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Strength Property of Concrete Using High Volume Fly Ash as a Part of Fine Aggregate Under 40 ℃ Air Curing

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ABSTRACT

In this study, it was experimented concerning the strength property of concrete using high volume fly ash under the environment of 40 degrees centigrade air curing that was severe with concrete, in two levels (cement content per unit volume of concrete of the normal strength concrete area and the high-strength concrete area). And strength property was clarified. The conclusions are as follows. It was clarified that the compressive strength of concrete using fly ash by 400kg/m^3 or more was negatively affected when the cement content was large. Under standard curing, the compressive strength of concrete using cement by 600kg/m^3 or more was the best when using fly ash by about 100kg/m^3, was not effective even if it used it any more. The compressive strength of concrete using fly ash by about 200kg/m^3 became the same degree of compressive strength(110N/mm^2 or more) as standard curing even 40℃air curing.

INTRODUCTION

Authors had established the mix proportion principle using fly ash as not a part of cement but a part of fine aggregate so far. We had clarified that the concrete using high volume fly ash was more excellent in strength properties than the concrete using no fly ash mixture, and it showed the high durability.

In addition, the concrete using recycled aggregate where the strength decrease is generally caused showed us the improvement of strength. There is report that the pore structure of concrete subdivides and the hardening body is denseness because it mixes high volume materials with a small particle like fly ash without decreasing the cement content per unit volume of concrete. Water cement ratio of the concrete is more than a regulated value though water binder ratio is small. Therefore, it has water necessary for cement in the concrete to continue hydration reaction. The concrete has the possibility that the strength developing can be continued by using water that has it in concrete under the environment exceeding the temperature 35℃. It is thought that the influence that it has for the curing period after it places and the retention period of the form is large.

In this study, it was experimented concerning the strength property of concrete using high volume fly ash under the environment of 40 degrees centigrade air curing that was severe with concrete, in two levels (cement content per unit volume of concrete of the normal strength concrete area and the high-strength concrete area). And strength property was clarified.

EXPERIMENTS

Materials

Table 1. shows the materials. Fly ash used in this study is specified type Ⅱ per JIS A 6201.

Table 1. Materials

	Physical properties	Symbol
ordinaly Portland cement	density 3.16g/cm^3	C
City water	—	W
Sea sand	density in oven-dry 2.54g/cm^3 absorption 1.55% solid content 60.3% fineness modulus 2.7	S
Crushed andesite	density in oven-dry 2.81g/cm^3 sbsorption 0.79% solid content 59.4% fineness modulus 6.6	G
Fly ash	density 2.25g/cm^3 ignition loss 2.22% specific surface area 3410cm^2/g total moisture content 0.07%	FA
High-range water-reducing admixture	polycarboxy ethereal density 1.06g/cm^3	AD1
AE admixture	alkyl ethereal density 1.03g/cm^3	AD2
Air control admixture	polyalkylen glycol derivative density 1.00g/cm^3	AD3

Mix proportion of concrete

Table 2. shows the mix proportion of concrete. For the mix proportion of series Ⅰ, the water content per unit volume of concrete and the cement content were fixed 185kg/m^3 and 285kg/m^3 that were the upper limit of JASS5(Japanese Architectural Standard Specification), and the fly ash content was 0 kg/m3, 244 kg/m^3(W/B=35%), 455kg/m3(W/B=25%). The mix proportion of series I is 3 kinds in total. The slump of N65-65 and N65-35 was 18±2.5cm. N65-25 was high fluidity type, the slump flow was 65cm±15cm. The air content of series Ⅰ was 4.5±1.5%. For the mix proportion of series Ⅱ, the water content was 165kg/m^3 that was the upper commendable value of high strength concrete of AIJ(Architectural Institute of Japan) and bulk volume of coarse aggregate per unit volume of concrete was 0.525 m^3/m^3 that was the commendable value of high fluidity concrete of AIJ. It was confirmed by preliminary experiments that it was not possible to mix the concrete, when the cement and fly ash content was 1100kg/m^3 or more. Then, the cement content was fixed 631kg/m^3. Upper limit of the fly ash content was 400kg/m^3; it was 0kg/m^3, 100kg/m^3, 200kg/m^3, 300kg/m^3, 400kg/m^3. The mix proportion of series Ⅱ is 5 kinds in total. The slump flow was 65cm±15cm. The air content was 3.0±1.5%.

