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Characteristics of Silica Fume Concrete

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ABSTRACT

Proper introduction of silica fume in concrete improves both the mechanical and durability characteristics of the concrete. The long-term compressive strength of silica-fume concrete has been recently questioned by some researchers. This paper reports the results of compressive strength data on 4- to 6-year-old cores obtained from well-documented field experiments where both silica-fume and non-silica fume concrete mixtures were used. The effectiveness of silica-fume concrete in resisting damage caused by corrosion of embedded steel has been investigated using an accelerated impressed voltage-testing setup. The physical properties of high strength silica fume concretes and their sensitivity to curing procedures were evaluated and compared with reference Portland cement concretes, having either the same concrete content as the silica fume concrete or the same water to cementitious materials ratio. The marked increase in the strength of the silica fume concrete over the two reference concretes, which was observed even at one day, was not accompanied by liberation of excessive heat. Moreover, the compressive strength results obtained on concrete cores taken after a 4-year period from an experimental column built with a very high-strength concrete also confirmed that there was no tendency for strength loss in silica-fume concretes. The experimental program comprised six levels of silica-fume contents (as partial replacement of cement by weight) at 0% (control mix), 5%, 10%, 15%, 20%, and 25%, with and without superplasticizer. It also included two mixes with15% silica fume added to cement in normal concrete. Durability of silica-fume mortar was tested in chemical environments of sulphate compounds, ammonium nitrate, calcium chloride, and various kinds of acids. It was found that there was an optimal value of silica-fume content at which concrete strength improved significantly. This paper deals with a literature review on ‘Characteristics of Silica Fume Concrete’.

Keywords

Silica; Cement; Concrete; Compressive Strength.

1. INTRODUCTION

Silica fume (micro-silica) has been recognized as a pozzolanic admixture that is effective in enhancing the mechanical properties and improving the chemical durability of concrete (Khedr and AbouZaid 1(94). The use of silica fume is growing in various parts of the world to produce economical high strength and/or chemical-resistant concrete [6]. Since the beginning of its use in concrete in Canada, silica fume has been used as a cement replacement material in normal strength concrete so as to obtain a desired 28-day compressive strength. It is presently used in the produced form or in the form of blended cement. The two major cement producers in Canada are presently marketing what is called type 10SFsilica-fume blended cement. Whether it is used in the as-produced form at a concrete plant or blended with Portland cement, its dosage is always less than 10% by weight of cement. In fact, 10% is the maximum dosage that is permitted by the A23.6 Canadian standard (Isabelle 1986). On some occasions, it has been deliberately used for other applications, such as to control potential alkali/aggregate reaction and to make very high-strength concrete (Aitcin et al. 1985; Ryell and Bickley 1987) [9]. Silica fume is a fine-grained (30-100 times finer than cement) by-product of silicon-metal production. Silicon oxide (Si02) usually makes up more than 90% of silica-fume constituents. Silica has basically three roles in concrete paste: it reacts with free lime, which results from hydration of cement; it fills in pores for better inter particle arrangement; and it may improve aggregate-paste bonding. In its chemical reaction with the free calcium hydroxide, a stronger cementitous compound of calcium silicate hydrate and water is produced. This reaction reduces the alkali content in the pores; i.e., it reduces the pH of the pore fluid in concrete. According to Diamond (l9X6) and Hausmann (I96X), alkaline environment of concrete pores (pH > 13) is essential to guard against the destruction of the passive protection of steel embedded in the concrete. This fact raises a question about the effect of using silica fume on the corrosion of reinforcing steel. Especially whether corrosion-related damage in concrete has been of significant concern in many situations [6].

