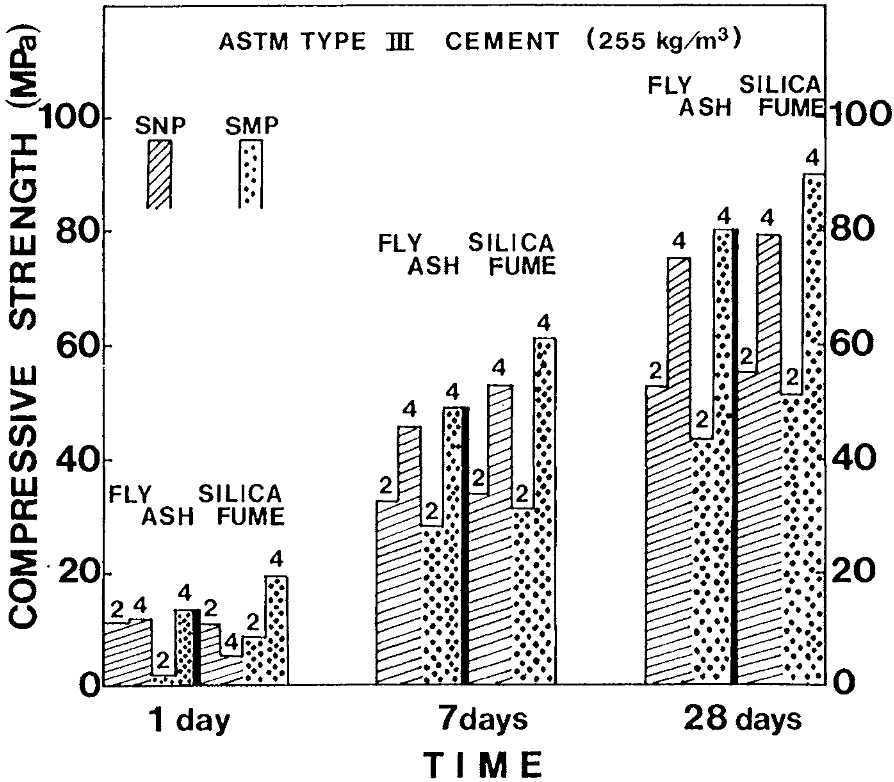

Fig. 5--Compressive strength of concretes with fly ash or silica fume (45 kg/m^3); slump = 220 mm; ASTM cement Type III; cement factor = 255 kg/m^3; figures on histograms indicate the percentage of superplasticizer by weight of cement; superplasticizer: SNP (sulphonated naphtalene polymer) or SMP (sulphonated melamine polymer)

