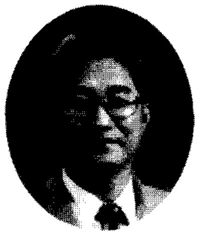
Effect of Powder and Aggregates on Compactability of High Performance Concrete



Lee, Seung-Han* Han, Hyung-Sub**

ABSTRACT

This study treated self-compacting high performance concrete as two phase materials of paste and aggregates and examined the effect of powder and aggregates on self-compacting high performance, since fluidity and segregation resistance of fresh concrete are changed mainly by paste. To improve the fluidity and self-compactibility of concrete, optimum powder ratio of self-compacting high performance concrete using fly ash and blast-furnace slag as powders were calculated. This study was also designed to provide basic materials for suitable design of mix proportion by evaluating fluidity and compactibility by various volume ratios of fine aggregates, paste, and aggregates.

As a result, the more fly ash was replaced, the more confined water ratio was reduced because of higher fluidity. The smallest confined water ratio was determined when 15% blast-furnace slag was replaced. The lowest confined water ratio was acquired when 20% fly ash and 15% blast-furnace slag were replaced together.

The optimum fine aggregates ratio with the best compactibility was the fine aggregate ratio with the lowest percentage of void in mixing coarse aggregate and fine aggregate in mixing the high performance concrete. Self-compacting high performance concrete with desirable compactibility required more than minimum of unit volume weight. If the unit volume weight used was less than the minimum, concrete had seriously reduced compactibility.

Keywords : high performance concrete, fluidity, compactibility, optimum fine aggregate ratio(S/a), the minimum of unit powder content

* KCI Member, Professor, Department of Civil Engineering, Keimyung University, Korea
** KCI Member, Master of Science, Department of Civil Engineering, Keimyung University, Korea

1. INTRODUCTION

To improv e quality of structure, it is essential to develop concrete which is not affected by workers' skill, shape of structure and arrangement of bar in placing concrete, and does not require tamping because of its fluidity, self-compactibility and segregation. Now we can find out various evidences of studying the concrete.[1,2)]

Most of those studies[3,4)] are classified into viscosity agent series, powder series and combined admixture series by the method of securing fluidity with high performance plasticizer and acquiring segregation resistance at high fluidity.

They, however, do not examine the influence of powder mix proportion and fine aggregate with the optimum fluidity and segregation of concrete, because they concentrate on the dispersion of coarse aggregate. Thus, the unit volume of coarse aggregate is less evaluated than that of common concrete and it causes to increase heat of hydration and drying shrinkage.[5)]

Therefore this study is designed to manufacture high performance concrete by evaluating fluidity and compactibility of concrete by various volume ratio of fine aggregate, paste and aggregates using fly ash and blast-furnace slag as powders on the basis of 2 phase materials mixing theory,[6)] for the fluidity and segregation resistance of concrete depends on paste.

It is also to provide basic materials for suitable design of mix proportion by calculating the optimum powder proportion and the optimum fine aggregate ratio of self-compacting high performance concrete.

2. OUTLINE OF THE EXPERIMENT

2.1. Materials

The properties of cement and powder used in the experiment are given in Table 1. The used cement was ordinary portland cement (OPC) made by A company. Powder for replacement was fly ash from Poryong in Chungnam and blast-furnace slag micropowder from Pohang in Kyongbuk.

Table 1 Chemical composition and physical properties of cement and mineral admixtures

Type	Blaine (cm^2/g)	Specific gravity	Ig.loss	Chemical composition					
				SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
OPC	3169	3.15	1.03	22.94	5.57	3.33	64.05	2.58	0.61
FA	3026	2.67	2.67	58.5	23.4	-	-	-	-
BS	4500	2.90	2.9	35.08	14.92	0.38	42.26	6.41	0.11

Fine aggregate consisted of Nakdong river sand from Koryong in Kyongbuk and its grading was adjusted by mixing crushed sand to meet KS grain size distribution in the figure 1.