Table 2. Mix Proportion of Concrete

	Symbol	W/C (%)	W/B (%)	Weight per unit volume (kg/m^3)					Admixture (C+FA)×%		
				W	C	FA	S	G	AD1	AD2	AD3
SeriesⅠ	N65-65	65	65	185	285	0	837	974	0.35	0.005	-
	N65-35		35			244	566		0.5	0.025	-
	N65-25		25			455	331		1.5	0.05	-
SeriesⅡ	N26-26	26	26	165	631	0	737	868	0.8	-	0.007
	N26-22		22			100	626		1.1	-	0.01
	N26-19		19			200	515		1.75	-	0.02
	N26-17		17			300	403		1.9	-	0.02
	N26-16		16			400	292		3.5	-	0.2

Mixing and curing

Mixing of series Ⅰ used revolving-paddle pan type mixer, series Ⅱ used omnimixer. The mixing time was made the range of 3-16 minutes that fresh properties became proper. The concrete cylindrical specimens were made by using φ100×200mm plastics mold. After it had placed, it carried to each curing room at once. After demolding at 1 day, it was cured under each curing condition. The curing condition was two kinds of 20℃water curing(standard curing) and 40℃air curing. The thermostatic chamber under 40℃ air curing kept 40±1℃ in temperature and 60±10%RH in humidity.

Test methods

The test of compressive strength, static modulus of elasticity and splitting tensile strength were tested according to JIS A 1108, JIS A 1149 and JIS A 1113. The test of compressive strength was tested at 3, 7, 28 and 91 day. The test of splitting tensile strength was tested at 7, 28 and 91 day. The specimen to test compressive strength at 3 and 7 day was measured cumulative pore volume. After the test of compressive strength, the test piece was crushed. Then, the sample of grain of 2.5-5mm was gathered from the parts except the coarse aggregate as a sample for the measurement. 105℃ dry method was used as a pre-processing of the sample. The cumulative pore volume of 2.5-200 nm in pore diameter was measured with nitrogen gas absorption equipment by absorption method. It was calculated by the BJH method using a standard isothermal of silica.

EXPERIMENTAL RESULTS AND DISCUSSIONS

Compressive strength

Figure 1. shows compressive strength under each curing condition. Both series Ⅰ and series Ⅱ, compressive strength of concrete using high volume fly ash as a part of fine aggregate increased under standard curing when the age passed. As for series Ⅰ with a little of the cement content, when the fly ash content increased, the increase rate of strength with the days was higher than series Ⅱ. Compressive strength of series Ⅱ specimens at 3 and 7day under 40℃ air curing was higher than compressive strength under standard curing. It is thought that this reason is that the hydration reaction became active at early time because the curing temperature is high. At early day, compressive strength of series Ⅰ specimens using fly ash under 40℃ air curing was higher than standard curing, however it using no fly ash was almost equal under standard curing. Compressive strength using no fly ash of both series

under 40℃ air curing hardly increased with the days, and that of series Ⅰ has decreased. Compressive strength using fly ash of both series under 40℃ air curing increased with the days.

