Evaluation of Mixing Conditions for the Production of Optimized High Flowing Concrete

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ABSTRACT

Most difficulties of inducing high fluidity on the concrete mixing design with a strength range of 210 to 240kg/cm^2 result from the segregation of aggregates due to the shortage of cementitious binders. To solve the problem, this study concentrated on finding the optimized amount of binder material which does not affect the concrete strength and is also economical. Also there were studies on the use of intermediate sized aggregates to avoid the gap-grading between coarse and fine aggregates so that the material segregation in high flowing concrete was and minimalized the fluidity and penetration capacity of the reinforcing bars was enhanced.

Throughout the parametric study with respect to water/binder ratio, superplasticizer, replaceable mineral admixture, the size of coarse aggregate and mixing methods, the effect of each constituent on the characteristics of high flowing concrete could be observed.

As a result of partially using stone powder or an intermediate class of aggregate (max. diameter 13mm), it was found that the fluidity of concrete significantly increased without material segregation and any change of compressive strengths. It was also proved in this study that proper mixing time and speed are significant factors influence the performance of high flowing concrete.

Keywords : fluidity, segregation, cementitious binders, stone powder, slump-flow, anti-washout admixture, U-type test, penetration capacity

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1. INTRODUCTION

The higher and larger the recent concrete structure tends to be with revitalization of the social overhead capital, the more advanced technology for construction than previous is actually required. But, social recognition for construction workers goes worse adversely and accordingly people are willing to evade from concrete working as they can. As the result, a series of large-scaled structures have been recently fallen down due to low quality of concrete in association with reluctant work.

Lots of studies for high flowing concrete have been suggested under the consideration that it is only a way to solve the confronted problems. However, most studies have been concentrated on the development of high strength/flowing concrete with use of large amount of cement, because this type of concrete can be easily made without material segregation which is known to be most difficult in high flowing concrete. Due to excessive application of cement, but, this concrete may cause the increase of construction cost with unnecessary rise of concrete strength and, even to make matters worse, it can develop cracks by high hydration heat in mass concrete. Practically, this high strength/flowing concrete is not much necessary to general construction field except special structures such as ultra-high story buildings, or thin-shell concrete structures and so on.

This study aims thus at the development of high flowing concrete which has normal strengths of 210 to 240kg/cm^2 but almost equivalent to high strength/flowing concrete in terms of slump-flow value and fluidity, which are indices of success in making high flowing concrete. High flowing concrete developed in this study is expected to be applicable to various construction area such as complex buildings located at a nuclear power station, heavy concrete structures exposed to severe environment, and general buildings which require low strengths and cost but high quality.

2. EXPERIMENTS AND TESTING METHOD

Tests were carried out with variation of material parameters such as cementitious materials, chemical admixture and mixing time, which are known to affect the fluidity of concrete significantly.

2.1 Materials

2.1.1 Cement and Mineral Admixture

Cement used in this experiment was Type I Portland cement commercially produced in Korea. As for the mineral admixture for the improvement of fluidity of concrete, fly ash produced at Boryeng, Chungnam was used for partial replacement of Portland cement. Physical and chemical characteristics for both cementitious materials are shown in Table 1.

2.1.2 Aggregates

Coarse aggregates used in this study were crushed stones with maximum sizes of 19mm. Fine aggregates were gathered from Han River. Material characteristics for aggregates are shown in Table 2.

2.1.3 Chemical admixture

Superplasticizer of polycarbon type, which is usually used for the fabrication of high strength or high flowing concrete, was applied in concrete mix.

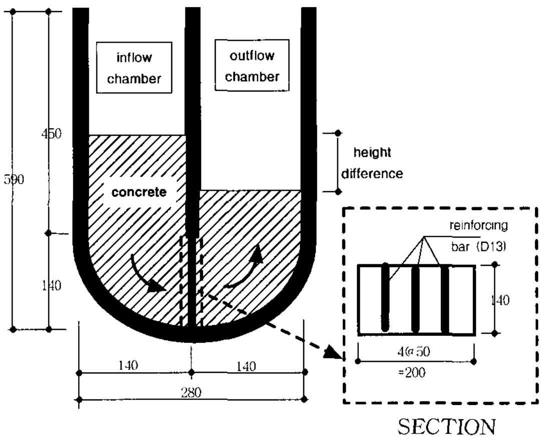

Fig.1 Schematic illustration of U-type box device

Anti-washout admixture was cellulose-ether type with specific gravity of 1.06± 0.02. Anti-washout admixture is generally used for the fabrication of anti-washout concrete in order to prevent the concrete from washing away in underwater construction. In this experiment, however, this admixture was added for the aggregates in the fresh concrete not to settle down easily by enhancing the viscosity of concrete. Since anti-washout admixture is quite expensive, the use of this admixture was tried to be as least as possible in the experiment.