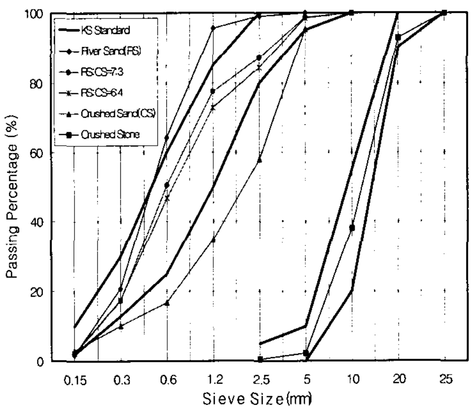


Fig.1 Grading curves of aggregate

Coarse aggregate was crushed stone from Koryong in Kyongbuk, of which grain shape was arranged into 0.731, the rectangular rate by an impact crusher to improve its fluidity. And its grading distribution is presented in Figure 1. The physical properties of all the aggregates are in Table 2.

Table 2 Physical properties of used aggregate

Type		Specific gravity	Absorption (%)	F.M.	Unit Weight (kg/m³)	Percentage of Solids (%)
River Sand(RS)		2.59	1.80	2.19	1527	59.1
Crushed Sand(CS)		2.64	2.07	3.82	1752	66.5
RS:CS	7:3	-	-	2.67	1695	65.1
	6:4	-	-	2.78	1671	64.2
Crushed Stone		2.71	0.94	6.91	1640	60.6

The used superplasticizer is included in melamine series, viscosity agent in cellulose ether series, and air entraining admixture in resin series. The chemical and physical properties of those chemical admixtures are shown Table 3.

Table 3 Chemical component and physical properties of chemical admixtures

Type	Characteristic	Main component	pH	Specific gravity
SP*1)	Dark brown	Melamine	11.5±1.5	1.22±0.02
AE*2)	Dark brown	resin	-	1.025±0.005
VA*3)	White	Cellulose	7±0.1 (1%Solution)	1.06±0.02

*1)SP : Superplasticizer
*2)AE : Air-Entraining Admixtures
*3)VA : Viscosity Agent

2.2. Experimental Procedure

2.2.1. Evaluation of confined water ratio

To specify the required unit water rate, it is necessary to calculate the unit water rate confined by cement or powder, in other words, the rate of water which does not contribute to fluidity.[7,8] High confined water ratio means that a lot of water was absorbed in powders and it refers to confined water volume. As indicated in figure 2, the proportion of confined water by powder, the intercept value on the vertical axis is called as confined water rate(β_p).

Large modulus of deformation needs great unit water volume to increase paste to be in the same range of flow. It was expressed as a slope of the line, E_p.

In this study, fly ash was replaced as much as 0%, 10%, 20%, 30% and 40% of cement. Blast-furnace slag(BS) is used by 0%, 15%, 30%, 45% and 60% of it.

They were mixed in accordance with the calculation of confined water ratio.[3] Each mix had various volume ratio of water to powder(W/P) including 1.1, 1.2, 1.3 and 1.4 to measure flow values by the change of volume ratio of water to powder.

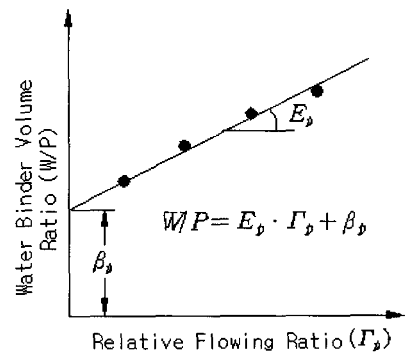


Fig.2 Linear regression analysis of β_p

2.2.2. Concrete experiment

The minimum unit powder was calculated by using 5 variations of unit powder, 450, 470, 500 550 and 650kg/m³. The ratio of fine aggregate to each unit powder was also varied 38%, 41%, 44% and 47% to get the optimum fine aggregate rate with the best fluidity and segregation. In addition, the fluidity and self-compactibility of high performance concrete were evaluated by the change of relative volume of aggregates and paste. The used powder was 20% of fly ash and 15% of blast-furnace slag with the smallest confined water rate to unit powder. The used fine aggregate was adjusted its grading with 7 to 3 of natural sand and crushed sand.