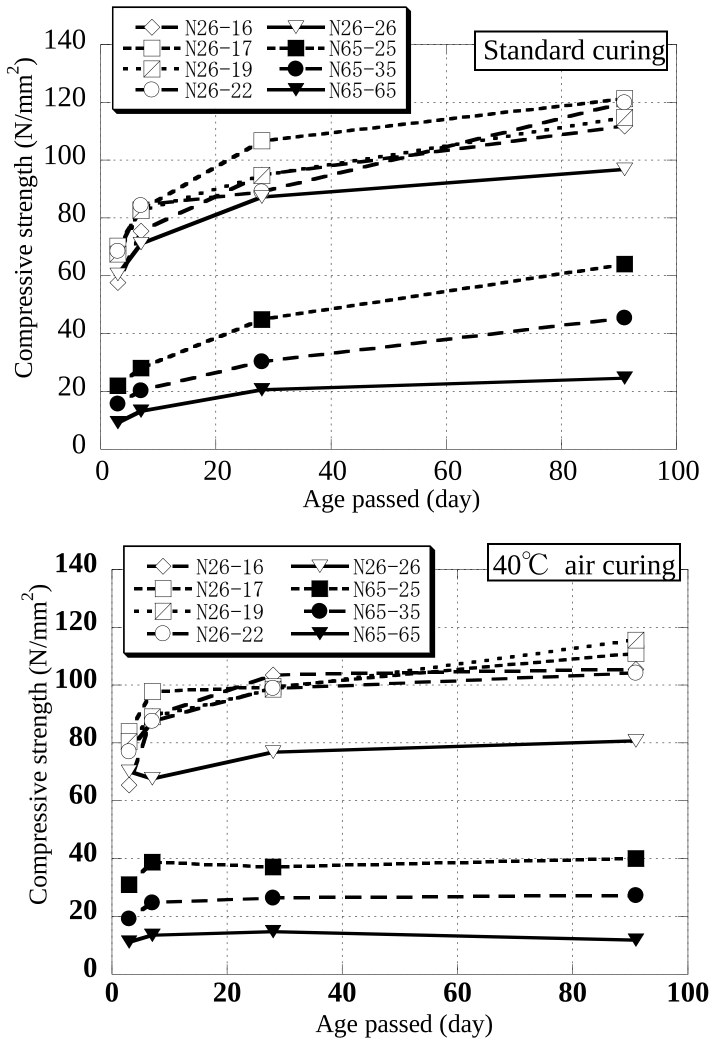

Fig. 1. Compressive Strength under Each Curing Condition

Figure 2. shows relation between compressive strength and fly ash content. Until 91day, compressive strength of series Ⅰ under standard curing in-creased when the fly ash content increased. The in-crease rate on especially at 91day was remarkable. For series Ⅰ under standard curing, the relation between the fly ash content and compressive strength was in a linear relation. For series Ⅱ under standard curing, Compressive strength according to increase in the fly ash content did not increased as remarkably as series Ⅰ. Compressive strength of concrete using fly ash of series Ⅱ increased than using no fly ash, however there was no difference of compressive strength by the difference of the fly ash content 100kg/m^3, 200kg/m^3 and 300kg/m^3 until 91day. Especially, compressive strength of concrete using fly ash by 300kg/m^3 was higher than by 400kg/m^3 in this experiment. It is thought that this reason is that fine particle such as cement and fly ash were used voluminously. It was clarified that the compressive strength of concrete using fly ash by 400kg/m^3 or more was