2.2 Testing Method

The purpose of this experiment is to examine the flowing characteristics of high flowing concrete and to seek the methods to improve the fluidity in the normal strength range. Therefore, the effects of stone powder as a material supplementing the lack of binders are investigated first in normal strength/high flowing concrete. Also, through extensive observations associated with smaller sizes of coarse aggregate, chemical admixture and mixing method, optimized mix design proportion and mixing method are to be suggested finally.

To do this, preliminary test was carried out to select suitable mixing parameters. As that result, optimized fine aggregate ratio (s/a) of 50% was determined. The amount of anti-washout admixture was fixed to 0.3% of unit water weight in order to make economical concrete.

The ratio of water to binders (W/P) was selected in the range of 46 to 50% which is seemed to meet the schemed normal strength of 210 to 240kg/cm^2. The amount of stone powder and chemical admixture were based on the destined slump flow value of more than 50cm. The percentage of stone powder replaced

Table 1 Chemical composition and physical characteristics of cement and mineral admixture

Items	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	Ig.Loss (%)	Specific gravity	Blaine (cm^2/g)
Cement	20.57	5.64	3.26	63.1	3.35	2.11	1.21	3.15	3,150
Fly ash	52.09	25.36	12.90	2.58	1.37	0.07	2.20	2.15	4,230
Stone powder		0.3	0.2	54.8	0.4			3.05	#300 pass

Table 2 Material characteristics of aggregates

Items	Specific gravity	Absorption ratio (%)	Finess modulus	Unit weight (kg/m^3)	Ratio of absolute volume (%)	Organic impurities
Fine aggregate	2.61	0.79	2.88	1.625	59.8	Good
Coarse aggregate	2.63	0.93	6.91	1.670	62.3	-

partially with cement was in the range of 2 to 10% of total binder material weight with increase of 2%. In the meanwhile, the percentage of fly ash was fixed to 20% of total binder weight. The amount of 13mm coarse aggregate for replacement of 19mm coarse aggregate was determined in the range of 10 to 50% of total coarse aggregate weight. Table 3 summarizes the range of application used for parametric study.

Mixing method used in this study is that binder materials, a mixture of cement, fly ash and stone powder were added with aggregates together first, and then agitated for 1 minute using a forced circulating mixer. Water and chemical admixture were added together and agitated thoroughly. But, total mixing period was varied from 2 to 8 minutes as a variable parameter. Rotating speed of the mixer was differently applied at 3, 9 and 15 rpm also. The fluidity or fillability

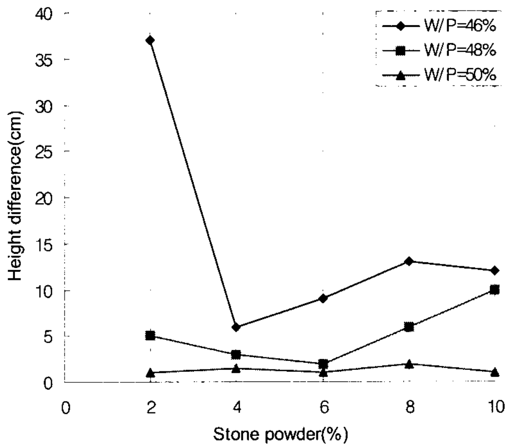

Fig.2 Results of U-type test with different application of power stone

of this concrete was evaluated using slump cone and U-type testing devices. Slump-flow and compressive strength tests were carried out in accordance with Korean Standard specification and U-type device was fabricatd specially to measure the difference of heights between inflow

Table 3 Parametric study

Mixing parameters	Criteria	Mixing range	Remarks
Unit water	kg/m^3	170 to 185	Ratio of fine aggregate (s/a)=50% Binder(P)=Cement+Fly ash+ Stone powder
Superplasticizer	Weight of binder×%	1.0 to 2.0	
Water/binder(W/P)	%	46 to 50	
Anti-washout admixture	Weight of unit water×%	0.3	
Stone powder	Binder×%	2 to 10	
Replacement of 13mm coarse aggregate	Weight of coarse aggregate×%	10 to 50	

