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INFLUENCE OF SILICA FUME REPLACEMENT OF CEMENT ON EXPANSION AND DRYING SHRINKAGE

G.A. Rao
Department of Civil Engineering, Indian Institute of Science, Bangalore-560 012, India

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ABSTRACT

An experimental investigation on the effect of silica fume on expansion of cement and drying shrinkage of mortars is reported. Tests were conducted on cylindrical specimens of 30 mm diameter and 30 mm height for expansion of cement pastes. The drying shrinkage of mortars was studied on bars of 25 mm square cross-section and 250 mm length. The variables of the study were percentage replacements of cement with silica fume. The test results indicate that the expansion of cement pastes with the incorporation of silica fume was less than in the ones without silica fume. The 28-day drying shrinkage of mortar bars increases as does the percentage of silica fume, whereas the shrinkage of mortar bars at 405 days for all replacements of silica fume was observed to be about 2.65 ± 0.11%. The addition of silica fume has no significant effect on the long-term drying shrinkage of the mortar. In this study silica fume was used as partial replacement of cement. The silica fume was varied from 0 to 30% by weight of cement. *© 1998 Elsevier Science Ltd*

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 w/c ratio and industrial and chemical admixtures has become a common practice. In fact, tremendous strength developments of concrete and mortar were observed in the current research. However, it was observed to be a deficient material with reference to a few secondary long-term properties.

Following cement hydration and hardening, the resulting product consists of a mixture of several compounds, all chemically combined with water in different forms. Calcium silicate hydrates play a vital role in influencing the characteristics of hydrated cement (1). The information available on expansion of cement pastes is relatively very limited. Colin et al. (2) studied the effect of silica fume on expansion characteristics of expansive cement pastes. It was observed that the presence of silica fume decreases the expansion characteristics. Pettersson (3) reported the effect of silica fume on alkali-silica expansion in mortar specimens. It was found that expansion of mortar was very large with the addition of silica fume, and also that small cracks were appeared on the specimens. Hooton (11) also reported that the silica fume reduces the expansion of mortar.

Even though strength development has increased, cracks develop during and after hardening of concrete and mortar. In view of the above facts, concrete mix designers must take precautions in dealing with autogenous deformation and autogenous change of relative humidity in the high-performance concretes. Shrinkage is a common phenomenon that is being observed in all cementitious products due to contraction of total mass upon loss of moisture. The drying shrinkage depends upon many parameters; among them are density, chemical composition, water-cementitious material ratio, relative humidity, duration of curing, type and size of aggregate, aggregate content, size and shape of the member, and type of exposure, all of which significantly affect shrinkage. The problem of drying shrinkage is more serious in such members whose surface area to volume ratio is large (4,5). Early stage chemical shrinkage of cement pastes with low w/c ratios is around 0.7 to 1.0% (6). The addition of silica fume markedly increases the autogenous shrinkage (7,8). The increase in volume content of aggregate and curing time and decrease in w/c ratio results in the decreased value of ultimate drying shrinkage (9). Silica fume increases the drying shrinkage of mortar and concrete (10,11). Long-term strength losses of concrete containing silica fume are linked to the structural effects of drying (12).

Research Significance

The use of silica fume in concrete has become widespread all over the world in the production of high-strength and durable concretes. In spite of its increasing use, little data has been published on the effect of silica fume on autogenous volume changes and drying shrinkage. Autogenous volume changes should be taken into account because of their importance in the interior of mass concrete and other exposure conditions. The experimental research program outlined in this paper is designed to investigate the influence of silica fume on expansion of cement pastes and drying shrinkage of mortar bars. Silica fume was varied from 0 to 30% by weight of cement.

Experimental Program

In this investigation an ordinary Portland cement was used. The physical properties of the cement are reported in Table 1. Silica fume used for this study was supplied by Nava Bharat Ferro Alloys Limited, Polvanch, Andhra Pradesh, India. The specific gravity was 2.051 and the specific surface was 14 to 16 m^2/gm. The SiO_2 content in the silica fume was 85%. The chemical composition is given in Table 2.

Natural river sand was used and the sand was graded with a maximum particle size of 1.18 mm and minimum size of 600 microns. The silica fume was used as partial replacement of cement from 0 to 30% by weight of cement. The water-cementitious material ratio was 0.5 for both expansion and drying shrinkage. The cementitious material to sand ratio was 1:3. The average temperature in the laboratory was 35 $\pm$ 2°C and the relative humidity was 65 $\pm$ 5%.

Test Results and Discussion

Table 3 gives the test results of the program. The expansion of cement without silica fume was 1.12 mm. The expansion was dropped to 0.3 mm for 5% replacement. The expansions of pastes gradually increased as silica fume replacement increased. At 30% replacement, the

TABLE 1
Physical properties of cement.

