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PRODUCTION AND PROPERTIES OF HIGH STRENGTH CONCRETES CONTAINING VARIOUS MINERAL ADMIXTURES

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ABSTRACT

This paper presents a study of the effects of type of mixer and mineral admixture on the workability and compressive strength of high strength concrete. The tilting drum mixer was found to be able to perform like the pan mixer in producing high strength concrete with compressive strength higher than 100MPa. The relationship between cylindrical specimen and cube specimen of high strength concrete was also studied and was found to be the same as the reported studies on conventional concrete.

Introduction

There have been many reported studies on the production and mechanical properties of high strength concrete using superplasticizer and ultra-fine cementitious powder particles, such as silica fume and ground granulated blast furnace slag(1). For example, in Japan, there was a 5-year national project sponsored by the Ministry of Construction of Japan since 1988(2) to carry out extensive studies on the development and applications of high strength concrete. In addition to the use of conventional mineral admixtures, such as silica fume and ground granulated blast furnace slag, etc., a new mineral admixture which encourages the formation of ettringite to reduce or refine the pore structure of concrete so as to produce concrete of very high strength has also been developed(3). In most of these studies, a powerful mixer, such as , the pan mixer, twin-shaft mixer or paddle mixer was usually used so as to ensure uniform mix. As for the type of specimen, it was either in the form of the cylindrical specimen or cubical specimen, but in countries like Japan and USA, the cylindrical specimen was used.

On the other hand, the pan type or paddle mixer is not commonly used or available in the production of high strength concrete on site or at the batching plant in some countries such as countries in Southeast Asia and Indochina, etc. In addition, the specimens used for the quality control of concrete are mostly cubical in shape instead of cylindrical and the ambient temperature of these countries is about 30℃, which is higher than that of most of the countries where the extensive research on high strength concrete has been carried out.

Therefore, for the reported data from countries like Japan and USA, etc., to be of use as a good reference for countries with different practices, and to promote and increase the use of high strength concrete containing various mineral admixtures in countries in Southeast Asia and Indochina, etc., there is a need to generate data on the properties of high strength concretes with various mineral admixtures under a higher ambient temperature taking the effects of type of mixer and specimen into consideration.

In this paper, the effects of type of mixer and mineral admixture on the workability and compressive strength of high strength concrete are reported. The mineral admixtures used were silica fume, ground granulated blast furnace slag and an ettringite-based cementitious material. The effect of type of specimen on the compressive strength of high strength concrete was also studied. In addition, the microstructure of hardened cement matrix in relation to the compressive strength and other strength properties of concrete was also investigated but it will be reported in another paper(4).

Experiment

Materials used and mix proportions

The cement used in this study was ordinary portland cement(OPC). The mineral admixtures used were silica fume(SF), ground granulated blast furnace slag(BFS) and an ettringite-based cementitious material(Hi-Fi). The chemical composition and physical properties of these cementitious materials are shown in Table 1. It can be noted that Hi-Fi has a high value of loss on ignition. This is because it consists of a water reducing admixture and an organic compound which has the ability to maintain the workability of concrete.

The superplasticizer used in this study was a high range air-entraining water reducing admixture(WRA) containing sodium salts of formaldehyde high condensate of β-naphthalene sulfonate and polycalboxylic acid copolymer with polyethylene oxide graft chains. River sand with specific gravity of 2.64 and F.M. of 2.77 was used as fine aggregate. Coarse aggregate was crushed granite with specific gravity of 2.66, and F.M. of 6.93, and the maximum aggregate size of 25mm.

Table 2 shows the mix proportions of concretes containing OPC only and OPC with various mineral admixtures. WRA was used to control the slump-flow values of these concretes within the range of 60 $\pm$ 5cm. The solid contents of WRA was ignored and therefore the weigth of WRA was taken as part of mixing water. The water to binder ratio(W/S) was kept at 0.3 throughout the study.

Mixing method

The pan mixer used in this study consisted of a horizontally mounted cylindrical pan arranged to rotate about a vertical axis and in which paddles were arranged to rotate eccentrically to the pan axis. This mixer has been reported to be particularly suitable for very dry high strength and consistent concrete(5).

The initial concrete temperature upon casting was 30 ± 2 ℃. Either the tilting drum mixer or pan mixer, both with a capacity of 100 liters, was used to produce 50 liters of concrete at each casting. When the tilting drum mixer was used, half of the amount of fine and coarse aggregates together with all the cementitious materials needed were first poured into the mixer followed by the remaining fine and coarse aggregates and the mixing water with or without WRA. All the materials were then mixed together for 180 seconds. This is to prevent the mortar from sticking onto the inner surface of the mixer. When the pan mixer was used, coarse and fine aggregates together with all the cementitious materials were first mixed together for 10 seconds; mixing water with or without WRA was then added into the mixer followed by 90 seconds of mixing.