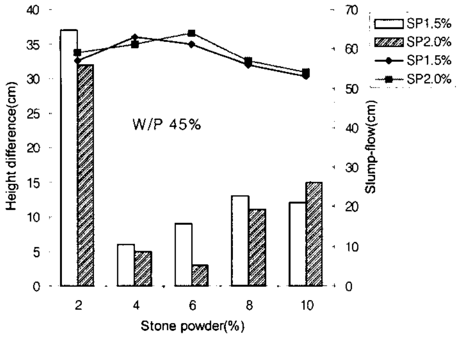

Fig.3 Response of slump-flow value and height difference of U-type test in association with different application of superplasticizer and stone powder (W/P=45%)

and outflow chamber, i.e., to evaluate the capacity of penetrating into reinforcing bars without congregation or settlement of aggregates as shown in Fig.1.

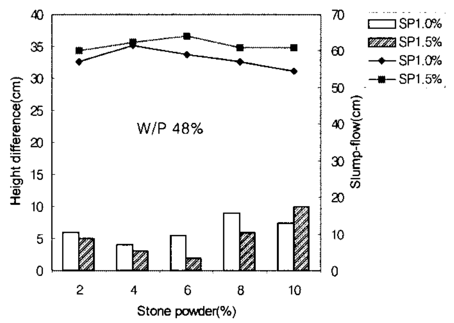

Fig.4 Response of slump-flow value and height difference of U-type test in association with different application of superplasticizer and stone powder (W/P=48%)

3. TEST RESULTS AND DISCUSSIONS

3.1 Characteristics of Fluidity Associated With the Amount of Binders

Figs. 2 to 5 show the results of slump-flow and U-type test in association with different amount of stone powder. It can be observed that, irrespective of W/P magnitude, slump-flow values tend to increase as the amount of stone powder increases. This may be due to that voids existing between aggregates are filled with fine particles of stone powder, which smooths interlocking between adjacent aggregates and follows the enhancement of fluidity. Once the added amount of stone powder was approached to a certain level, however, the slump-flow value was decreased inversely due to too much increase of viscosity and stickiness. In terms of U-type test, the increase of stone powder resulted in the reduction of height difference between inflow and outflow, but showed worse effects also when the dosage beyond a reference level was applied. This may be explained from that excessive addition of powder requires more consumption of mixing water than normal proportion, which accordingly results in the lack of consistency as shown in the result of slump-flow test. In the meanwhile, W/P of 48% and 50% showed comparatively good result of 5cm below in height difference. Best results were observed at the replacement of stone powder with 4% of total binder weight for W/P of 48% and 6% for W/P of 50% respectively. Different effects of the amount of stone powder on the fluidity are thought to be significantly related to unit water required to keep the plasticity.

W/P of 50% showed good results irrespective of different application of stone powder.

As for the effect of superplasticizer, the increase of the amount generally resulted in the enhancement of both fluidity and penetrating capacity of the concrete as expected. As shown in Figs. 3 and 4, however, concrete of applying too much stone powder showed worse performance. This indicates that, in case of using large amount of stone powder, superplasticizer is of insignificant importance.

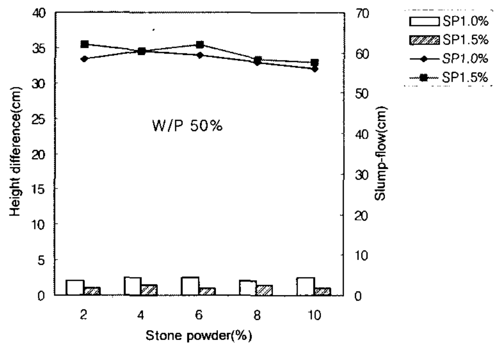

Fig.5 Response of slump-flow value and height difference of U-type test in association with different application of superplasticizer and stone powder (W/P=50%)

the material of hydraulic hardening or setting with ages, but, too much application of stone powder results in the decrease of compressive strengths with corresponding reduction of cement amount.

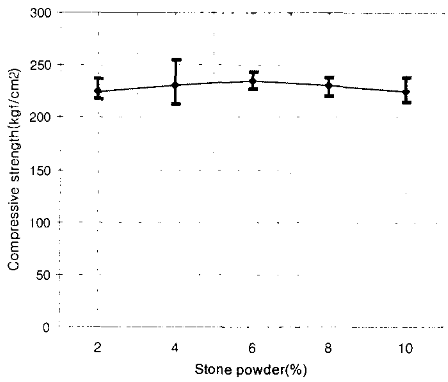

Fig.6 Relationship between the addition of stone powder and compressive strengths at 28 days

3.2 Response of Strengths to Addition of Stone Powder

Fig.6 shows the relationship between the addition of stone powder and compressive strength at 28 days. It can be observed from the figure that the application of stone powder does not affect compressive strength severely.

