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MICROSTRUCTURE AND STRENGTH PROPERTIES OF HIGH STRENGTH CONCRETES CONTAINING VARIOUS MINERAL ADMIXTURES

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ABSTRACT

This paper studies the effect of type of mineral admixture on the relationship between the compressive strength, the splitting tensile strength and the flexural strength of high strength concrete. The microstructures of concretes containing various mineral admixtures in relation to these properties were also investigated. The ratio of splitting tensile strength to compressive strength was found to be independent of the type of mineral admixture used, but the ratio of flexural strength to compressive strength varied with the type of mineral admixture in concrete. The mechanism of producing high strength concrete was found not only to depend on the total pore volume of hardened cement matrix but also on the pore size distribution and the morphology of the hydration products.

Introduction

To promote and increase the use of high strength concrete containing various mineral admixtures in countries like those in Southeast Asia and Indochina, there is a need to generate data on the properties of high strength concretes with various mineral admixtures at about 30 ℃, taking the effects of the types of mixers and specimens into consideration(1). For this reason, the effects of the type of mixer and mineral admixture on the workability and compressive strength of high strength concrete at 30 ± 2 ℃ were studied and discussed in an earlier paper(1).

This paper is a follow-up on the earlier paper(1). This paper examines the relationship between the compressive strength, the splitting tensile strength and the flexural strength of concrete with or without a mineral admixture together with the microstructure of the concrete. The mechanisms of strength development of high strength concretes containing different mineral admixtures are also compared and discussed in connection with its microstructures.

Experiment

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 materials(Hi-Fi). The chemical composition of these cementitious materials and the experimental details have been provided in the earlier paper(1). The samples used in this study were from the same batches as the samples used in the previous paper(1). They were all prepared using a pan mixer.

In this paper, tests were carried out to monitor the compressive strength, the splitting tensile strength and the flexural strength of hardened concrete. For the compressive strength test , cylindrical specimens with a dimension of ϕ 10x20cm were used. For the splitting tensile strength test, cylindrical specimens with a dimension of ϕ 15x15cm were prepared. For the flexural strength or modulus of rupture test, prismatic specimens of 10x10x40 were used. Mortar specimens prepared from wet-screening were also given the same curing condition and periods as the corresponding concrete specimens. At the time of testing, CaO was used as a drying agent to P-dry the specimen for 48 hours. Pore size distribution and the porosity of the specimen were then measured by using a mercury porosimeter. In addition, SEM observation was made on the hardened sample.

Results and Discussion

Compressive strength vs flexural strength or splitting tensile strength

Fig.1 shows the relationships between the compressive strength and the flexural strength or the splitting tensile strength of concretes prepared by using the pan mixer of OPC only or OPC with various mineral admixtures. Each data point shown in the figure is the average of three identical specimens. It can be seen that concretes with OPC only and OPC with Hi-Fi fall on the same line. With the same compressive strength, their flexural strengths are higher than that of concrete containing OPC with BFS or SF. The ratio of flexural strength with respect to compressive strength for concretes containing OPC only or OPC with Hi-Fi is in the range of 1/12 to 1/13, and for concrete containing OPC with BFS or SF is in the range of 1/15 to 1/16. The ratio of splitting tensile strength with respect to compressive strength is 1/17 to 1/18 irrespective of type of mineral admixture used.

Microstructure of mortar in relation to the strength properties of concrete

Fig.2 shows the relationship between the total pore volume per unit gram of cementitious paste and the corresponding cylinder compressive strength of concrete. The former was obtained using mortar wet-screened from the corresponding concrete. It can be seen that the compressive strength of concrete increases with a decrease in the total pore volume. However, this relationship depends on the type of mineral admixture used. Compared to concrete with OPC only and concretes with other mineral admixtures, concrete containing Hi-Fi has a higher compressive strength even though it has a larger total pore volume, whereas, concrete containing BFS has a lower compressive strength even though it has a smaller total pore volume per gram of cementitious paste.