TABLE 1

Chemical composition and physical properties of cementitious materials

Samples	Ig. loss	insol.	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3
OPC	1.4	0.2	22.0	2.8	5.2	64.1	1.5	1.8
Hi-Fi	11.2	—	26.5	1.9	3.2	30.9	2.6	21.8
SF	2.4	—	84.2	8.9	1.0	0.5	0.4	1.2
BFS	0.2	—	33.6	1.1	14.9	40.8	7.4	0.1

	OPC	Hi-Fi	SF	BFS
Specific gravity	3.16	2.65	2.21	2.89
Specific surface area(cm^2/g)	3200*	8700*	220000**	8000*

(*Blain method, ** N_2 gas adsorption method)

TABLE 2

Mix proportions of concretes with and without various mineral admixtures

additives	Gmax (mm)	SL-flow (cm)	air (%)	S/A (%)	W/B (%)	Unit weight (kg/m^3) W	C	Add.	S	G	WRA
—	25	60±5	3±1	37.3	30	179	630	—	584	963	10
Hi-Fi	25	60±5	3±1	45.2	30	144	400	80	809	963	0
SF	25	60±5	3±1	36.5	30	173	567	63	563	963	16
BFS	25	60±5	3±1	36.5	30	176	378	252	561	963	13

Properties studied

Air content, slump and slump-flow tests for fresh concrete were performed and the values of slump and slump-flow were monitored with respect to time during the first 90 minutes. For the compressive strength test, cylndrical specimens with a dimension of ϕ 10x20 cm and cubical specimens of 15x15x15cm were prepared. All the concrete specimens in this study were compacted by using a poker-vibrator upon casting. Specimens were first cured in a constant-temperature room at 30 ± 2 ℃ for 24 hours followed by demoulding, and then seal-cured in plastic bags until the scheduled age of 7, 28 or 91 days at 30 ± 2 ℃.

Results and Discussion

Slump and slump-flow vs elapsed time

Table 3 shows the slump and slump-flow values of concretes containing various mineral admixtures versus the elapsed time at 30 ± 2 ℃. The concretes were prepared either using the tilting drum or pan mixer. The results suggest that the tilting drum mixer can also be used like the pan mixer to produce high strength concretes containing various mineral admixtures that usually have a high viscosity.

TABLE 3
Slump and slump-flow with elapsed time

Type of mixer	Additives	air (%)	Slump and {slump-flow} (cm)			
			0	30min	60min	90min
Pan	OPC	3.4	21.9{55×55}	13.2{22×22}	8.1{ - }	2.0{ - }
	Hi-Fi	3.4	21.8{55×56}	22.3{56×58}	20.6{44×46}	18.9{35×38}
	SF	3.8	23.0{52×54}	14.3{22×20}	5.3{ - }	1.2{ - }
	BFS	3.3	23.4{62×66}	21.3{38×40}	14.2{23×24}	8.3{ - }
Tilting drum	Hi-Fi	3.5	22.5{58×60}	23.0{60×62}	22.9{58×58}	21.3{54×56}
	SF	3.8	22.8{53×56}	16.4{24×25}	8.2{ - }	3.8{ - }

For concretes with Hi-Fi, it can be seen that irrespective of the type of mixer used, their slump values and slump-flow values show less change with time as compared to other concretes. This is due to the presence of a chemical admixture in Hi-Fi, which has the capability of maintaining the workability of concrete. On the other hand, the case of concrete with BFS or SF or without mineral admixture at all, there is significant drop in slump and slump-flow with time.

Table 3 also shows that irrespective of concrete with or without a mineral admixture, loss of slump value and slump-flow value of concrete prepared by using the tilting drum mixer are smaller than those of the corresponding concrete prepared by the pan mixer. This effect of the type of mixer used is more obvious for concretes with Hi-Fi as compared to other concretes. This is believed to be due to the larger shear stresses induced in the pan mixer compared to the shear stresses induced in the tilting drum mixer.

Compressive strengths of concretes with and without various mineral additives

Figure 1 shows the 28-day and 91-day (cylinder) compressive strengths of concretes containing OPC only and OPC with various mineral additives in relation to the type of mixer used. Each result presented in the figure is the average of three identical specimens. It can be seen that with the same water to binder ratio of 0.3 and same sealed curing period of either 28 or 91 days, the compressive strength of concrete containing OPC with Hi-Fi or SF can be

10MPa higher than that of concrete containing OPC only or OPC with BFS. Especially, for the case of concrete containing Hi-Fi, it can be seen from its mix proportion shown in Table 2 that even though the concrete contains a significantly smaller amount of binder as compared to other concretes, the compressive strength can be the same or even have a higher long term strength than the concretes containing BFS or SF, irrespective of the type of mixer used.

It can also be observed that the 28-day and 91-day compressive strengths of concretes containing OPC with Hi-Fi or SF prepared by using the tilting drum mixer are the same as those of the corresponding concretes prepared by using the pan mixer. This observation together with the results shown in Table 3 clearly show that the tilting drum mixer can perform like the pan mixer in producing high strength concrete with compressive strength higher than 100MPa after 28 days of sealed curing.