Especially, but, replacement of 6% of total binder with stone powder showed slightly higher strength. This may be explained from that, in a point of microscopic view, the use of stone powder shall lead to a closer and denser texture than the case of not using stone powder because finer grains of stone powder fill the voids inside concrete, thus improving the compactness of the material and at the same time increasing the properties of the fresh mix. Since stone powder is not

3.3 Fuidity Associated With Aggregates of 13mm Size

Though the effect of stone powder on the fluidity without material segregation was evaluated to be significant throughout experiment, the use of stone powder has still problems of obtaining materials and applying to construction field practically because the product is currently used for feeding stuff. Thus, it is thought to be necessary to study the effect of sizes of coarse aggregate as an alternative.

Segregation is generally defined as separation of the constituents of a concrete mixture so that their distribution is no longer uniform. In the case of concrete, the coarse aggregates tend to separate out since they settle more than finer particles. However, its extent can be

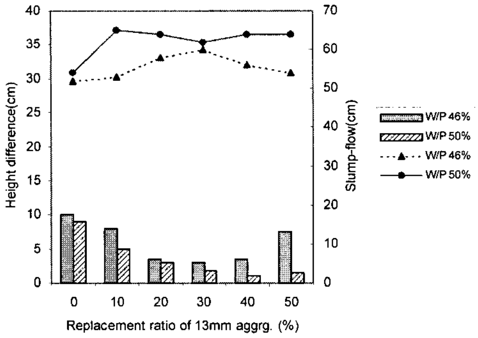

Fig.7 Effect of replacement with 13mm aggregates on the fluidity and penetration capacity

controlled by the choice of suitable grading. Though coarse aggregates are properly blended to be in a uniform grading when produced in the factory, they may be gap-graded possibly and we are in fact using these[3]. Therefore, it is thought that to fill the gap existing between the sizes of any two adjacent particles with proper particles is of significant importance because high flowing concrete is much more sensitive to the distribution of grading than conventional concrete.

Based on this concept, it was tried in this study that some of max. aggregate sizes of 19mm were replaced by those of 13mm which has much finer particles and has been used at the construction of asphalt pavement. The result of evaluating fluidity and penetrating capacity is shown at Fig.7. It can be observed that the combined use of 13mm and 19mm aggregates improved much more fluidity and penetration of reinforcing bars than exclusive use of 19mm, especially in the case of partial replacement of 20 to 30% in W/P of 46%. However, in the case that the replacement was more or less than indicated, both of fluidity and penetration were not satisfactory due to poor grading distribution, implying that the quantity of water necessary for making the required flowing concrete should be further added. Replacement rate of 20 to 50% in W/P of 50% showed good results of fluidity and penetration capacity.

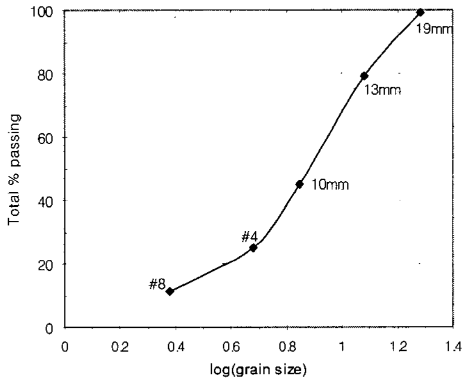

Fig.8 Sieve analysis for grain sizes of 13mm

3.4 Characteristics of Fluidity Associated with Mixing Time and Speed

In general, the longer mixing time within the range that material segregation does not take place, the more significantly the quality of concrete is improved because ingredients of the concrete are distributed uniformly in the mixer. It follows the improvement of strength and durability. Therefore, it is important to know the optimum mixing time necessary to produce a concrete uniform in composition. But this time shall varies depending on the type of mixer. In other words, the length of mixing time can have a close relationship with the revolution speed of the mixer.