The mixing method of concrete was followed as Figure 3 below.

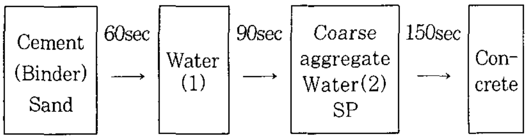


Fig.3 Mixing method of concrete

The mixed concrete was taken slump flow test for measuring air volume and fluidity. U type compacting test apparatus[9] in Figure 4 was utilized for testing its self-compactibility. V type funneling test apparatus in Figure 5 measured its related flow speed.

In slump flow test, concrete was tamped with a slump cone and filled in one story without applying any vibration. After leveling the surface of it, the slump cone was lifted up carefully. When concrete stops moving, the maximum diameter of it and the diameter of its vertical contact position were measured. The average of both diameters was its slump flow.

The arrival speed of 50cm slump flow area[10] was the time arriving from the moment of lifting the slump cone to the moment of maximum 50cm diameter.

$$\text{Arrival speed of 50cm slump flow area } (\text{cm}^2/\text{sec}) = \frac{\text{50cm slump flow area} - \text{area of slump cone}}{\text{Passing time of 50cm flow area}}$$

U type compacting test apparatus was used with the contents in Figure 4. Deformed bars D13 were arranged 5cm distance away each other in the test apparatus. The test apparatus was comparted by a shutter. Concrete was poured into the one side of it and was flowed out by opening the shutter after 1 minute. Then the height difference of both sides referred to the difference of self-compacting height.

Relative flow speed test was performed to measure flow speed with V type funneling test apparatus in Figure 5. After closing a shutter of the outlet for irrigation water, concrete was inserted into the perpendicular rod and leveled evenly. Then, the outlet was opened to flow concrete. The time was the flow time when the concrete from the top was flowed until the bottom appeared. Utilizing it, relative flow speed was calculated with the formula below.

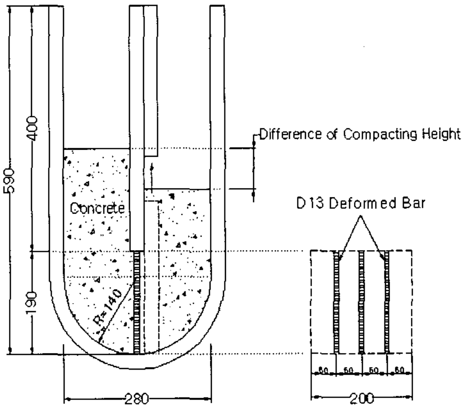


Fig.4 U type compacting test apparatus

Relative flow speed = $10/V_t$

V_t : Flow speed (sec)

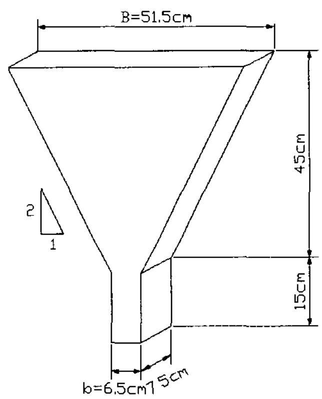


Fig.5 V type funneling test apparatus in concrete

To prepare a specimen for strength test, concrete was placed in the Φ10cm mold and demolded after being cured in a moist room for 24 hours.

The demolded specimen was cured in water with a water tank at 20±1℃ during the specified ages.

3. EFFECT ON SELF-COMPACTIBILITY OF HIGH PERFORMANCE CONCRETE

3.1. Effect of Powder on Fluidity of High Performance Concrete

Table 4 shows experimental values of confined water ratio and modulus of deformation by fly ash, blast-furnace slag and their combined replacement.

According to the table, the modulus of deformation ranges 0.07~0.11 and confined water ratio covers 1.03~1.11. The confined water ratio and modulus of deformation by each powder were changed as follows.