On the other hand, silica fume in concrete increases its impermeability, electrical resistivity, and tensile strength. These three fold improvements in concrete properties can enhance its resistance to corrosion-related damage. The first hinders water, oxygen, and chloride ingression to the steel electrode. Higher electrical resistivity reduces ionic conduction [6].Since many of the high strength concretes are formulated by using pozzolans, and the silica fume might be included in this category, there is always the concern to what extent are these concretes more sensitive to the water curing procedures than concretes prepared with Portland cement only. This is particularly important in hot-dry climactic conditions, where the concrete is dried more readily, thus perhaps eliminating the moisture that is needed for the progress of the pozzolanic reaction which can continue to occur beyond the initial few days of the water curing period. In evaluating the effect of curing, one should consider the overall strength of the concrete, as well as the properties of the concrete skin (i.e. outer layer), which protects the steel reinforcement [10]. The object of the present work is to characterize high strength silica fume concretes from the points of view of heat generation, shrinkage and sensitivity to curing, and to compare their performance with that of concretes made ofPortland cement only, havingeither the same cement content or the same water to cementitious materials ratio [10].

1. **Helpful Hints**

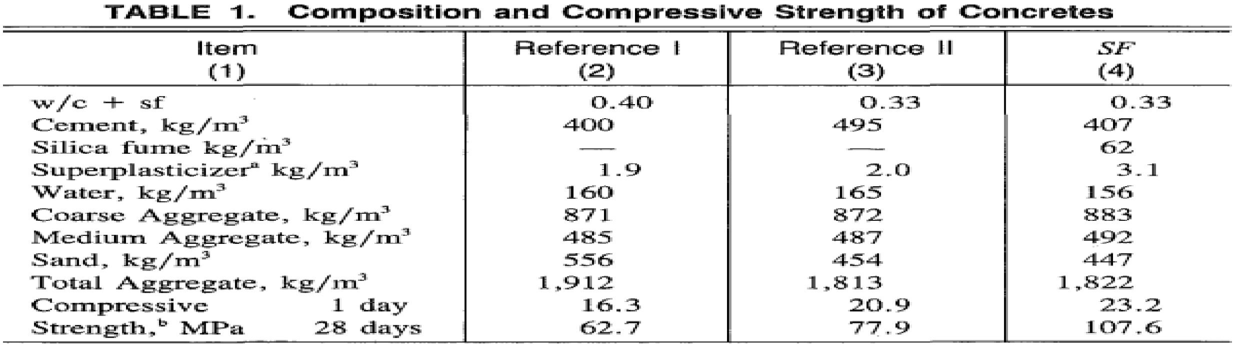

TABLE 1. Composition and Compressive Strength of Concretes

Item (1)		Reference I (2)	Reference II (3)	*SF* (4)
w/c + sf		0.40	0.33	0.33
Cement, kg/m^3		400	495	407
Silica fume kg/m^3		—	—	62
Superplasticizer^a kg/m^3		1.9	2.0	3.1
Water, kg/m^3		160	165	156
Coarse Aggregate, kg/m^3		871	872	883
Medium Aggregate, kg/m^3		485	487	492
Sand, kg/m^3		556	454	447
Total Aggregate, kg/m^3		1,912	1,813	1,822
Compressive	1 day	16.3	20.9	23.2
Strength,^{b} MPa	28 days	62.7	77.9	107.6

2. LITERATURE REVIEW

2.1 General

The experimental program for this research was designed to study the effect of silica fume on different concrete characteristics (Fig. 1). These characteristics were divided into three categories: fresh concrete, hardened concrete, and durability of mortar.

2.2 Materials and Mix Composition

There are three techniques for incorporating silica fume relative to cementing the concrete mix: addition to cement, partial replacement of cement by equal weight of silica fume, and partial replacement of cement by less weight of silica fume. The first technique is used when special concrete with high strength is required. When the purpose is to save cement content, the second technique is used, which usually results in higher quality concrete. Since concrete yields higher quality with 1:1 replacement, it is possible to use silica fume to reduce the cost for comparable quality by reducing the cement content and replacing it with a lesser amount of silica fume; this describes the third technique [8]. The composition of the concretes studied in the present work is given in Table 1. They were all high strength concretes, prepared with Portland cement only (reference I and II) and with 15% silica fume *(SF)* by weight of cement. All the concretes had the same slump (80 to 120 mm) and contained superplasticizer (Melment).