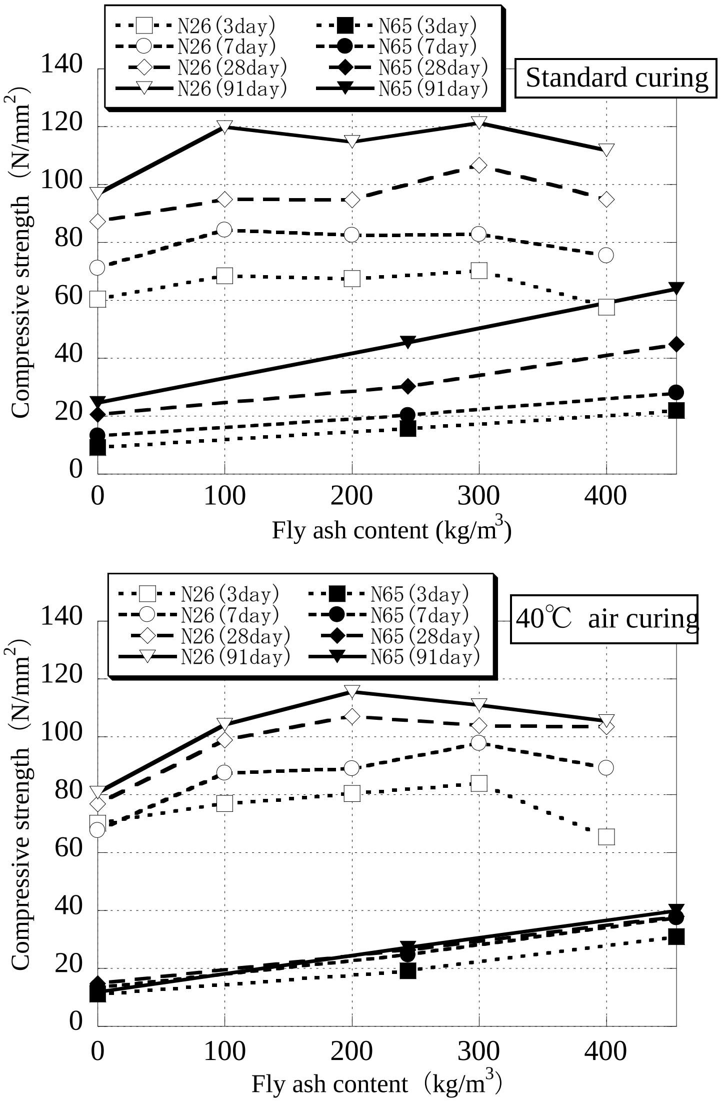

Fig. 2. Relation Between Compressive Strength and Fly Ash Content

negatively affected when the cement con-tent was large like series Ⅱ. Under standard curing, the compressive strength of concrete using cement by 600kg/m^3 or more was the best when using fly ash by about 100kg/m^3, was not effective even if it used it any more. Some studies have reported that W/B 20% was a limit value of the mixing, and when the fly ash content was increased within the range, compressive strength was high1). Afterwards, mixing the concrete of W/B 20% or less by technological of admixture development became possible, however it was shown in this experiment that the amount of the best mixture of cement and fly ash that influenced compressive strength existed in this range. For series Ⅰ under 40℃ air curing, the relation between the fly ash content and compressive strength was in a linear relation, but The increase rate became low compared with the standard curing. For series Ⅱ, compressive strength increased remarkably when the fly ash content increased. Especially, the effect of the fly ash content on compressive strength was large by the passage of days. Under 40℃air curing , the compressive strength of concrete using fly ash by 200 and 300kg/m^3 was higher than by 400kg/m^3. Accordingly, the compressive strength using cement by 600kg/m^3 or more was the best when using fly ash by about 200kg/m^3, was not effective even if it used it any more. The compressive strength of concrete using no fly ash under standard curing was about 100N/mm^2, however it under 40℃ air curing was about 80N/mm^2. The compressive strength of concrete using fly ash by about 200kg/m^3 became the same degree of compressive strength(110N/mm^2 or more) as standard curing even 40℃air curing. This shows that the hardening body is denseness and makes water necessary for hydration reaction easy not to dissipate as we described in the beginning. Accordingly, the concrete using fly ash can make appropriate hydration reaction run by using cement and fly ash by 931kg/m^3 less than even under a comparatively very bad curing condition.

Pore structure of concrete

Figure 3. shows cumulative pore volume of series Ⅱ at 3 and 7 day. The measuring method that uses mercury is not good on an environmental influence though a concrete pore volume is generally measured by mercury intrusion porosimetry. Then, the cumulative pore volume was measured by the gas adsorption method that did not use mercury though only the range limited up to 2.5-200 nm in pore diameter was able to be measured. The cumulative pore volume at early day was measured, because the compressive strength under 40℃ air curing was higher than standard curing. The cumulative pore volume up to 2.5-200 nm in pore

