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COMPARISON OF MECHANICAL PROPERTIES AND DURABILITY OF MORTAR MODIFIED BY SILICA FUME AND FINELY GROUND BLAST FURNACE SLAG

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ABSTRACT : Experimental investigation on the effect of silica fume and finely ground blast furnace slag on mechanical properties and durability, including compressive and flexural strength, water absorption, carbonation and chloride ion penetration test of mortar is reported in this paper. The variables of the study are percentage replacement of cement with silica fume and slag. The test results indicate that the mechanical properties of silica fume and slag modified mortar are improved to a great extent, whereas the water absorption is reduced and carbonation and chloride ion penetration depth of modified mortar are reduced and decreased markedly as compared to that of plain mortar. It is also interesting to note that partial replacement of cement by 30% silica fume and 40% slag improve both mechanical properties and durability of modified mortar. The silica fume and slag is varied from 0 to 50% by weight of cement and superplasticizer is used as 6% by weight of binder (cement and silica fume or slag).

KEYWORDS : Silica fume, blast furnace slag, compressive strength, flexural strength, water absorption, carbonation, chloride ion penetration.

INTRODUCTION

In recent times, significant developments have been observed in concrete technology. Among them is the evolution of high performance concrete, in which use of low water-cement ratio and industrial and chemical admixtures has become a common practice Such admixtures usually include silica fume, finely ground blast furnace slag and fly ash that can react the hydrates of cement in concrete and mortar (Mehta and Gjorv 1982; Bache, 1981; Setwiter and Mehta, 1989; Sabir, 1997). It is known that silica fume is highly reactive pozzolan (Metha and Gjorv, 1982) and because of its fineness it reacts in a relatively short time with the hydrated calcium hydroxide present in the cement paste transforming lime into calcium silicate hydrate

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(Bache, 1981). The purpose of the present investigation is to prepare a mortar with sufficient mechanical resistance and high durability. This study evaluates the influence of increasing additions of silica fume and finely ground blast furnace slag with a specifc surface of 10,070 cm^2/g on the characteristics of the mortar. The use of silica fume increases in the water requirement and a consequent reduction in workability. Using water reducing agents can solve this problem. Slag can be used to replace cement in order to improve the mechanical properties and durability of mortar, but its reactivity is much lower than silica fume.

LITERATURE REVIEW

The use of silica fume and slag in cement mortar and concrte (Sabir, 1997; Duval and Kadri, 1998; Taheri and Breugel, 1998; Nakamoto *et al.*, 1998; Macda *et al.*, 1998; Li *et al.*, 1998) has become widespread all over the world in the production of high strength and durable mortar. In spite of its increasing use little data is available on the chloride ion penetration, carbonation and water absorption and mechanical characteristics of silica fume with superplasticizer and slag (specific surface area 10,070 cm^2/g) modified mortar.

PURPOSE AND SCOPE

The experimental research program outlined in this paper is designed to investigate the influnce of silica fume with superplasticizer and slag on flexural and compressive strength behavior, water absorption, water-cement chloride ion penetration and carbonation of modified mortar.

Silica fume and slag was varied from O to 50% by weight of cement while superplasticizer was used at 6% by weight of binder (cement and silica fume).

MATERIALS

Cement: Ordinary Portand Cement specified in Japanese Industial Satandard (JIS R 5210, Portland Cement) was used in all mixes. The physical properties and chemical analysis of cement are reported in Table 1.

Table 1. Physical Properties and Chemical Composition of Cement.

Physical Properties:						
Density (g/cm^3)	Blaine's Specific Surface (cm^2/g)	Setting Time (h-min)		Compressive strength (N/mm^2)		
		Initial Set	Final Set	3d	7d	28d
3.16	3320	2-22	3-32	29.1	43.5	60.8

Chemical Composition (%)											
Ig. Loss	Insol	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	R_2O	CL
1.7	0.1	21.1	5.1	2.9	64.4	1.4	2.0	0.30	0.45	0.60	0.005

Sand

River sand (size 1.2 mm or finer) was used for the preparation of mortar in all mixes.

Admixtures

Silica fume which is a by-product in the manufacturing process of ferro silicon and metallic silicon was used as siliceous admixture and water reducing agent (commercial brand name "Mighty 150" from Kao Corporation, Japan) was employed as chemical admixture. The chemical analysis and physical properties of silica fume are listed in Table 2 (a) and that of slag which is the by-product of the manufacturing process of pig iron in blast furnace are listed in Table-2(b).