The superplasticizer content was adjusted for each mix, to the maximum that could be added without leading to undesirable effects such as bleeding. Thus, more of this admixture could be accommodated in the *SF* mix, because of its higher surface area. With this approach to adjusting the superplasticizer content, each mix represents the maximum density and strength potential that can be derived from its cementitious material, while maintaining a plastic and workable concrete of about 100 mm slump.

Reference I concrete is representative of a mix composition for achieving high strength using Portland cement only, without excessive cement (-400 kg/m3). The design of the *SF* concrete was based on reference I, with the addition of 15% *SF* by weight of cement (and keeping the cement content at —400 kg/m3) at the expense of sand. The reduction in the water to (cement + silica fume) ratio, w/c + sf, from 0.40 in the reference I concrete to 0.33 in the *SF* concrete represents the water reducing effect when silica fume is added in combination with a superplasticizer. For additional comparison, another reference concrete (Reference II in Table 1) of Portland cement only, was prepared and studied, which had the same water to cementitious materials ratio of 0.33, as the *SF* concrete, and higher cement content than reference I concrete. The Portland cement was equivalent to ASTM Type I, produced by Nesher, Israel. The *SF* was a product of SKW Canada, with Si02 content of 92.7% and a specific surface area (N2 BET) of 18.3 m2/g. mixing was carried out in a drum mixer at 20° C controlled room, and the specimens were cast as 70 mm cubes and 70 X 70 X 280 mm bars [10].

3. METHODOLOGY

3.1 Tests

In the present study, three series of tests were carried out with these concretes, to determine: (1) The heat evolution in adiabatic conditions; (2) the shrinkage of mature concretes; and (3) the effect of curing on the strength and on the properties of the skin [10]. Detailed results regarding the strength development and microstructure of these concretes are provided by Goldman and Bentur (1988) [2].

3.2 Heat Liberation

Heat liberation was determined in adiabatic conditions using aTonindustriePrietechnik Model 6010 calorimeter. Immediately after mixing, the concrete was cast into a 0.006 m3 cylindrical container which was inserted into the calorimeter, and at this time (i.e. 20 minutes after adding the water), the measurement was initiated and the temperature was continuously recorded [10]. The heat liberated at each time could be calculated from the temperature rise and the weight of the concrete, by assuming that the heat capacity of the concrete remained constant, and could be evaluated from the heat capacity and content of the individual ingredients of the fresh concrete, prior to any hydration reactions [4]. Obviously, this assumption is not an accurate one. Yet, since most of the concrete volume consists of non-reactive aggregates this is a reasonable approach for a first estimate