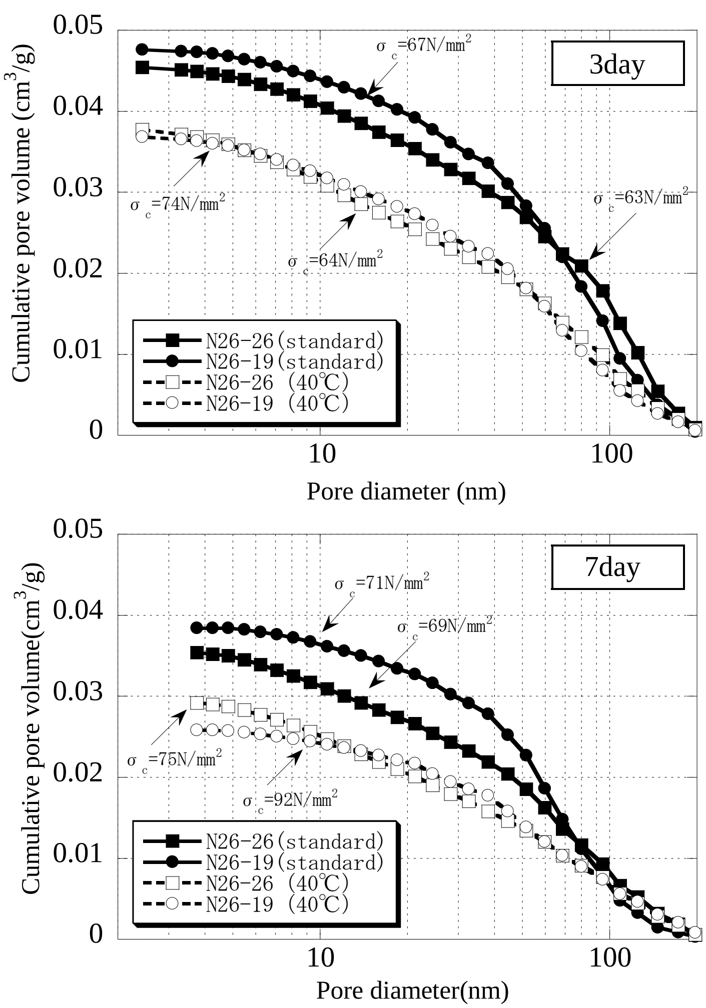

Fig. 3. Cumulative Pore Volume

diameter under 40℃ air curing was lower than the standard curing both at 3 and 7 day. There is report that the compressive strength of concrete is high when the cumulative pore volume measured by mercury intrusion porosimetry is small. It is thought that hydration reaction in the concrete progresses because it is ex-posed under high temperature, the cumulative pore volume decreases, and the hardening body is denseness. In this experiment, there was no clear difference in the relation between using of fly ash and cumulative pore volume until 7 days. The strength property of concrete using fly ash under high temperature environment is scheduled to be clarified by researching pore structure of the specimens with a little of cement content and that of long term age in the future.

Static modulus of elasticity

Figure 4. shows relation between static modulus of elasticity and fly ash content. Both series Ⅰ and seriesⅡ, static modulus of elasticity under standard curing increased when the age passed. That under standard curing almost showed the constant value regardless of an increase of the fly ash content. Both series Ⅰ and seriesⅡ, that under 40℃ air curing al-most showed the constant value even if he age passed. For series Ⅰ the static modulus of elasticity used fly ash under 40℃ air curing increased more than that no used fly ash, however that for seriesⅡ almost showed the constant value regardless of an increase of the fly ash content.