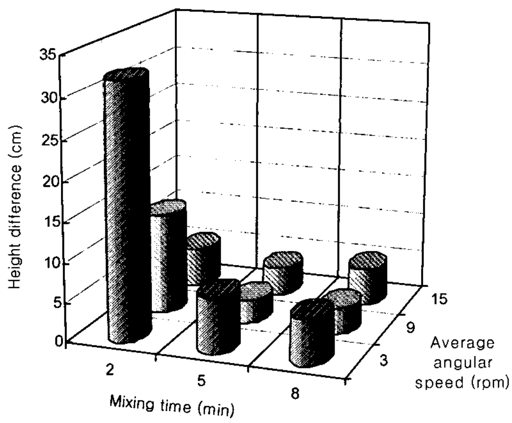

Fig.9 Effects of mixing time on the height difference of U-type test

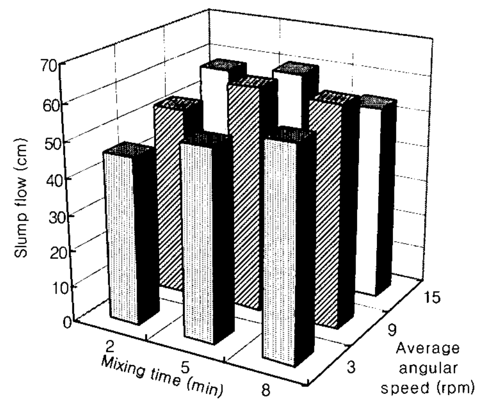

Fig.10 Effects of mixing time on the slump-flow values

Since in compare with normal concrete, high flowing concrete is apt to lose viscosity and correspondingly cause congestion of aggregates, great care in selecting mixing method should be taken in order for material segregation not to occur. Figs. 9 and 10 represent the mixing time and speed required for sufficient uniformity of the high flowing concrete mix. It can be seen from those figures that 2 minutes of mixing, usually adopted for the mixing of ordinary concrete, was not sufficient to provide satisfactory results in both of fluidity and penetration, and rapid speed of revolution yielded better quality of concrete. It can be observed that mixing for 5 minutes with speed of 9 rpm produces the most optimum fluidity and penetration capacity. But prolonging the mixing time and speed beyond this value results in no significant improvement in concrete quality. As mentioned before, since the exact value of the optimized mixing time varies with the type of mixer and depends on its size also, the order of feeding the ingredients into the mixer and conditions of construction field and so on, the given information is only applicable to laboratory. It is thought that trials to find out the optimized values have to be performed in accordance with site conditions when high flowing concrete is practically applied to a site.

3.5 Comparison with Other Country's Results

Japan is known to be one of countries performing the most active research with respect to high flowing concrete. As a result of comparing our results with Japanese as shown in Table 4, it is found that Korean aggregates are in short of finer particles which make an important role of governing fluidity as mentioned earlier. In addition, the shape of crushed stone is much more angular than Japanese. Actually, grading requirements depend to some extent on the shape and surface characteristics of the particles. Sharp and angular particles with rough surfaces should have finer particles to reduce interlocking and to compensate for the high friction between particles. This fact may reveals that our mix design proportion requires finer particles and intermediate sizes of aggregate to acquire the identical performance of high flowing concrete of Japan.

In terms of economics, the cost associated with high flowing concrete becomes increased in compare with conventional concrete due to the use of anti-washout admixture or more dosage of superplasticizer. Since Japanese labor charge is very high, however, application of chemical admixture is not limited to the use. In considering a continuous increase of the labor charge in Korea also, the application of high flow concrete to the practical field shall be very active in the near future, even now some of the sites are applying high flowing concrete in a tentative way.

4. CONCLUSIONS

As a result of studying the effects of constituents on the formation of high flowing concrete, it can be concluded as follows:

(1) To fill the gaps formed by size differences between adjacent particles is a critical solution to increase the fluidity and penetration capacity in high flowing concrete. In this case, the application of stone powder shows an increase of fluidity without material segregation or excessive application of chemical admixture.

(2) It is expected to utilize the stone powder commonly to get the satisfied high flowing concrete because it can establish a required cohesion and compressive strength without harmful effect on concrete quality.

(3) Partial replacement of coarse aggregates with maximum sizes of 13mm helps to make the high quality of flowing concrete.

(4) Mixing time and revolution speed of the mixer are significantly related to the characteristics of fluidity. Generally, high flowing concrete requires longer mixing time than conventional concrete in a extent that material segregation does not occur. But they converge into a certain specific value for the production of optimized concrete. It is expected in the future that study on mixing constituents, mixer type, the order of feeding materials and the amount of materials applied should be extended to get more comprehensive results.

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Table 4 Comparison of concrete constituents between Korea and Japan

Items	Korean	Japanese	Remarks
Blaine of OPC	Less than 3,300	more than 3,300	
Shape of crushed stone	Angular and lots of schists	rounded and not much schists	
Mineral admixture	Low fineness	High fineness	Blast furnace slag, Fly ash etc.

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