Table 4 Test results of confined water ratio

Type	β_p *1)	E_p *2)	Type	β_p	E_p
C100	1.08	0.09	C75FA10BS15	1.05	0.08
C90FA10	1.07	0.07	C60FA10BS30	1.08	0.07
C80FA20	1.065	0.07	C45FA10BS45	1.073	0.07
C70FA30	1.06	0.07	C65FA20BS15	1.03	0.08
C60FA40	1.05	0.07	C50FA20BS30	1.075	0.07
C85BS15	1.06	0.11	C35FA20BS45	1.07	0.08
C70BS30	1.07	0.11	C55FA30BS15	1.04	0.08
C55BS45	1.09	0.11	C40FA30BS30	1.07	0.08
C40BS60	1.09	0.11	C25FA30BS45	1.08	0.07

*1) β_p : Confined Water Ratio

*2) E_p : Modulus of Deformation

C75 FA10 BS15
- BS15 — Blast-furnace Slag 15%
- FA10 — Fly ash 10%
- C75 — Cement 75%

3.1.1. Effect on confined water ratio of powders and their replaced volume

The confined water ratio was changed in Figure 6 by various ratio of replaced fly ash.

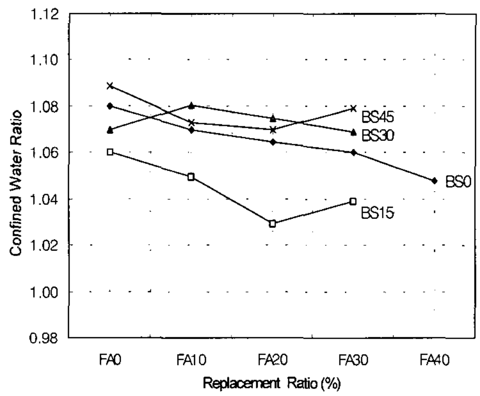


Fig.6 Confined water ratio according to replacement ratio of Fly ash

When the fly ash was only replaced, the ratio of replacement increased with decreasing confined water ratio. Since fly ash decreased the confined water ratio like prior studies[3] with the same result, concrete mixed with fly ash had larger fluidity than common concrete.

Confined water ratio was also decreased as the ratio of replaced fly ash when fly ash and blast-furnace slag were replaced together.

Figure 7 shows the change of confined water ratio by blast-furnace slag of the fineness 4500㎠/g.

Ordinary portland cement, of which confined water ratio is 1.08, has the lowest confined water ratio when 15% of blast-furnace slag is replaced, regardless of individually replacing blast-furnace slag or combinedly replacing it and fly ash. If blast-furnace slag is replaced over 15%, confined water ratio inclined to be increased.

When used cement is mixed with 15% of blast-furnace micropowder and 20% of fly ash together, it shows the lowest confined water ratio of 1.03. It means that the mixture ratio above is effective on improving the fluidity of the cement.

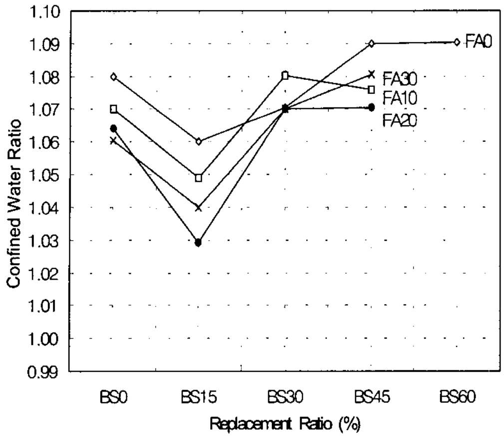


Fig.7 Confined water ratio according to replacement ratio of blast-furnace slag

3.1.2. Modulus of deformation changed by kinds and replacement ratio of powder

Quality fly ash has the effect of ball bearing by its spherical shape to improve the fluidity of concrete. Blast-furnace slag, however, does not increase yield value and plastic viscosity of concrete because of its flat and wide glassy particles, with not considerable effect on the fluidity of concrete.