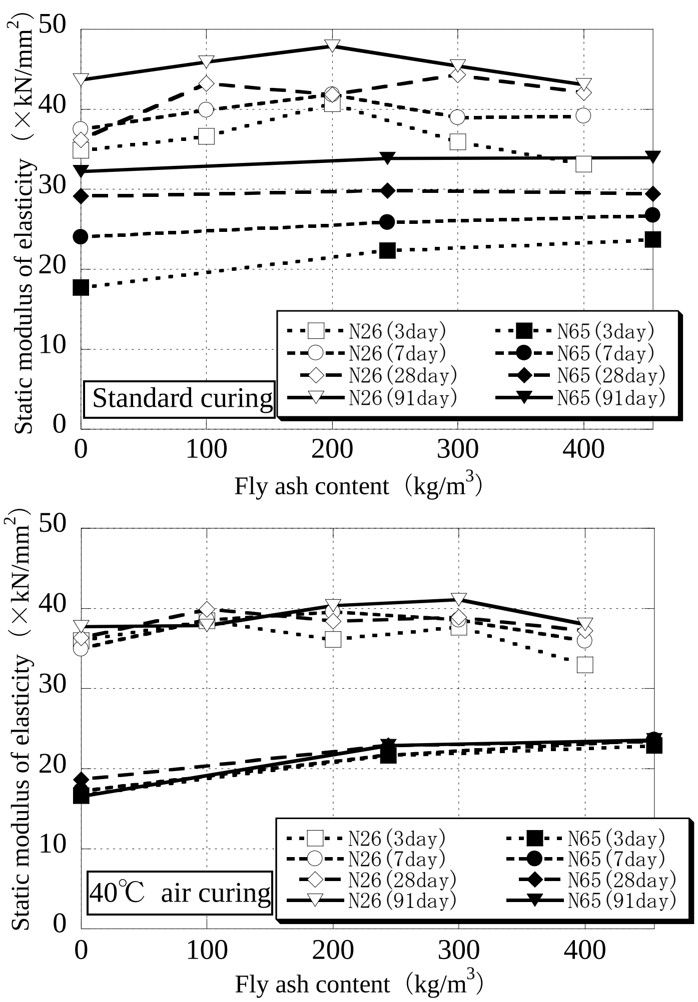

Fig. 4. Relation Between Static Modulus of Elasticity and Fly Ash Content

Relation between compressive strength and static modulus of elasticity

Figure 5. shows relation between compressive strength and static modulus of elasticity. The regression curve in figure is the NEW-RC of Japan (36N/mm^2 or more) when assuming γ =2.4 (weight of unit volume of concrete of series Ⅱ), K_1=1.0(coefficient for influence of aggregate), and K_2=1.1(coefficient for influence of admixture) and curve of AIJ standard for structural calculation of reinforced concrete structures (1991)(36N/mm^2 or less) when assuming γ =2.2(series Ⅰ). For relation between compressive strength and static modulus of elasticity under standard curing, only N65-65(no us-ing fly ash) of series Ⅰ was distributed from the re-gression curve up, however the concrete using fly ash was distributed near the regression curve. There-fore, it can be shown in two regression curves. Under 40℃ air curing, series Ⅰ was distributed near the curve of AIJ(1991). Series Ⅱ was distributed under the New-RC curve. Here, when 1.0 that was the coefficient value when fly ash was not used was substituted for K_2 that was the coefficient for influ-ence of admixture, it was distributed near the New-RC curve. Therefore, the concrete using fly ash un-der 40℃ air curing can appropriately evaluate the relation between compressive strength and static modulus of elasticity by the regression curve of the NEW-RC to disregard the influence of the admixture.