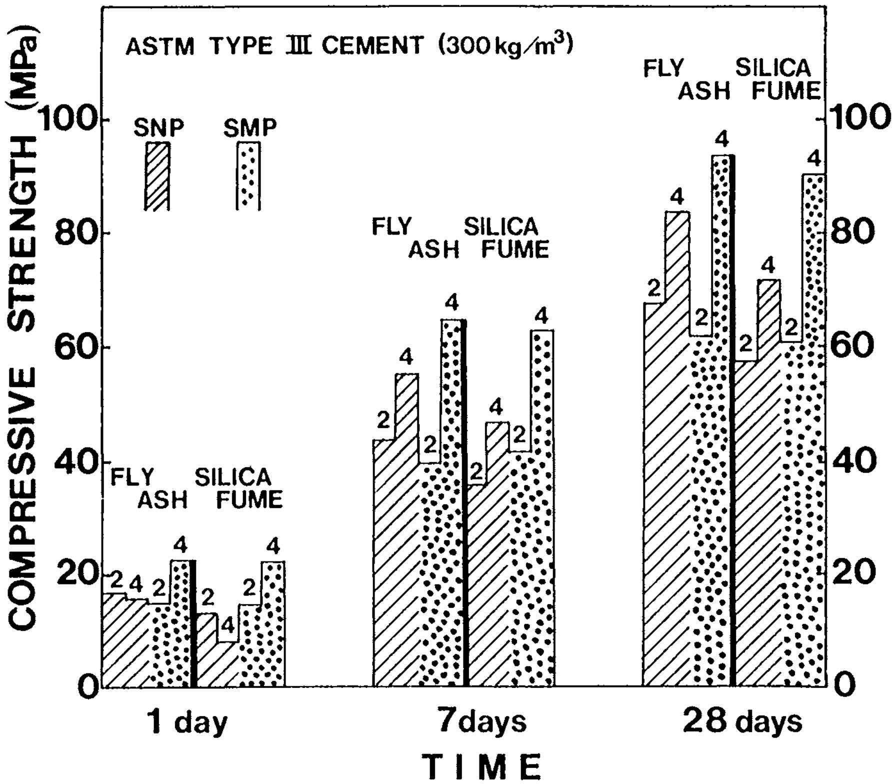

Fig. 6--Compressive strength of concretes with fly ash or silica fume (45 kg/m^3); slump = 220 mm; ASTM cement Type III; cement factor = 300 kg/m^3; figures on histograms indicate the percentage of superplasticizer by weight of cement; superplasticizer: SNP (sulphonated naphtalene polymer) or SMP (sulphonated melamine polymer)

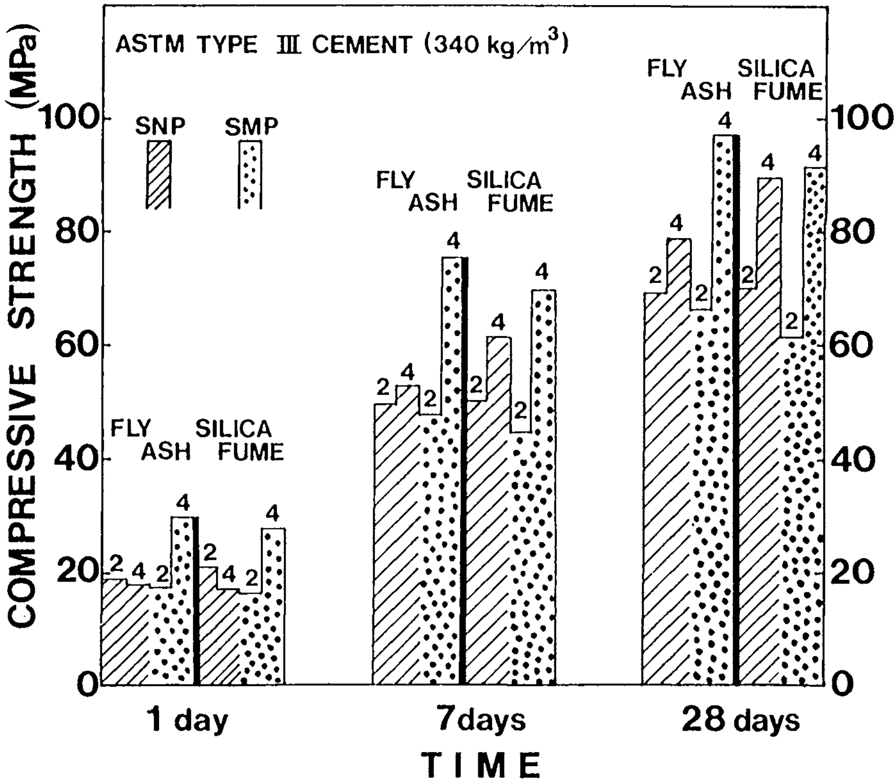

Fig. 7--Compressive strength of concretes with fly ash or silica fume (60 kg/m^3); slump = 220 mm; ASTM cement Type III; cement factor = 340 kg/m^3; figures on histograms indicate the percentage of superplasticizer by weight of cement; superplasticizer: SNP (sulphonated naphtalene polymer) or SMP (sulphonated melamine polymer)