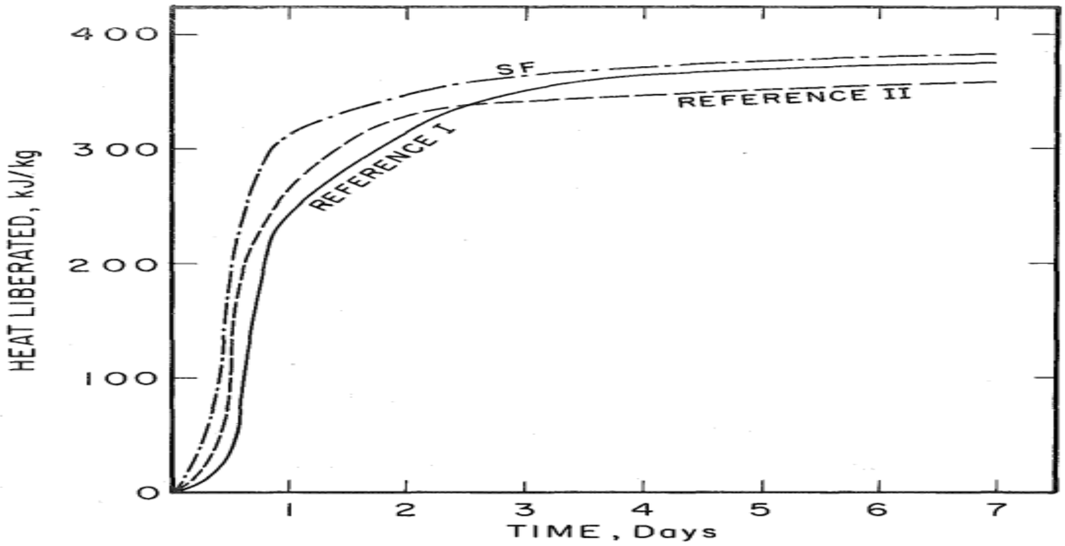

FIG. 1. Calculated Heat Liberation Curves per Unit Weight of Cement[10]

3.3 Drying Shrinkage

Drying shrinkage was determined in free conditions in which concrete bars (70 X 70 X 280 mm) were subjected to an environment of 20° C/50% RH, and their weight and length changes were monitored periodically. All of the concretes were cured for 28 days in lime water at 20° C, prior to the exposure to the drying conditions [10].

3.4 Curing Effects

The effect of limited water curing was evaluated in two different environmental conditions, one of which might be considered as mild (20° C/ 60% RH) and the other as harsh (30° C/40% RH) [8]. The water treatment in the mild conditions included 7 days curing in water, followed by exposure to 20° C/60% RH until the age of test. For comparison, companion concrete specimens were kept continuously in water until testing. The continuously water cured specimens were tested for strength in a saturated surface dry (SSD) condition. The air cured concretes were also tested SSD and this was achieved through immersion in water for 48 hours prior to testing [10]. The latter procedure was intended to compare the strength of the air and water cured concretes under similar surface moisture conditions.

The water curing procedure in the 30° C/40% RH conditions was intendedto simulate a field practice in which the concrete is sprayed twice a day with water and then exposed to the hot-dry conditions. This was achieved by immersing the concrete specimens in water for 5 minutes, twice a day, and then exposing to 30° C/40% RH. This water treatment was carried out for 1, 2, 3 or 6 days, immediately after demolding. The specimens were kept sealed in the molds during the first day. After the termination of the water curing period the specimens were kept in 30° C/40% RH, until 28 days. For comparison to a proper water curing procedure, companion specimens were subjected to a 6 day continuous water immersion (after being sealed in the moulds for the first day) and then exposed to 30° C/40% RH [7].

The properties of the concretes were evaluated by testing for compressive strength, and the properties of the concrete skin were assessed by determining the depth of carbonation under accelerated conditions, for 28 days (30° C/50% RH, 5% C02). The specimens tested were 70 mm cubes (for strength) and 70 X 70 X 280 mm prisms (for depth of carbonation). The prisms were split periodically to determine the depth of carbonation by phenolphthalein, using the procedure recommended by RILEM Committee CPC-18 (1984).

4. CONCLUSION

Results indicated general superior performance of silica-fume concrete and mortar with 1:1 cement replacement, compared to respective control concrete and mortar that incorporates type I cement and the same mix proportions. The silica fume presented herein as a mineral admixture is employed to produce concrete of special characteristics or to produce less expensive concrete of comparable characteristics, as silica fume is less expensive than cement. On the basis of the experimental results of this research, the following main conclusions are inferred.Test results have clearly shown significantly better performance of concrete containing silica fume as 1:1 replacement of cement. It is important to note that the graphs are plotted to different scales. The effect of silica fume is more noticeable for the 28day curing period than for the 7-day period. On the other hand, the effect of curing period was not as significant for the control mix. Longer curing allows the Pozzolanic activity to develop, leading to the significant performance improvement. The variation in electric current was not consistent. Therefore, maximum or high values of current, or electric resistivity, alone will not be a sufficient qualitative indicator of the concrete performance. The time to crack, has given a better indication. It increased for concrete with higher resistance to corrosion damages when comparison was done within each test group. However, discrepancy was observed in obvious cases e.g., saline versus fresh water saturation in different groups.