Figure 8 shows the correlations with relative flowing ratio and water cement volume ratio by replacement ratio of blast-furnace slag and fly ash.

Moduli of deformation of the components are expressed as the inclination of each line. When fly ash is replaced as much as 40% of cement, its modulus of deformation is 0.07. Replaced blast-furnace slag micropowder has 0.11 of modulus of deformation. Both moduli of deformation are larger than 0.09 of ordinary portland cement. The replacement of blast-furnace slag increases required water cement volume ratio to promote the flow of the same range in comparison with fly ash.

Thus, increasing replaced fly ash reduces confined water ratio and maintains modulus of deformation. It greatly contributes to improve the fluidity of concrete.

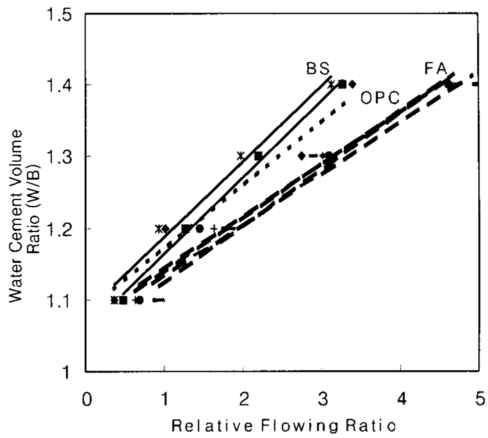


Fig.8 Test results of powder

3.2. Effect of Aggregate on High Perform- ance Concrete

3.2.1. Percentage of void changed by fine aggregate ratio and fineness ratio

Aggregate with fine grading and narrow void requires small cement paste to be surrounded with aggregate particles. Therefore, it is general that concrete with constant unit cement and unit water has improved workability. In this study, percentage of void changed by fine aggregate is explained in figure 9 and 10 in order to know minimum percentage of void by S/a.

When the mixture ratio of natural sand and crushed sand is 7 : 3, fine aggregate ratio with the smallest percentage of void is 40% in this study.

In case the mixture ratio is 6 : 4 and the fineness aggregate ratio is 2.78, minimum percentage of void is 45%. It means that the higher the fineness aggregate ratio increases, the larger the minimum percentage of void.

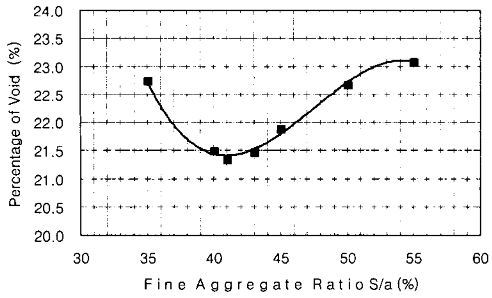


Fig.9 Percentage of void according to fine aggregate ratio (7 : 3)

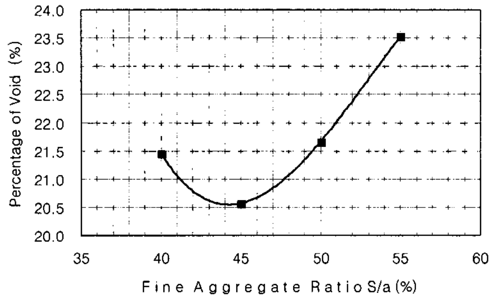


Fig.10 Percentage of void according to fine aggregate ratio (6 : 4)

3.2.2. Effect of fine aggregate on self-compactibility

Self-compactibility of concrete is changed by various fine aggregate ratio and percentage of void. To find out the changed degree, flow test is performed with different unit powder volume and fine aggregate ratio. Table 5 shows the results. According to it, larger unite powder volume needs smaller use of high performance plasticizer to maintain the same fluidity. It is considered that unit powder volume increase improves the workability of concrete. In figure 11 based on this table, the difference of self-compacting height is explained with various fine aggregate ratio. As seen in see the figure, the best self-compactibility appears in 41% of the smallest percentage of void, with no relations to unit powder volume.