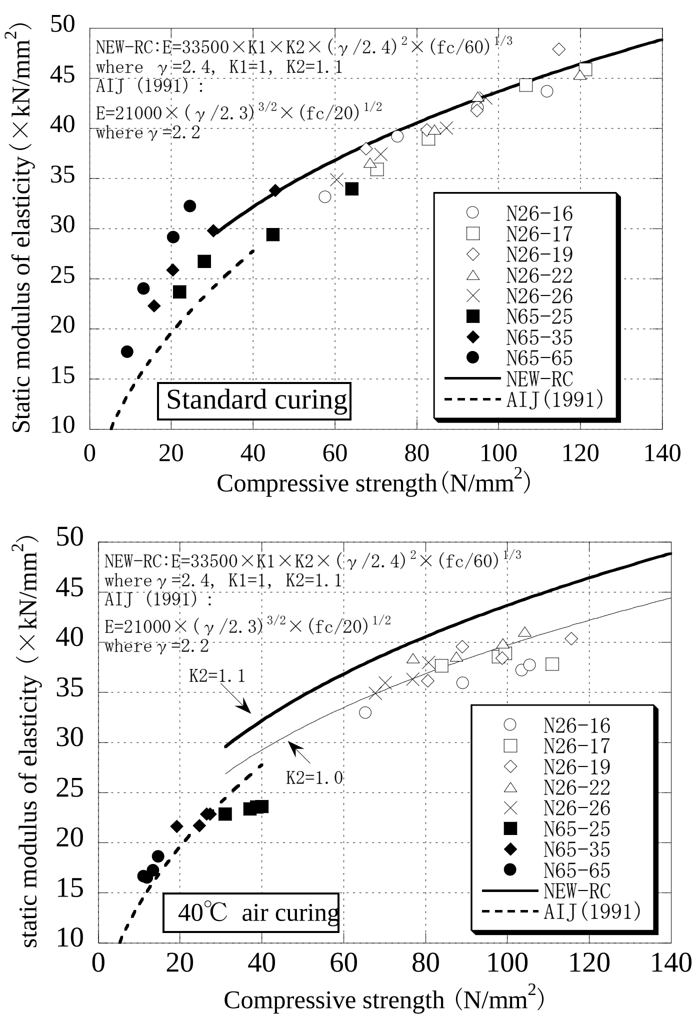

Fig. 5. Relation Between Compressive Strength and Static Modulus of Elasticity

Split tensile strength

Figure 6. shows relation between split tensile strength and fly ash content. For series Ⅰ under standard curing, split tensile strength of all mix pro-portions increased when the age passed and the fly ash content increased. For series Ⅱ under standard curing that increased when the age passed, however that did not increase when the fly ash content in-creased. That of concrete no using fly ash was higher than by 100kg/m3 or more. Split tensile strength doesn't increase even if concrete with large of the cement content increases the fly ash content. For se-ries Ⅰ under 40℃ air curing, split tensile strength increased when the fly ash content increased until 91 day. However, that hardly increased when compar-ing it by the same mix proportion though age passed. For series Ⅱ, that showed the tendency similar to se-ries Ⅰ. And that increased when using fly ash by about 200kg/m^3, was not effective even if it used it any more. Accordingly, it was clarified that the cur-ing condition influenced aging of split tensile strength of the concrete using high volume fly ash.

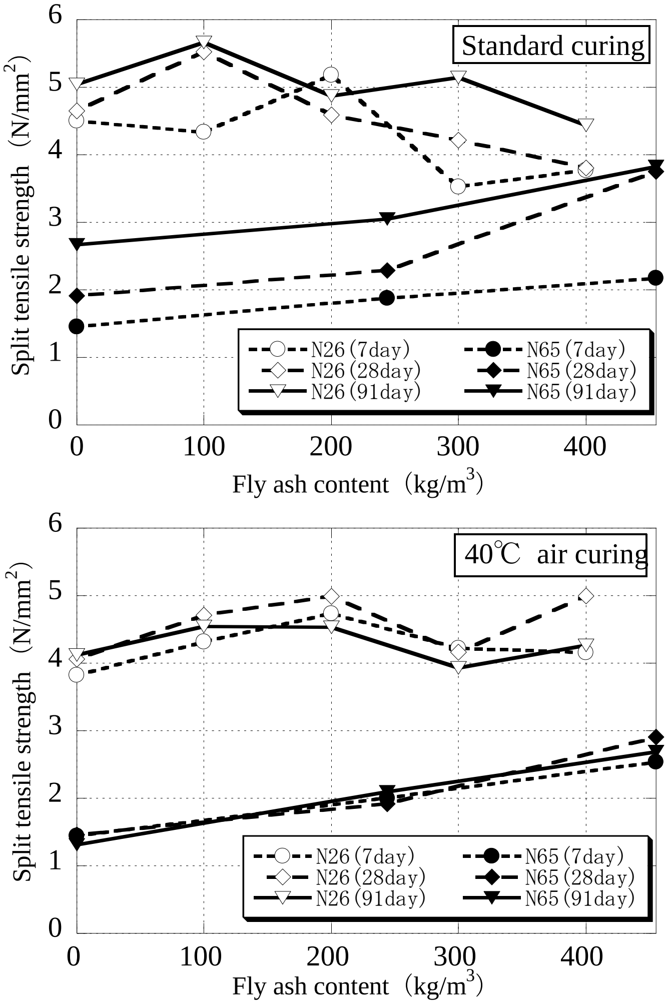

Fig. 6. Relation Between Split Tensile Strength and Fly Ash Content

Relation between compressive strength and split tensile strength

Figure 7. shows relation between compressive strength and split tensile strength. Both

standard curing and 40℃ air curing, series Ⅰ was distributed near the regression curve. Series Ⅱ was almost distributed under the regression curve. Especially, under standard curing it varied widely from the regression curve.