Table 2 (a). Physical Properties and Chemical Compostion of Silica fume.

Physical Properties:		
Density (g/cm^3)	Particle size (µm)	Specific Surface (m^2/g)
2.20	0.1to 0.2	18 to 20

Chemical Composition (%)								
Ig. Loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	S	C	K_2O	Total
0.36	95.5	0.35	0.61	0.41	0.12	2.15	0.50	100

Table 2 (b). Physical Properties and Chemical Composition of Finely Ground Blast Furnace Slag.

Physical Properties:								
Density (g/sm^3)			Glass Content (%)			Specific Surface (cm^2/g)		
2.91			98			10,070		
Chemical Composition (%):								
SO_3	SiO_2	Al_2O_3	Fe_2O_3	CaO	Mgo	Na_2O	K_2O	T-S
0.12	33.5	14.5	0.49	43.1	5.5	0.22	0.40	0.95

PREPARATION OF MIXES

For silica fume modified mortar, four series of mixes were made using a binder-sand ratio of 1:3 (by weight). Another four series of mixes were made for slag modified mortar. Mix SF-O (Table 3) and SL-O (Table 4) were made with Portland Cement and sand (1:3) using a water-cement ration of 0.69. This ratio was set at a deliberately high value in order to reproduce real situation with a high workability (flow value was adjusted to 170±5 mm as per Japanese Industrial Standard) without superplasticizer. In the other three mixes for silica fume modified mortar (SF-30, SF-40 and SF-50), the cement was replaced by silica fume in the proprtion of 30%, 40% and 50%, respectively (Table 3). On the other hand for slag modified mortar (SL-30, SL-40 and SL-50), the cement was replaced by silica fume in the proportion of 30%, 40% and 50%, respectively (Table 4). The flow value of both silica fume and slag modified mortar was adjusted to 170±5 mm for all mixes in this investigation as per Japanese Industrial Standard.

Table 3. Mix Proportion of Silica Fume Modified Mortar

Type of Mortar	Mix designation	Binder Sand Ratio (by mass)	SF Cement Ratio (%)	WRA content (wt % of binder)	Water Binder ratio (%)	Flow	Air Content (%)
Un-modified	SF-0	1:3	0	----------	69	169	6.8
Modified	SF-30		30	6	57	171	5.8
	SF-40		40	6	61	168	7.6
	SF-50		50	6	65	170	6.6

Note : Binder= Cement+ Silica Fume (SF)
WRA= Water Reducing Agent

Table 4. Mix Proportion of Slag Modified Mortar

Type of Mortar	Mix designation	Binder Sand Ratio (by mass)	Slag Cement Ratio (%)	Water Binder ratio (%)	Flow	Air Content (%)
Un-modified	SL-0	1:3	0	69	169	6.8
Modified	SL-30		30	63	171	7.8
	SL-40		40	65	174	7.6
	SL-50		50	67	173	7.2

Note: Binder= Cement + Slag

PREPARATION AND CURING OF SPECIMENS

Accrding to the stipulations of Japanese Industrial Standard (JIS) the specimen for the flexural and comperessive behavior and water absorption tests were made with dimensions of 40x 40x 160 mm. Whereas the samples for the carbonation and chloride ion penetration tests were made with dimensions of 40 x 40 x 80 mm. All samples were stored for 2-day moist (20°C, 80% RH), 5-day water (20°C), and 21-day dry (20°C, 50% RH) curing condition.

TEST PROCEDURE

Flexural strength test : This test was carried out according to Japanes Industrial Standard (JIS A 1172). Three-point loading was applied. The flexural strenght was obtained by averaging the three measured values of the tested specimen.

Compressive Strength Test : This test was carried out according to Japanese Industrial Standared (JIS A 1172). Broken parts of the specimen from flexural strength test were used. The compressive strength was obtained by averaging the six measured values.

Water Absorption Test : This test was carried out according to Japanese Industrial Standard (JIS A 6203). The produced specimen were dried at a temperature of 80±2^0 C until the mass became constant (W_0). Then the specimen were immersed in clean water at a temperature of 20±2°C for 1 hour, 3 hours, 5 hours, 9 hours, 24 hours and 48 hours. After the desired immersion period had passed, the specimen were taken out and the surfaces were wiped quickly with wet cloth and then weighed (W_1) immediately. From the following formula the rate of water absorption was calculated.