Fig. 3 shows the pore size distribution of mortar specimens wet-screened from concretes containing OPC only and OPC with various mineral additives. It can be observed that right from the early age, mortar containing Hi-Fi has more finer pores, i.e., less pores larger than

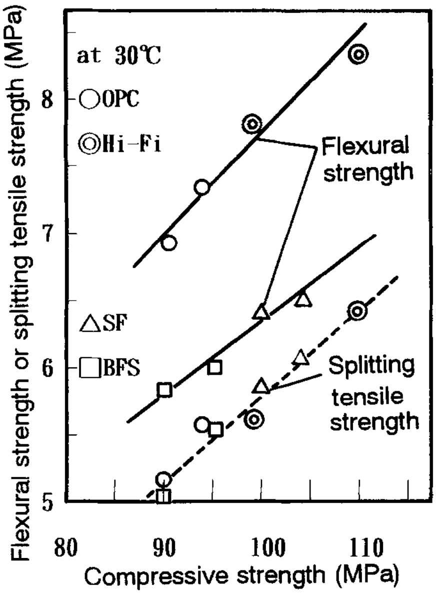

FIG.1
Relation between compressive strength and flexural strength or splitting tensile strength of concretes with various mineral admixtures

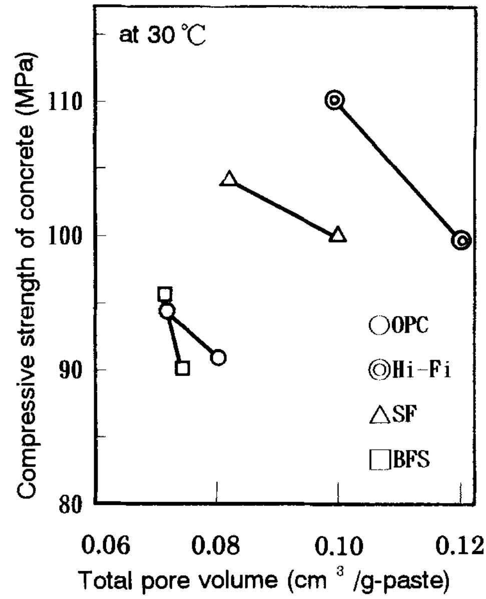

FIG.2
Relation between compressive strength of concrete and total pore volume of the corresponding mortar

10^{-1} um, compared to mortars containing OPC only and OPC with other mineral admixtures. This is because of the formation of AFt right from the early age and thus leading to less large pore right from the early age(2). It can also be seen that for mortar with SF, the amount of large pores with diameter of 10^{-1} um decreases with a longer curing period. This is attributed to the continuous and long-term pozzolanic reaction of SF even when water to binder ratio is low (3). On the other hand, in the case of mortar containing BFS, a substantial amount of pores with diameter of 10^{-1} um remain present even after a long period of curing. This result suggests that when water to binder ratio is low, the reactivity of BFS has not been fully developed even when it reaches 91days of age. As a result of no large pore reduction with time, concrete containing BFS has a relatively lower compressive strength even though it has a smaller total pore volume as compared to other concretes.

Fig.4 shows the SEM micrographs of C-S-H in the hardened mortar specimens containing OPC only and OPC with various mineral admixtures. Without a mineral additive, type III C-S-H of granulated shape was observed. In addition, a relatively significant amount of the platy crystals of $Ca(OH)_2$ was also observed. In the case of mortar containing SF, as for the mortar with OPC only, type III C-S-H of granulated shape was also observed. However, $Ca(OH)_2$ could not be observed because of its dense microstructure. For mortar containing BFS, needle-like C-S-H was found to be irregularly formed in the hardened matrix and the structure was loose. In the case of mortar containing Hi-Fi, crystals with granulated shape, with bar shape, and with large corn shape were detected. In addition, as shown in Fig.4, the formation of needle-like crystal of AFt in the pore structure was also observed. The above microstructural study therefore shows that the addition of Hi-Fi or ettringite-based cementitious material will lead to pore size distribution having more smaller pores as compared to other