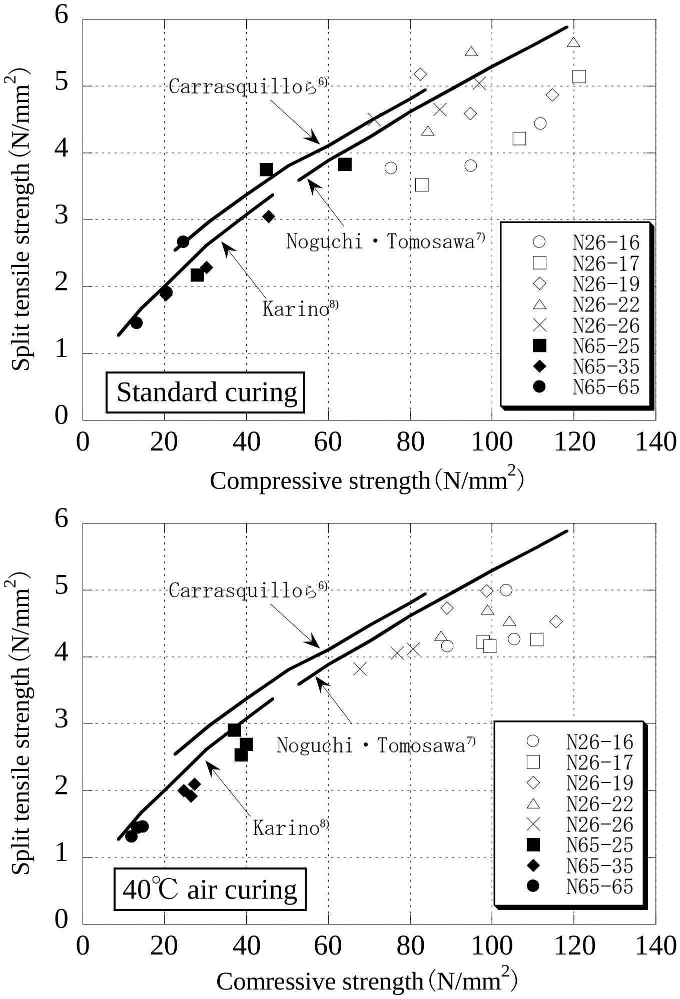

Fig. 7. Relation Between Compressive Strength and Split Tensile Strength

CONCLUSIONS

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

- Compressive strength of series Ⅱ specimens at 3 and 7day under 40℃ air curing was higher than compressive strength under standard curing. It is thought that this reason is that the hydration reaction became active at early time because the curing temperature is high. For the concrete using fly ash, the cumulative pore volume up to 2.5-200 nm in pore diameter under 40℃ air curing was lower than the standard curing at early day. It is thought that hydration reaction in the concrete progresses because it is exposed under high temperature, the cumulative pore volume decreases, and the hardening body is denseness.

- It was clarified that the compressive strength of concrete using fly ash by 400kg/m3 or more was negatively affected when the cement content was large. Under standard curing, the compressive strength of concrete using cement by 600kg/m3 or more was the best when using fly ash by about 100kg/m3, was not effective even if it used it any more. The compressive strength of concrete using cement by 600kg/m3 or more and no fly ash under standard curing was about 100N/mm2, however it under 40℃ air curing was about 80N/mm2. The compressive strength of concrete using fly ash by about 200kg/m3 became the same degree of compressive strength(110N/mm2 or more) as standard curing even 40℃air curing.
- Relation between compressive strength and static modulus of elasticity under standard curing can be shown in two regression curves of the NEW-RC and AIJ of Japan. The concrete using fly ash under 40℃ air curing can appropriately evaluate the relation between compressive strength and static modulus of elasticity by the regression curve of the NEW-RC to disregard the influence of the admixture. Both standard curing and 40℃ air curing, series I was distributed near the regression curve of research in the past. Series II was almost distributed under the regression curve.

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