When unit weight of powder is 450kg/㎥, 41% of the smallest percentage of void shows the lowest difference of self-compacting height, 19.0㎝.

Table 5 Test results of Concrete

Unit Weight of Powder (kg/m^3)	S/a (%)	SP (C×%)	Slump flow (cm)	Arrival speed of 50cm (cm^2/sec)	Difference of Compacting Height by U type Apparatus(cm)	Air content (%)	Compressive Strength (kg/cm^2)
450	38	3.0	58.0	51	23.0	7.0	408
	41		56.5	53	19.0	4.7	428
	44		48.5	-	25.0	5.0	445
	47		43.5	-	27.0	5.0	446
470	41	3.0	60.0	76	1.0	5.7	407
500	41	3.0	69.5	220	1.0	5.1	445
550	38	2.0	64.5	281	7.0	4.2	422
	41		64.5	256	2.5	5.8	418
	44		45.5	-	12.5	5.5	420
	47		44.0	-	16.0	8.0	425
650	38	1.5	66.5	512	1.0	4.3	429
	41		69.0	452	1.0	4.5	457
	44		64.0	414	2.0	4.8	466
	47		65.0	532	2.5	5.2	501

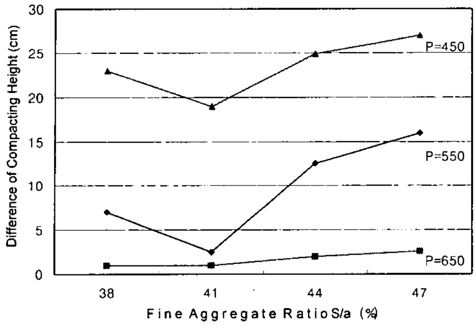


Fig.11 Correlation difference of compacting height with S/a according to unit weight of powder

Unit weight of powder, 550kg/㎥ has the best compactibility at 41% of fineness aggregate ratio. In case of 38%, 44% and 47% of fine aggregate ratio, the difference of compacting height gradually increases. Unit weight of powder, 650kg/㎥ has proper difference of compacting height less than 2.5cm at every fine aggregate ratio. The increase of the unite powder weight causes longer average distance among aggregates. Due to it, the friction among them deceases and finally the difference of compacting height reduces.

With the variation of unit powder weight, the smallest percent of void, 41% has good compactibility. It can be explained that much residue exists after filling in voids of aggregate in case of small percentage of void. As the result, a theory is established that residual paste increases the average distance among aggregate particles and reduces their friction.

Fig.12 is the change of slump flow by the fine aggregate ratio. 38% and 41% of fine aggregate ratio have almost same flow values. Higher ratio of it tends to reduce slump flow.

When unit weight of powder is 450kg/㎥, slump flow of concrete by the change of fine aggregate ratio is not included within 65±5cm of target slump flow, even though high performance plasticizer in melamine series is used as the maximum as recommended value, 3%. As fine aggregate ratio increases, slump flow reduces.

When unit weight of powder is 550kg/㎥, flow value is good value of 64.5cm until 41% of fine aggregate ratio. But higher fine aggregate ratio causes serious reduction of flow value.

In using unit weight of powder, 650kg/㎥, all fine aggregate ratio and compactibility are in good condition. 41% of fine aggregate ratio has 69.0cm of flow value.

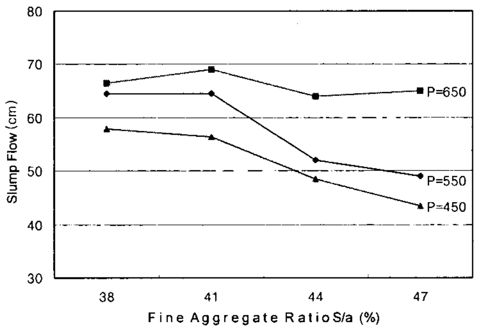


Fig.12 Correlation of slump flow with S/a according to unit weight of powder

According to Okamura et al.,[3] for manufacturing high performance concrete, the used volume of coarse aggregate occupies 50% of absolute volume of it. On the other hand, this study suggests the mixture ratio for manufacturing high performance concrete with good compactibility that 53% coarse aggregate of unit weight of powder 650kg/㎥ and 59% of 550kg/㎥ on the basis of 41% fine aggregate ratio.