Water absorption (%)= $(W_1 - W_0)/W_0 \times 100$

The mean of three values was used.

Carbonation Test : This test was carried out according to Japanese Industrial Standard (JIS A 6203). Before carbonation test, the finished and bottom surfaces and two ends of the cured mortar specimen were coated with epoxy resin paint. The mortar specimens were then placed in a carbonation test chamber for 14 days, in which the relative humidity, temperature and CO_2 gas concentration were controlled at 60% R. H., 30^0C and 5%, respectively. After accelerated carbonation, the mortar specimen were split and the split cross-sections were sprayed with a 1% phenolphthalein alcoholic solution. The depth of each cross-section without color change after spraying the phenolphthalein alcoholic solution was measured with slide calipers as carbonation depth as shown in Fig. 1.

Chloride-ion Penetration Test : This test was carried out according to Japanese Industrial Standard (JIS A 6203). Specimen were immersed in 2.5% Nacl solution at 20°C for 7 days for chloride ion penetration test. After immersion, the specimen were split at the desired immersion periods and the split cross-sections were sprayed with 0.1% sodium fluorescein and 0.1 N silver nitrate solution. The depth of the rim of each cross section that changed to white color was measured by using slide calipers as a chloride ion penetration depth as shown in Fig. 1.

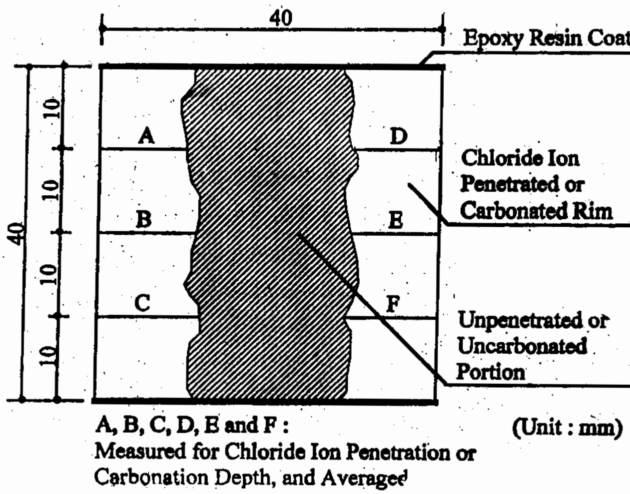

Fig 1. Cross-section of Specimen after Carbonation or Chloride Ion Test.

RESULTS AND DISCUSSIONS

Mechanical Properties

It is now well know that OPC replaced by suitable siliceous admixtures (silica fume and slag) enhances the strenght of mortar. Even higher dosages may be employed if suitable water reducing agents are used (Setwiter and Mehta, 1989). Silica fume improves the properties of mortar and concrete in two ways. One physically and another chemically (Sabir, 1997). At early ages when the chemical phenomenon is still latent, the physical phenomenon act immediately. According to some researchers (Mehta and Gjorv, 1982; Bache- 1981; Setwiter and Mehta, 1989; Sabir, 1997) this physical phenomenon is due to the siliceous fineness, its large specific surfaces and to the fact that its particle fill the existing spaces between the various granules of the cement and those between the cement paste and the sand. This act as a filler reducing porosity of the bulk cement matrix and resulting in a densified structure. On the other hand, slag in this study had relatively less siliceous fineness and low specific surface area as compared to that of silica fume. Later, the chemical reaction between siliceous admixtures and the calcium hydrate also comes in to action, producing hydrated calcium silicate. After 28 days of curing, the samples were tested for compressive and flexural strenght tests according to Japanese code. The results of these tests are shown in Figs. 2 and 3, respectively. It is clear from these figures that 30% silica fume gives higher compressive and flexural strength compared to that at 40% and 50%.

It is interesting to note that 40% slag gives higher compressive strength than that at 30% and 50%. It is clear that 30% silica fume and 40% slag modified mortar gives better mechanical properties than plain mortar.

