diameter of concrete placing in summer was the largest among that in three seasons. On the contrary the total pore volume and average pore diameter of concrete placing in winter was the smallest among that in three seasons. The trend of pore-size distribution with different season in placing was correlated to the trend of carbonated thickness and long-term strength with different season in placing. It is mean that the hydration of cement past placing in summer was not enough to that placing in winter. Therefore it is considered that the microstructure of fly ash concrete placing in winter was denser than that in summer although the early-age strength of fly ash concrete was lower than that in summer.

Compared with the effect of fly ash replacement ratio to total pore volume and average pore diameter, average pore diameter was lower as fly ash replacement ratio was larger. On the other hand, the trend of total pore volume was not coincident with the trend of fly ash replacement ratio. At least it was clear that the fly ash replacement ratio of 20% was most effective to concrete with regard to the both of total pore volume and average pore diameter in spite of different seasons in placing.

It has been said that resistance of carbonation and development strength are disadvantage for fly ash concrete so that the concentration of OH^- in pore solution of fly ash concrete tends to decrease with the age increment and early-age strength of fly ash concrete is lower than that of normal concrete without fly ash but that is not strictly true. When the unit concrete of cement is constant, a part of fine aggregate is replaced to fly ash and concrete is placing in winter, the average pore diameter at age of ten years decreases one fifth of normal concrete placing in summer and the performance of fly ash concrete is very superior to that of normal concrete.

CONCLUSIONS

The following general conclusions can be drawn from the study provided in the paper:

- The strength of fly ash concrete taking core from exposed specimens as placed outdoor for ten years was lager than that of normal concrete without fly ash at the same age of concrete.
- The long-term strength of core specimen placing in summer was lower than that in winter and autumn. Therefore the concrete placing in summer needs enough attention of good curing for hot water concreting.
- The strength of fly ash concrete increased with an increase of fly ash replacement ratio and it was higher than normal concrete regardless of the placing different season.
- The carbonated thickness of fly ash concrete was smaller than of normal concrete without fly ash with different season in placing.
- The trend of pore-size distribution with different season in placing correlated to the trend of carbonated thickness and long-term strength. The progress of carbonation, which placing in autumn and winter, were earlier than that in summer at the same strength.

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