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Cement & Concrete Composites 27 (2005) 593–598

Cement & Concrete Composites

www.elsevier.com/locate/cemconcomp

Effect of pozzolans on the performance of fiber-reinforced mortars

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Abstract

Randomly oriented short fibers have been shown to increase tensile strength and retard crack propagation of cement based materials such as fiber-reinforced mortars for diverse applications, especially in aggressive environments. In the case of reinforced concrete, it is very important to produce a ''high quality'' cover in order to prevent corrosion of the rebars. In order to obtain a high performance material the use of a pozzolan is advisable because low permeability is achieved. The objective of this research was to determine the effect of pozzolans such as silica fume (SF), fly ash (FA), and metakaolin (MK) on the properties of fiber-reinforced mortars. Different types of natural and synthetic fibers were used. A superplasticizer was used to keep the same workability as that of the control mortar. Results of the mechanical and durability properties of the fiber-reinforced mortars are reported. The results show that a loss of resistance due to embedding fibers in mortar is compensated for by the increase in strength caused by silica fume or metakaolin additions to the mortar. The addition of 15% of SF or MK produces an improvement of up to 20% and 68%, respectively, when compared with those mortars without addition. There is a significant decrease in the coefficient of capillary absorption and chloride penetration when a highly pozzolanic material is incorporated into the matrix. In general, these materials, especially SF and MK, improve the mechanical performance and the durability of fiber-reinforced materials, especially those reinforced with steel, glass or sisal fibers. The fly ash addition had a different performance, which could be attributed to its low degree of pozzolanicity.

Keywords: Fiber-reinforced mortars; Pozzolan; Fly ash; Metakaolin; Silica fume; Natural fibers; Synthetic fibers

1. Introduction

It is very important to obtain high performance mortars for utilization in some applications, for instance as a material to be used for shotcreting in repair and rehabilitation applications. Considerations about the durability of the material are very necessary, particularly when a structure is subjected to severe marine and industrial environments [1,2].

Incorporation of fibers in cementitious materials has gained importance, in part because of the reduction of shrinkage cracking, which it can improve the durability of the materials. The arresting shrinkage cracks may help diminish the permeability of a material. However, it is well known that, in general, the compressive strength of the material reduces and the permeability increases because of the embedding of some types of fibers into matrixes. To compensate for these changes, an important option is the use of supplementary materials, which can lead to densification of the mortar.

The main task of this investigation was to determine the effects of the incorporation of various supplementary materials on strength, permeability, and chloride diffusion of a Portland cement mortar, with and without the fiber reinforcement. Both natural and synthetic fibers were studied. Also, the electrochemical behavior of reinforcing bars (rebars) incorporated in such mortars was determined.

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0958-9465/$ - see front matter
doi:10.1016/j.cemconcomp.2004.09.010

2. Experimental program

A Portland cement which is marketed as ASTM Type V was used. Its properties, together with those of four supplementary cementing materials are reported in Table 1. These additions were a commercial silica fume (SF); a blast furnace slag (GGBS) from Companhia Siderurgica Tubarão in Brazil; a metakaolinite (MK), obtained by thermal activation of a Kaolin from Antioquia (Colombia); and a fly ash (FA) from Manizales (Colombia). The silica fume, metakaolinite and fly ash were added at amounts of 15% by weight relative to the cementitious material content (Portland cement + addition), while the GGBS was proportioned at 70% of the cementitious fraction. The mixes used were prepared by blending the Portland cement with each one of the mentioned pozzolans. The cementitious matrixes were all mortar mixes. A graded natural river sand with a maximum particle size of 6 mm was used. The sand–cement ratio (by weight) of the mixes was 3:1. Superplasticizer–cement ratio fluctuated between 0.015 and 0.03. The amount used for each mix was that necessary to achieve a specified range of mortar flow between 100 and 115 (NTC 111). Because of this fact, the water—(Portland cement + addition) ratio varied between 0.52 and 0.64.

Six different types of natural (Fique, F; Sisal, S; and Coir, C) and synthetic (Steel, St; Glass, G; and Polypropylene, PP) fibers were used. Fique is a native Colombian plant from which a fiber is extracted. Sisal and coir (coconut) fibers were sourced from Brazil [3]. The fibers were chopped into 10 mm lengths. These were embedded in the blended cement mortars in the proportion of 2.5% by weight of the cement. The designations of the various mortar mixes are noted in Table 2.

A conventional food mixer was used to prepare the mixes which were cast in specimen moulds as follows:

- 50 mm cubic specimens were prepared for the measurement of compressive behavior at 3, 7, 28, 60, and 90 days of normal curing according to ASTM C39.

Table 1
Properties of Portland cement and supplementary materials

Component	Cement	GGBS	FA	MK	SF
SiO_2	20.99	33.19	56.73	52.52	96.85
Fe_2O_3	3.64	0.6	6.58	1.84	0.50
Al_2O_3	5.24	15.74	19.30	44.65	1.88
CaO	63.99	42.11	5.54	0.34	–
MgO	1.78	7.89	2.98	0.00	0.00
Loss on ignition	2.22	0.00	6.51	1.71	0.43
Density, kg/m^3	3140	2880	2500	2570	2270
Pozzolanic activity index with cement at 28 days	–	98.4[a]	75.2[b]	92.6[b]	103.6[c]

[a] ASTM C989.
[b] ASTM C618.
[c] ASTM C1240.

Table 2
Designation of mixes

Mix type	Matrix
M1	Cement mortar without addition
M2	Cement mortar + 15% silica fume (SF)
M3	Cement mortar + 15% metakaolin (MK)
M4	Cement mortar + 15% fly ash (FA)
M5	Cement mortar + 70% ground granulated blast furnace (GGBS)

- 50 × 100 mm (diameter × height) cylindrical specimens were prepared for total absorption and percentage permeable void volume testing at 31 days of curing according to ASTM 642, and for the determination of the capillary absorption coefficient at 45 water curing days following an European standard procedure [4].
- 95 × 50 mm (diameter × height) cylindrical specimens were prepared for Chloride penetration testing at 30 standard curing days according to ASTM C1202.
- Specimens for electrochemical monitoring were prepared by casting and compacting mortar with a steel bar located centrally in a 50 × 100 mm (diameter × height) cylindrical mould. The ends of the bar had previously been wrapped with insulating tape, leaving an exposed area of 1600 mm^2. After demoulding, specimens were partially immersed in a 5% NaCl solution. The corrosion potential (E_{corr}) and corrosion rate (I_{corr}) of each of the embedded bars were monitored over eight months by, respectively, the half-cell potential (ASTM C876) and linear polarization resistance (ASTM G59) techniques. The value of I_{corr} was calculated from the Stern–Geary equation:

$$I_{corr} = B/R_p \quad (1)$$

where B is 26 mV, the value recommended for the active or corroding steel, and R_p is the polarization resistance.

3. Experimental results and discussion

3.1. Compressive strength

Some of the additions were observed to enhance the compressive strength of the Portland cement mortar (M1) as can be seen in Fig. 1. The incorporation of SF, GGBS, and MK increased the average compressive strength by 23%, 19%, and 6%, respectively.

As expected, the incorporation of fibers in the plain mortar caused a reduction in its compressive strength. For comparative purposes the results obtained at 90 curing days are presented in Fig. 2. In the case of steel fibers a small decrease (6.6%) was noted, but for PP and sisal a considerable reduction (∼30%) was observed. However,