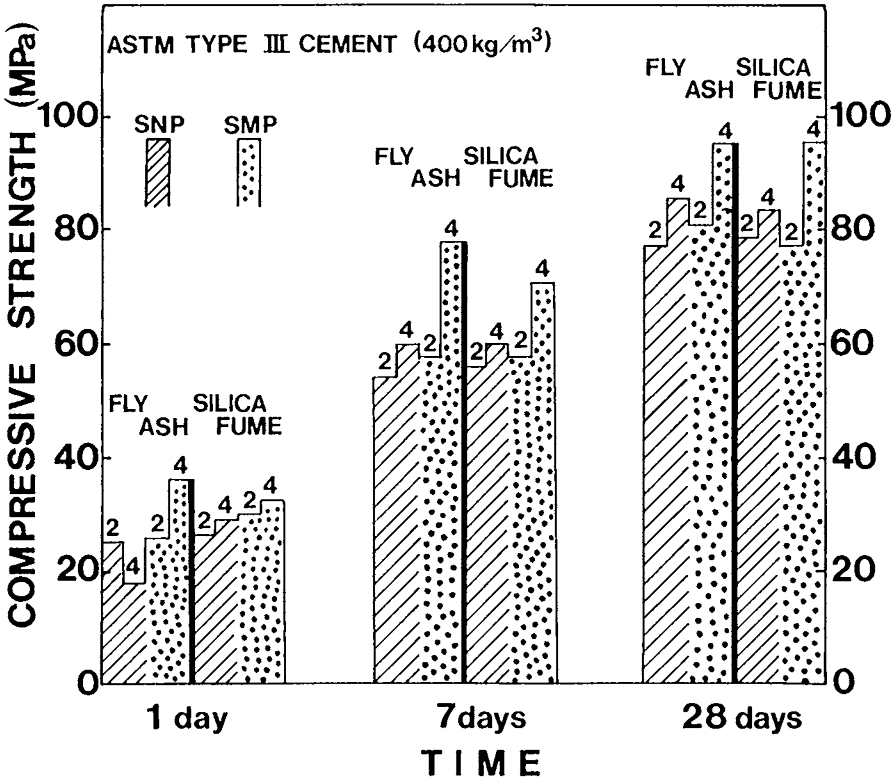

Fig. 8--Compressive strength of concretes with fly ash or silica fume (60 kg/m^3); slump = 220 mm; ASTM cement Type III; cement factor = 400 kg/m^3; figures on histograms indicate the percentage of superplasticizer by weight of cement; superplasticizer: SNP (sulphonated naphtalene polymer) or SMP (sulphonated melamine polymer)

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A Study on Superplasticized Concrete Containing High Volumes of Blast-Furnace Slag

by S. Nishibayashi, A. Yoshino, S. Hideshima, M. Takada, and T. Chikada

Synopsis: This paper describes an experimental study of mix designs and characteristics of fresh and hardened superplasticized concrete containing high volumes of blast-furnace slag.

The results show that using superplasticized concrete in a mix design with a large amount of blast-furnace slag allows a lower water content than that of the base concrete, a lower superplasticizer dosage to attain the same increase in slump, and a somewhat lower percentage of fine aggregate. Also, the compressive strength of the hardened concrete was as high as that of the non-superplasticized concrete.

Keywords: blast-furnace slag; compressive strength; fresh concretes; hardened concretes; mix proportioning; plasticizers; water content; workability

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INTRODUCTION

For the purposes of improving the workability of concrete and improving qualities such as drying shrinkage and durability, a large amount of data on superplasticized concrete using ordinary cement have been accumulated.

To improve the durability of concrete, especially through the prevention of alkali-aggregate reactions, it has been recommended that blast-furnace cement or blast-furnace slag be incorporated into concrete.

In consideration of this, it can be expected that in the future there will be an increase in the use of superplasticized concrete mixed with high content of blast-furnace slag.

This study was conducted for the purpose of establishing appropriate mix designs for superplasticized concrete incorporating high contents of blast-furnace slag, and to gain an understanding of the properties of the fresh and hardened concrete.