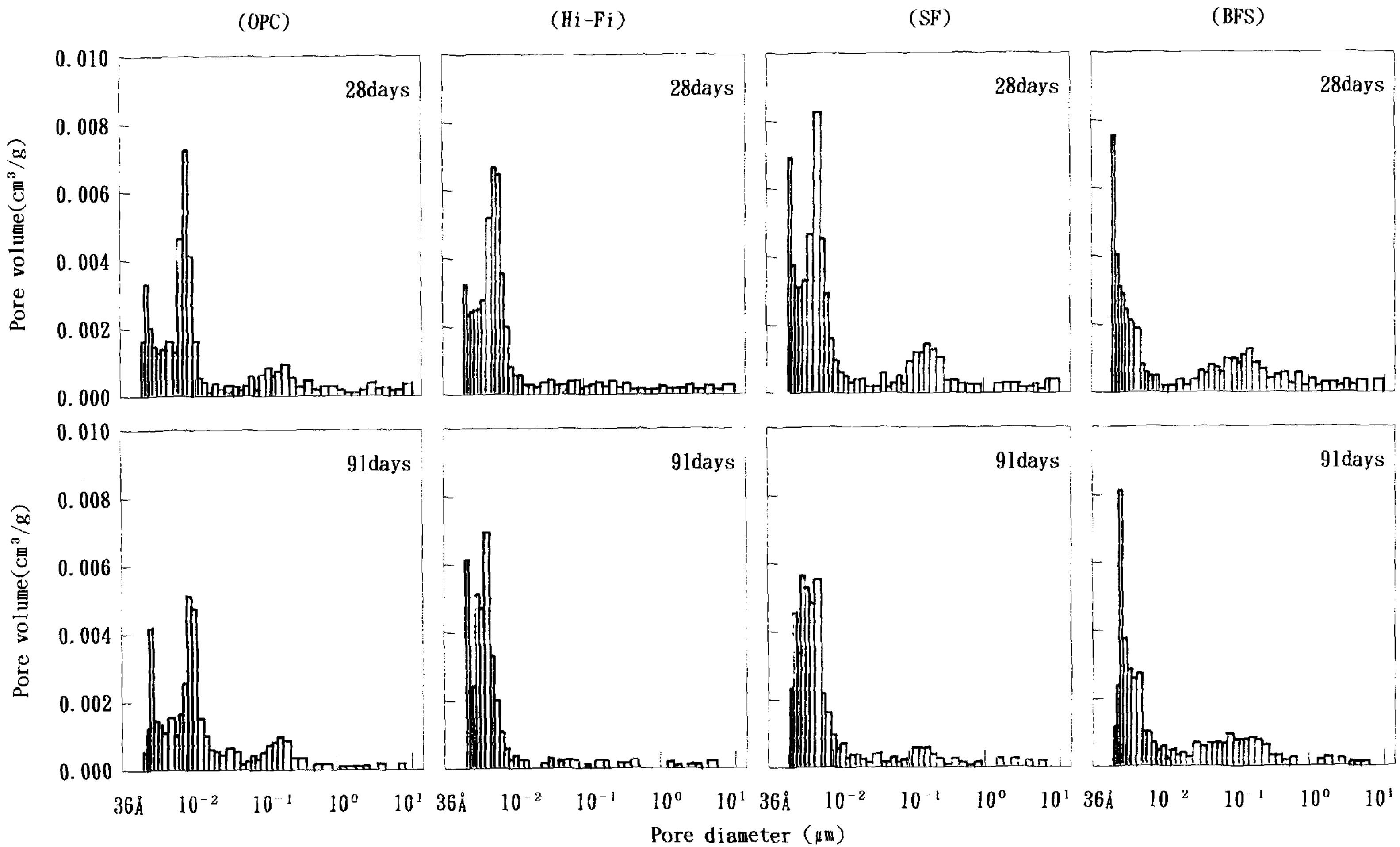

FIG.3
Pore size distribution of mortars with various mineral admixtures

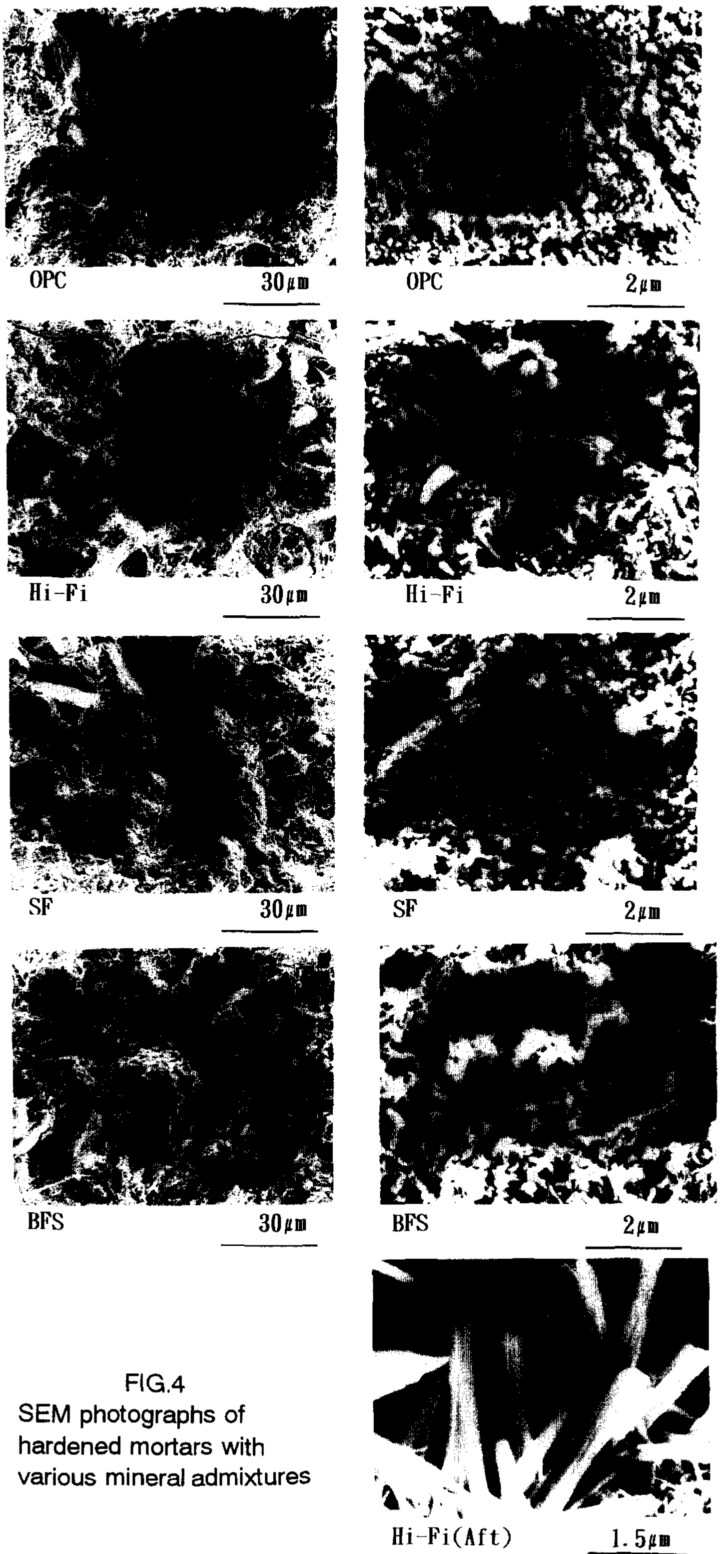

FIG.4
SEM photographs of hardened mortars with various mineral admixtures

cementitious materials. In addition, the ettringite-based cementitious material will also lead to the formation of needle-shaped and bar-shaped C-S-H crystals. This leads to higher compressive strength and flexural strength of the hardened cement matrix. In other words, the results obtained in this study together with the SEM observation suggest that the mechanism of producing high strength concrete does not only depend on the total pore volume of hardened cement matrix but also on the pore size distribution and on the morphology of the hydration products.

Conclusions

Based on the experimental results and SEM observation in this study, the following conclusions can be made:

(1) With the same compressive strength, the flexural strength of concrete containing OPC only and OPC with Hi-Fi are about the same, but both are higher than that of concrete with BFS or SF. The ratio of flexural strength with respect to compressive strength for concrete containing OPC only or OPC with Hi-Fi is in the range of 1/12 to 1/13, and for concrete containing OPC with BFS or SF is 1/15 to 1/16.

(2)The ratio of splitting tensile strength with respect to compressive strength is 1/17 to 1/18 irrespective of type of mineral admixtures used.

(3)The compressive strength of concrete increases with a decrease in the total pore volume per unit gram of paste. However, this relationship depends on the type of mineral admixtures used.

(4)Compared to concrete with other mineral admixtures, concrete containing ettringite-based cementitious material has a higher compressive strength even though it has a larger total pore volume per unit gram of paste. This is because it has a lesser amount of large pore as compared to concrete containing other mineral additives. These results together with the SEM observation show that the mechanism of producing high strength concrete does not only depend on the total pore volume of hardened cement matrix but also on the pore size distribution and the morphology of the hydration products.

References

1. T.H.Wee, Y.Matsunaga, Y.Watanabe and E.Sakai, Cement & Conrete Res., 25(4) 709 (1995)
2. Y.Matsunaga, Y.Watanabe,K.Nakagawa and E.Sakai, Gypsum & Lime, No240,324(1992) (in Japanese).
3. E.Sakai, T.Kida,K.Kosuge and J.Sugita, Extended Abstracts The 48th Annual Meeting of JCA, 784(1994)(in Japanese).