It means fluidity and compactibility of fresh concrete significantly depend on percentage of void in mixing coarse and fine aggregates, and relative volumes of aggregate and paste, rather than the effect of coarse aggregate.

3.2.3. Evaluation of compactibility by the change of unit weight of powder

Shindoh et al.,[11] reported that required unit weight of powder is about 500kg/㎥ for good compactibility. Cho et al.,[12] asserted that minimum unit weight of powder is 550kg/㎥ to manufacture super flow concrete.

This study examined the critical aggregate volume to cause closing by aggregate and minimum unit weight of powder to manufacture high performance concrete. The correlation with slump flow and the difference of compacting height were described in figure 13 by increasing unit powder weight of concrete in specifying fine aggregate ratio.

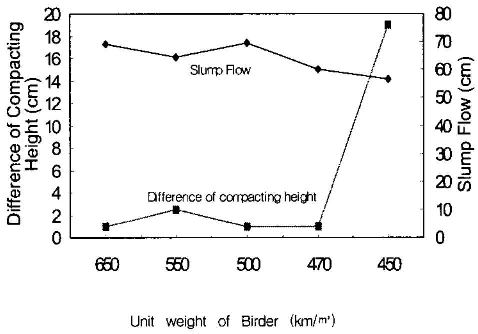


Fig.13 Correlation of the difference of compacting height with slump flow according to unit weight of powder

First, the volume of high performance plasticizer suitable for slump flow 65±5cm reduces against the increase of unit powder weight. It is interpreted that the increase of unit powder weight causes to enlarge residual paste filling in voids among aggregates, resulting in increasing the fluidity of concrete.

In the test of compactibility, more than 470kg/㎥ of unit powder weight has good compacting within 2.5cm of the difference of compacting height. But, 450kg/㎥ of it has seriously increased difference of compacting height. It seems that it is originated from closing by friction among aggregates by relative volume of paste and aggregate. Therefore, more than 470kg/㎥ of unit powder weight is the most appropriate volume for the design of mix proportion to manufacture self-compacting high performance concrete. It can also be said that critical aggregate volume is 0.657㎥/㎥.

3.3. Properties of Compressive Strength

Figure 14 shows the change of compressive strength with age of 28 days by various unit powder weight and fine aggregate ratio.

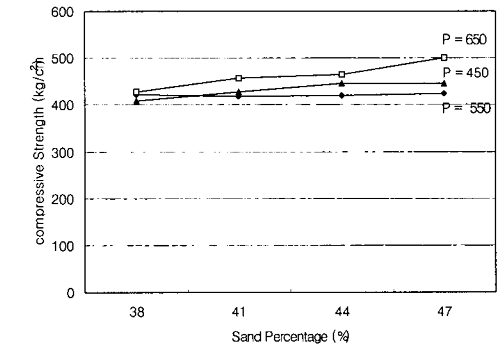


Fig.14 Compressive strength according to S/a

The compressive strength by unit powder weight and fine aggregate ratio is included within 400~500kg/㎠ without any distinct difference. It gradually increases as fine aggregate ratio is higher.

Figure 15 has the change of compressive strength with age of 28 days by unit weight of powder.

The compressive strength by unit powder weight ranges from 400kg/㎠~500kg/㎠ without any special inclination.

It results from constant water cement volume ratio consisting of rich mix with unit weight of powder, 450kg/㎥.