Materials

Normal portland cement was used in this investigation. The physical properties of the cement are shown in Table 1. The blast-furnace slag is quick-cooled blast-furnace slag which was pulverized in a roller mill. The physical properties and the chemical constituents are shown in Table 2. The fine aggregate (S) was river sand. The coarse aggregate (G) was crushed stone. The physical properties of the aggregates are shown in Table 3.

Three admixtures were used, an AE water-reducing agent (AEWR), an AE agent (AE), and a superplasticizer (SP). Their main constituents are shown in Table 4.

The compressive strength and the static modulus of elasticity were measured for hardened concrete specimens before and after the addition of the superplasticizer.

The ages of measurement were 7 days, 28 days, and 91 days. All specimens were standard cured. As well, all specimens were stored in a constant-temperature chamber at $20 \pm 2^{\circ}C$ between the mixing and the testing.

TEST PROCEDURES AND CONDITIONS

The mix designs and conditions of the superplasticized concrete are as follows: The base concrete (before addition of the superplasticizer) was AE concrete with a target slump value of 12±1 cm and a target air content of 4.5±0.5%. The binding material content was set at 350 kg/m^3. The slag content $\left(\frac{Gs}{C+Gs}\right)$ was 0, 55, 70, and 85%. The fine aggregate content was determined at mixing time in order to obtain the maximum workability with the same water content. Superplasticized concrete was prepared by letting base concrete stand for 60 minutes after mixing, and then re-mixing in the mixer for 30 seconds after adding the prescribed amount of superplasticizer.

The measured items were: For the fresh concrete, the change in slump over time, the change in air content over time, bleeding, and setting times; and for the hardened concrete, the compressive strength and the static modulus of elasticity. The measurements of the change in slump over time were taken for the base concrete immediately and after letting the concrete stand for 30 minutes and 60 minutes after mixing. The superplasticizer was then immediately added, and the slump was measured after the concrete stood for 30, 60, 90, and 120 minutes. The change in air content over time was measured at 60 minutes and 120 minutes after the addition of the superplasticizer. Bleeding and setting time measurements were performed on the samples before and after addition of the superplasticizer.

In the bleeding tests, mixed concrete was poured into a ø 25 cm x 28.5 cm cylinder. The bleeding was measured over time. Measurements were taken until the bleeding stopped. The setting time measurements were based on the ASTM C 403 "Time of Setting of Concrete Mixtures by Penetration Resistance"

TEST RESULTS AND DISCUSSIONS

Concrete mix design

The results on mix designs based on a large percentage of blast-furnace slag in superplasticized concrete are listed below. The relationship between the water content and the slump of the base concrete containing an AE water reducing agent is shown in Fig. 1. The slump is in direct proportion to the water content. When blast-furnace slag was used, the water content could be reduced to achieve the same slump; the greater the percentage of slag, the greater the reduction in water content. In this experiment, with the target slump value of the base concrete at 12cm, and using 85% slag, the water content was 11 kg/m^3 less than concrete using no slag at all. This is considered to be due to the fact that quick-cooled blast-furnace slag becomes glass-like, and the smooth surface of the powder increases the flowability.

The relationship between the dosage of the AE agent and the air content is shown in Fig. 2. As the percentage of slag was increased, the dosage of the AE agent had to be increased to achieve the same air content. To achieve the target air content of 4.5%, as set in this experiment, the AE agent dosage required for concrete containing 85% slag was double that of concrete containing no slag at all.

The relationship between the dosage of the superplasticizer and the increase in slump is shown in Fig. 3. The slump increase is in direct proportion to the dosage of the superplasticizer.

When slag was used, the slump increased with increases in slag, at a constant dosage of superplasticizer. The effect of the superplasticizer in concrete containing slag was considered to be good. As stated above, slag is considered to exert an influence to increase the flowability.