DURABILITY

Because of small particle size, the siliceous admixtures (silica fume and slag) particles occupies the voids between the cement grains, acting as a filler, reducing the porosity of the bulk cement matrix and resulting in a densified structure. Figure 4 gives the results of the water absorption tests carried out in this present study. It was found that the reduction in the water absorption of silica fume modified mortar was about 25% of that obtained for unmodified mortar. In general, the addition of silica fume results in pore refinement and increased water tightness of the cement matrix. The refinement of the pore structure, however, leads to reduce permeability of the hydrated cement paste

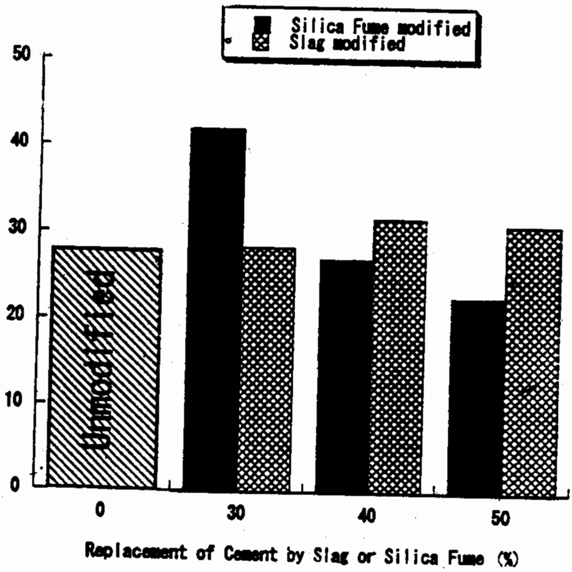

Fig 2. Compressive Strength of Silica Fume and Slag modified mortar

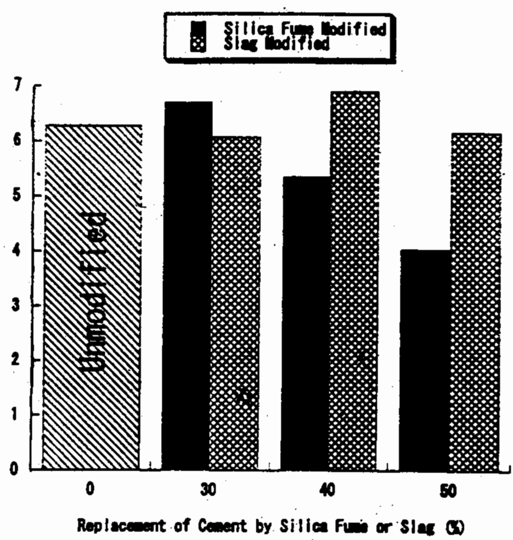

Fig 3. Flexural Strength of Silica Fume and Slag modified mortar

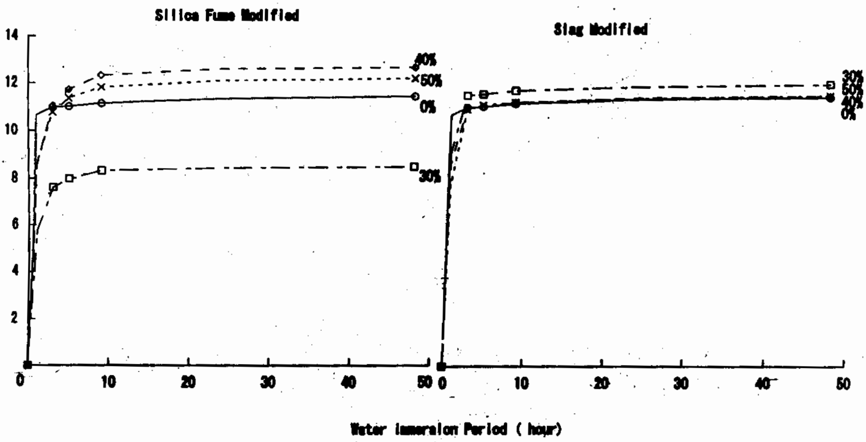

Fig 4. Water Absorption of Silica Fume and Slag modified mortar

and this could lead to a retarded moisture migration through the cement matrix. It is interesting to note that the use of slag did not show any significant reduction in the water absorption compared to the plain mortar.