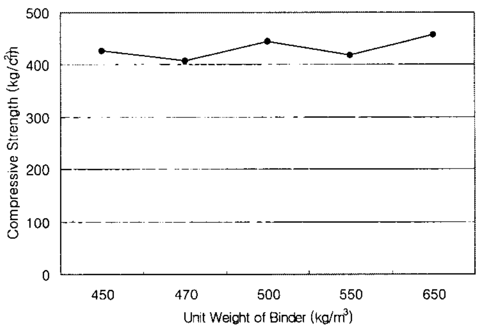


Fig.15 Compressive strength according to unit weight of powder

4. CONCLUSIONS

We concluded the following in this study by researching the effect of powder and aggregate on the compactibility of high performance concrete, using fly ash and blast-furnace slag.

1. Optimum compactibility of concrete can be acquired in the smallest percentage of void when coarse and fine aggregates are mixed. Consequently, optimum fine aggregate ratio has the smallest percentage of void to make good compactibility of high performance concrete.
2. When self-compacting high performance concrete is mixed, its good compactibility requires more unit weight of powder than the minimum. According to this study, the minimum unit weight of powder is 470kg/m³ and it can be said 0.657m³/m³ as maximum aggregate volume.
3. The more replaced fly ash increase, the higher fluidity rises. It causes to reduce confined water ratio. Blast-furnace slag has the lowest confined water ratio when it is replaced by 15%. 15% blast-furnace slag and 20% fly ash of their mixture are replaced to show the lowest confined water ratio.
4 The compressive strength of high performance concrete with the age of 28 days is more than 400kg/cm² when the confined water ratio is 33%.

REFERENCES

1. By Hiromi Fujiwara, Yoshihide Shimoyama, Rokuro Tomita and Hiroyasu Kubota, "Fundmental Study on the Self-Compacting Property of the High Fluid Concrete" Proceedings of the Japan Concrete Institute, Vol.14, No.1 P.27~32.
2. By Masahiro Yurugi, Noboru Sakata, Minoru Iwai "Studies on Self-Consolidating Concrete Containing Segregation Controlling Admixture" Proceedings of the Japan Concrete Institute, Vol.14, No.1 P.51~56.
3. Okamura, H. et al., "High-Performance of Concrete", Giboudou, 1997.
4. Byun, K. J., "Research and Application of High Performance Concrete" Journal of the Korea Concrete Institute, Vol.6, No.1, 1994, pp. 2~23.
5. By Eiji Sudo, Yoshihiro Masuda and Shinji Gomi "The influence of Fine Aggregate Grading on Workability of High-Fluidity Concrete" Proceedings of the Japan Concrete Institute, Vol.18, No.1 pp.123~128.
6. Murata et al.,"Science and Technique of Concrete", Sankaidou, 1996.
7. Kwon, Y. H. and Park, C. L., "A Development and Practicality Study of High Performance Concrete", Journal of the Korea Concrete Institute, Vol.7, No.5, 1997, pp. 421~50.
8. Yoon, J. H., Cha, T. H., Hong, S. J. and Kwon, G. H., "An Experimental Study on the Manufacturing and Application of High-Workable Concrete", Proceeding of the Korea Concrete Institute, Vol.8, No.2, 1996, pp. 109~117.
9. Kwon, Y. H., Lee, S. S., Ahn, J. H, and Park, C. L., "The Study on the Mix Design of the Super Flowing Concrete", Proceeding of the Korea Concrete Institute, Vol.8 No.2, 1996, pp. 283~289.
10. Kim, G. Y., Choi, H. Y., Kim, H. K. and Kim, M. H., "The Experimental Study on the Influence of Relation between Cement Paste and Aggregate Volume to Effect the High Flowing and Engineering Properties of High Flowing Concrete" Proceeding of the Korea Concrete Institute, Vol.8, No.2, 1996, pp. 301~307.
11. By Takefumi Shindoh, Yasunori Matsuoka, Somnuk Tangtermsirikul and Jun Sakamoto "A study of the basic physical propertis of super workable concrete" Vol.13, No.1, 1991, pp.179~184.
12. Cho, I. H., Han, C. H., Noh, J. H. and Jaung, J. D., "Experlmental Study on the Development of High Perf- ormance Concrete" (Propertles of Super-flowing Concrete), Journal of the Korea Concrete Institute, Vol.5, No.2, 1994, pp. 51~56.