Property	Result
Finess of Cement (%)	2.65
Normal Consistency (%)	31.5
Setting times (min.)	
Initial	135
Final	335
Specific Gravity	3.168
Compressive strength (N/mm^2) at	
3 days	21.06
7 days	30.14
28 days	48.74

expansion was 0.62 mm. This shows that the addition of silica fume reduced the expansion of cement pastes. The chemical combination of the cementitious material and water (i.e. hydration) has been accompanied by generation of heat, which under the given temperature conditions, has an important effect on the expansion of the pastes. It can be stated that the chemical combination of the cementitious material was different for various percentages of silica fume in the mix. The reduction in expansion of the pastes with the addition of silica fume may be due to reduction of free lime content in the mix. The CaO present in the cementitious material produces $Ca(OH)_2$, which acts as a source of alkalinity. This alkalinity is gradually destroyed by CO_2 in the form of carbonation shrinkage (7).

Drying shrinkage of mortar bars without silica fume was 0.012%. The experimental results indicate that silica fume changes the drying shrinkage of mortars very significantly. It was observed that the drying shrinkage increases as the percentage of silica fume increased. This fact is evidently supported by the literature (6,7,8) cited in this paper. The shrinkage of mortar bars at 405 days indicate that the effect of silica fume was almost the same for all replacements. The principal drying shrinkage of hardened mortar bars was due mainly to the drying and shrinkage of the gel formed by hydration of the binder (cement + silica fume). The incorporation of silica fume increased the water requirement of the mix to produce a flow

TABLE 2
Chemical composition of silica fume.

Chemical compound	Result (%)
Silica (SiO_2)	84.0–86.0
Alumina Oxide (Al_2O_3)	1.0 (max)
Iron Oxide (Fe_2O_3)	2.0–3.5
Silica + Alumina + Iron Oxide ($SiO_2 + Al_2O_3 + Fe_2O_3$)	87–90.5
Calcium Oxide (CaO)	1.0–1.5
Loss on Ignition	4–7

TABLE 3
Test results.

Mix designation	SF/B* (%)	Expansion (mm)	Drying shrinkage %	
			28 Days	405 Days
MSF0	0.00	1.12	0.012	2.648
MSF1	5.00	0.30	0.020	2.652
MSF2	10.00	0.32	0.032	2.728
MSF3	15.00	0.46	0.036	2.720
MSF4	20.00	0.52	0.064	2.720
MSF5	25.00	0.57	0.076	2.640
MSF6	30.00	0.62	0.088	2.520

* Cement plus silica fume.

of 110 to 115%, which is due to the increase in fineness of the binder with the addition of silica fume. Autogenous shrinkage or self desiccation shrinkage occurs during the hydration of cement. This is due to the formation of cohesive and adhesive solids as a result of reactions between cementitious material and water wherein the volume of the end product is less than the initial volume of the constituents. The $Ca(OH)_2$ formed during the hydration of cement reacts with CO_2 present in the atmosphere causes carbonation shrinkage. This may be a major factor which has influenced the shrinkage of mortar bars at the age of 28 days. The addition of silica fume on the long-term drying shrinkage of mortars has no influence. The pozzolanic reaction of silica fume was complete in the early ages of mortar. The test results overestimate the drying shrinkage of bars. In fact the restraining effect of aggregates drastically reduces the drying shrinkage of mortars and concretes. The drying shrinkage at the age of 405 days was as much as $2.65 \pm 0.11\%$ with the 1.18 mm maximum size of sand grains size. The use of larger sand grains might have reduced this significantly. The value of drying shrinkage was 2.648% for mortar without the addition of silica fume. Added to the above fact, the shrinkage of mortar bars was about 2.7% in general. This higher percentage of drying shrinkage is due to the severe exposure conditions, water-cementitious material ratio, duration of curing, surface area to volume ratio, etc.

Conclusions

1. The results of the experiments indicated that silica fume behaved differently in its effect on cement pastes. The specimens with silica fume exhibited reduced expansion.
2. The effect of silica fume on drying shrinkage of mortar is very significant at early ages. The mortar bars experienced higher values of drying shrinkage with the incorporation of silica fume. A higher content of silica fume increased the drying shrinkage more.
3. It can be concluded that the addition of silica fume increases the content of calcium silicate hydrate, which is the most important factor causing shrinkage at 28 days.
4. The pozzolanic action of silica fume was complete at the early ages. The effect was insignificant at later ages.

5. The long-term drying shrinkage (i.e. at 405 days) of mortars was not influenced much by the addition of silica fume.

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