Relationship between cylinder and cube compressive strengths

Figure 2 shows the relationship between the compressive strengths of cylindrical specimens and their corresponding cubical specimens in relation to the two types of mixers. Each data point shown in this figure is the average of three identical cylindrical or cubical specimens.

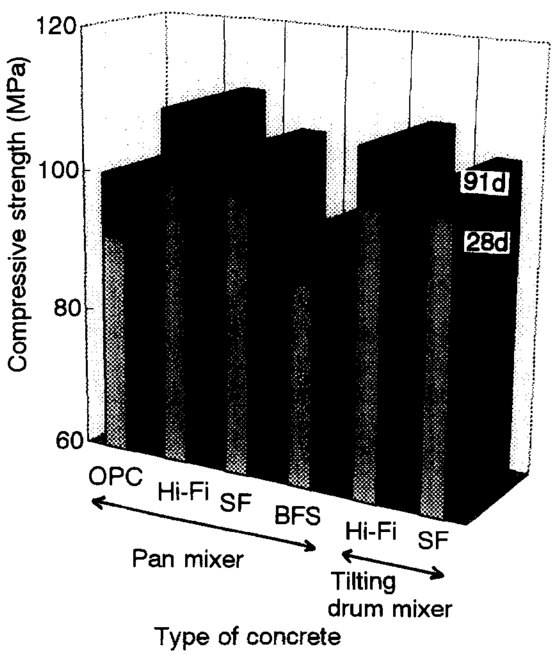

FIG.1
Compressive strengths of concretes with and without various mineral admixtures

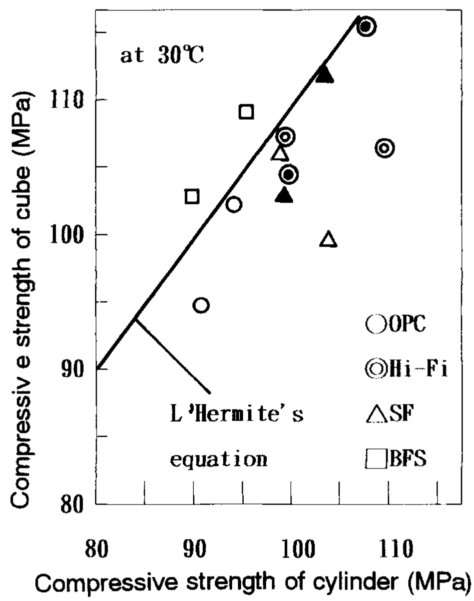

FIG.2
łelation between cylinder and cube compressive strengths(Open symbol: pann mixer ; Dark symbol : tilting drum mixer)

With the exception of some of the specimens containing OPC with SF or Hi-Fi, and with a longer curing age and prepared by using the pan type mixer, it can be seen that the compressive strengths obtained from 150mm cube specimens are generally about 5 to 10% higher than those of the corresponding cylindrical specimens with a dimension of ϕ 100x 200mm. This is about the same as the results reported from the studies (6) on conventional concrete, i.e., concrete with cube compressive strength lower than 60MPa, after taking the size effect into consideratin. Besides concrete containing OPC with BFS, the results obtained from this study also generally show a close but lower cube compressive strength than the value obtained from the following relationship proposed by L'Hermite(7):

$$\sigma_{cube} / \sigma_{cyl} = 0.76 + 0.2\log(\sigma_{cube}/2)$$

where σ_{cube} : compressive strength of cube in MPa
σ_{cyl} : compressive strength of cylinder in MPa

On the other hand, for concrete containing OPC with BFS, the cube compressive strength is about 3MPa higher than the value obtained from the relationship proposed by L'Hermite. These results seem to suggest that L'Hermite's equation on the relationship between cube and cylinder compressive strengths can also be used for high strength concrete but the application of this equation may have to take the effect of mineral admixture in concrete into consideration.

Conclusions

Based on the results presented in this paper, the following conclusions can be made:

(1)Like the pan mixer, the tilting drum mixer can also be used to produce high strength concretes containing various mineral admixtures that usually have a high viscosity. In addition, irrespective of whether the high strength concrete is with or without mineral admixture, those concretes produced by using the tilting drum mixer have less loss of slump and slump-flow with time as compared to those produced by using the pan mixer.

(2)With the same water to binder ratio of 0.3, the (cyrinder) compressive strength of concrete containing OPC with SF or Hi-Fi can be 10MPa higher than that of concrete containing OPC only or OPC with BFS for the same curing age.

(3)For high strength concrete, the compressive strength obtained from 150mm cube specimens is about 5 to 10% higher than that of the corresponding cylinder specimens of dimensions ϕ 100x200mm. This is about the same as the reported studies on conventional concrete.

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