For chloride ion penetration test the data show that reference sample (unmodified sample) already had a chloride ion penetrated of 26% after 7 days of test. On the contrary, samples with varies silica fume contents show a decrease in chloride ion penetration depth from 28% to 85%. Samples with vaious slag content show a similar decrease from 60% 80%. Figure 5 gives the result of chloride ion penetration test carried out in this present study.

For carbonation test, the data show that reference sample (unmodified sample) alredey had a carbonation by 27% after 14 days of accelerated carbonation test. Samples with various silica fume contents show a decrease in carbonation to 16% only. It is interesting to note that samples with 40% and 50% silica fume shows increase in carbonation depth from 23% to 47% rather than a decrease. Samples with various slag content show a decrease in carbonation depth from 14% to 54%. These decreases occurred for two reasons. Firstly, the increased percentage of silica fume increases the quantity of calcium hydrate fixed by the pozzolan action. Secondly, the increased quantity of reaction products reduce the porosity of the cement paste preventing the CO_2 and CL^- from penetrating the paste. Figure 6 gives the result of carbonation test carried out in the present study.

and Slag modified mortar

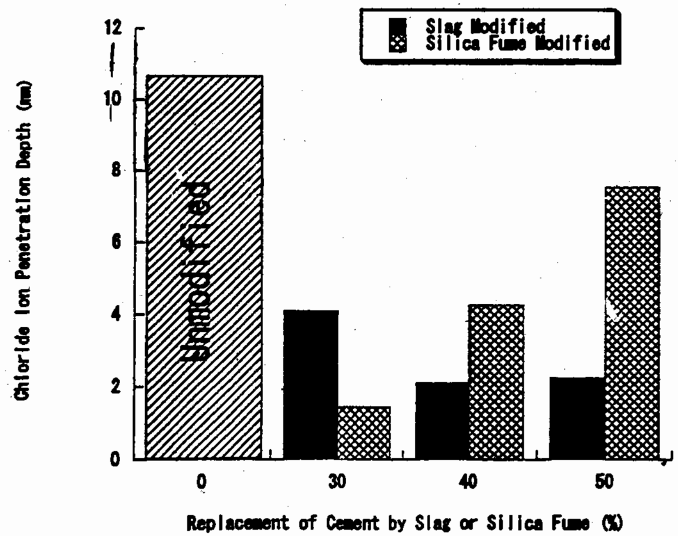

Fig 5. Chloride Ion Penetration depth of Silica Fume and Slag modified mortar

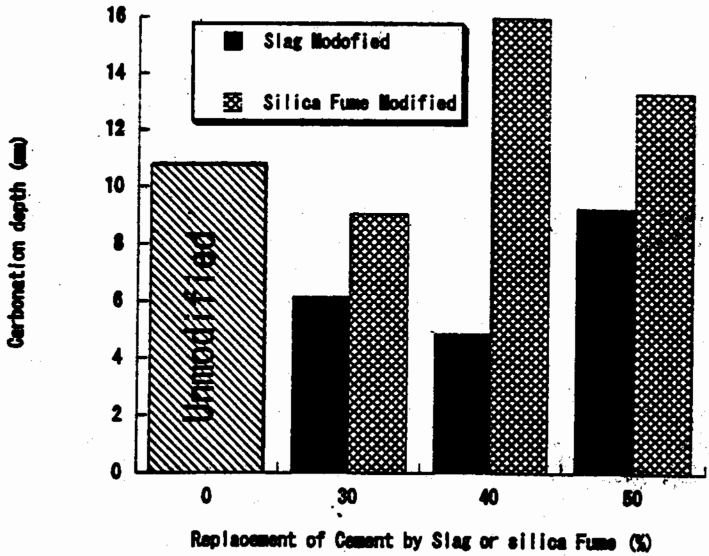

Fig 6. Carbonation depth of Silica Fume and Slag modified mortar

Overall a 30% silica fume shows lowest carbonation and chloride ion penetration depth.

CONCLUSIONS

The employment of silica fume and slag leads to the improvement of both mechanical properties and durability of modified mortar. The emploment of 30% silica fume with superplasticizer and 40% slag in mortar leads to the improvement of both compressive strength and flexural strength. The addition of 30% silica fume reduces the water permeability by about 25% of that for reference mortar. The use of slag did not result in any significant reduction in the water absorption. The carbonation and chloride ion penetration depth of modified mortar decrease markedly with a 30% silica fume and 40% slag.

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