For the study to find the optimal fine aggregate percentage of superplasticized concrete, the relationship between the fine aggregate percentage of total aggregate and the slump, at the same water content, is shown in Fig. 4.

In this experiment, for concrete without slag, a fine aggregate percentage of 45-46% produced the maximum workability. The optimal percentage for slag-containing concrete was 43-44%. Thus, a reduction of 2% in the fine aggregate produced workable concrete. This reduction is thought to be due to the fact that, compared to cement, slag particles are smaller and have a relatively large surface area. The optimal mix designs of slag-containing superplasticized concrete, as determined from the results of this study, are shown in Table 5.

Change in slump and air content over time

The measurements of the change in slump over time, before and after the addition of the superplasticizer, are shown in Fig. 5, and those of the air content are shown in Fig. 6. In the control concrete, during the 60 minutes between the mixing and the superplasticizer addition, the rates of both the slump and the air content showed slow decrease. After the addition of the superplasticizer, the slag concrete showed a somewhat larger decrease, especially after 60 minutes had elapsed since the addition of the superplasticizer.

The change in the air content with time showed basically the same trend. The reduction in the air content, both before and after the superplasticizer addition, was especially evident in the slag concrete. This is considered to have had an influence on the reduction in slump. It is considered that superplasticized concrete containing large percentages of slag should be placed within a short period after the addition of a superplasticizer.

To ensure the air content after the addition of the superplasticizer, it is considered that addition of an AE agent with the superplasticizer is effective.

Bleeding and setting time

The test results showed the bleeding of the slag concrete and control concrete were similar. In either case, the bleeding of the superplasticized concrete tended to be somewhat greater than that of the control concrete; the increase was slightly larger in the slag concrete.

The setting time measurements are shown in Fig. 7. Both before and after superplasticizer addition, the use of slag had no effect on the initial setting time.

The greater the percentage of slag, the longer was the final setting time. This is considered to be due to the slow rate of hydration of slag concrete as compared with the control concrete.

Compressive strength and the static modulus of elasticity

The compressive strength test results of concrete are shown in Fig. 8. Regardless of the percentage of slag used, the compressive strength of the superplasticized concrete was in all cases identical to that of the control concrete. Similar results were found for the modulus of elasticity.

CONCLUSIONS

As the percentage of blast-furnace slag was increased, the water content required to attain the same slump decreased and the dosage of AE agent required to maintain the same air content increased.

The increase in slump due to the addition of the superplasticizer increased with increases in the percentage of slag. Slag in concrete appears to act as a superplasticizing agent.

The optimal fine aggregate percentage of the slag concrete was approximately 2% less than that of the non-slag concrete.

In slag concrete, the loss in slump with time after the addition of the superplasticizer tended to be somewhat large. This reduction was especially large after 60 minutes had elapsed from the time of the addition of the superplasticizer.

The incorporation of slag in concrete did not significantly effect the initial setting time. However, the final setting time increased with increases in the percentage of slag.

Regardless of the percentage of the slag used, the compressive strength of the superplasticized concrete was the same as that of the control concrete.

REFERENCES

(1) Y. Tsuji, N. Susa, and K. Fukuzawa "Properties of Fresh Superplasticized Mortar with Blast Furnace Slag", Review of the Thirty-seventh General Meeting, The Cement Association of Japan, May, 1983, pp. 112-113.

(2) Y. Nakanishi, S. Goto, M. Daimon, and K. Nakagawa "Properties of Hardened Paste of Alkali Activated Slag Cement", Review of the 41st General Meeting, The Cement Association of Japan, May, 1987, pp. 44-47.

(3) A. Oshio, T. Sone, and A. Matsui "Properties of Concrete Containing Mineral Powers", Review of the 41st General Meeting, The Cement Association of Japan, May, 1987, pp. 114-117.

(4) Japan Society of Civil Engineers "Recommendations for the Design and Construction of Concrete Containing Ground Granulated Blast-Furnace Slag as an Admixture", Concrete Library of JSCE No. 11, June 1988