First, results of accelerated impressed potential tests show that silica-fume dosages increase concrete's protection to embedded steel against corrosion. Second, performance of concrete in resisting corrosion-related damage is optimum at 15% silica-fume replacement of Portland cement. Using the criterion adopted in this study, silica-fume concrete is several times better than a control mix. Third, electrical resistivity alone is not an adequate indication of concrete performance in resisting corrosion damage. It is preferable to use superplasticizer when introducing silica fume to concrete in order to keep the water ratio at acceptable levels and obtain reasonable and maintainable workability. Sodium naphthalene sulfonate is found effective with no side effects. Compressive strength of silica-fume concrete is significantly improved up to 56 days. However, there is a drop in the early strength in normal (without accelerators) mix design.

5. RESULTS

The effect of the silica fume on the strength, microstructure and composition of the concretes was discussed in detail (Goldman and Bentur 1988). The strength of the concretes after 1 and 28 days of water curing is given in Table 1. The silica fume concrete was stronger at 28 days than both reference concretes. The higher 28 days strength of the silica fume concrete even when compared to reference II which had the same w/c + sf ratio, was attributed by Goldman and Bentur (unpublished), to the improved aggregate- paste bond in the silica fume system. This strengthening trend is similar to that reported in other studies (e.g. Sellevold and Radjy 1983). Even at one day, the strength of the *SF* concrete was greater than reference II concrete, suggesting that the *SF* provides a positive influence even as early as one day.

6. REFERENCES

[1] G. D. Ransinchung R. N., and Brind Kumar N. (2010). “Investigations on Pastes and Mortars of Ordinary Portland

[2] Cement Admixed with Wollastonite and Microsilica.” ASCE Mat. J(22) 305-313.

[3] Yazdani, M. Filsaime, and S. Islam (2008). “Accelerated Curing of Silica-Fume Concrete.” ASCE Mat. J(20) 521-529.

[4] Amitava Roy, Nicholas Moelders, Paul J. Schilling, and Roger K. Seals (2006). “Role of an Amorphous Silica in Portland Cement Concrete.” ASCE Mat. J(18) 747-753.

[5] Xianyu Jin, and Zongjin Li (2003). “Effects of Mineral Admixture on Properties of Young Concrete.” ASCE Mat. J(15) 435-442.

[6] David B. McDonald, A. S. AI-Gahtani, Rasheeduzzafar, A. A. AI-Mussallam, Yacoub M. Najjar, and Imad A. Basbeer (1996). “Discussion of Resistance of Silica-Fume Concrete to Corrosion-Related Damages.” ASCE Mat. J(8) 177-178.

[7] Safwan A. Khedr, and Ahmed F. Idriss (1995). “Resistance of Silica-Fume Concrete to Corrosion-Related Damage”. ASCE Mat. J.(7). 102-107.

[8] Mohammad Shamim Khan, and Michael E. Ayers (1995). “Minimum Length of Curing of Silica Fume Concrete.” ASCE Mat. J(7) 134-139.

[9] Safwan A. Khedr, and Mohamed NagibAbou-Zeid (1994). “Characteristics of Silica-Fume Concrete.” ASCE Mat. J(6) 357-375.

[10] P. C. Aitcin, and P. Laplante (1990). “Long – Term Compressive Strength of Silica-Fume Concrete”. ASCE Mat. J(2) 164-170.

[11] ArnonBentur, and Ariel Goldman,(1989). “Curing Effects, Strength and Physical Properties of High Strength Silica FumeConcretes”. ASCE Mat. J. (1). 46-58

[12] Detwiler, R., and Mehta, K. (1989). "Chemical and physical effects of silica fume on the mechanical behavior of concrete." ACI Mat. J., 86(6), 609-614.

[13] Perraton, D., Aitcin, P. C., and Vezina, D. (1988). "Permeabilities of silica-fume concrete." Permeability of concrete, ACI SP-108, Amer. Concrete Inst., Seattle, Wash., 63-84.