Construction and Building Materials 26 (2012) 613–618

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Compressive strength and sulfate resistance of limestone and/or silica fume mortars

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ARTICLE INFO

Article history:
Received 17 March 2011
Received in revised form 25 May 2011
Accepted 18 June 2011
Available online 13 July 2011

Keywords:
Limestone
Silica fume
Mortar

ABSTRACT

In this study, compressive strength and sulfate resistance of mortars containing silica fume and/or limestone in different replacement levels were examined. For this purpose, limestone was used as 5%, 20%, 35% and silica fume was used as 5%, 10%, 15% by weight of cement. Sixteen different blended cements were prepared containing limestone and/or silica fume in different ratios. Mortar mixtures were prepared using these 16 cements. Flow values and 2, 7, 28, 90, 180 day-compressive strengths of the mortar mixtures were determined. In addition, sulfate resistances of mortars were separately determined in sodium and magnesium sulfate solutions. Consequently, it was seen that negative effect of silica fume on workability of mortars and limestone on compressive strength of mortars can be compensated by using limestone and silica fume together. Simultaneous use of limestone and silica fume was showed to increase sulfate resistance of mortars.

1. Introduction

Silica fume is a by product from electric furnaces used in the manufacture of silicon metal or silicon alloys [1–5]. It is well known that, this product has several advantages such as high ultimate strength, high sulfate resistance and low heat of hydration when used in Portland cement concrete. These advantages derived from high specific surface and pozzolanic activity of silica fume particles [1–3,6–8]. Limestone is used for various aims in cement and concrete, as a raw material of clinker, as aggregate in concrete and an additive in cement [6]. The usage of limestone powder in cement has several advantages such as, high early strength, high workability, low water requirement, low production cost of concrete and low CO_2 emission in the cement production [9–13]. Portland limestone cements can be produced by partial replacement of limestone from 6% to 35% according to European Standard EN 197-1 [14].

The aim of this study was to investigate simultaneous effect of silica fume and limestone on compressive strength and sulfate resistance of mortars. In this scope, mortars containing various amounts of silica fume (5%, 10%, 15% by weight of cement) and/or limestone (5%, 20%, 35% by weight of cement) were prepared. Then flow values and 2, 7, 28, 90, 180 days uniaxial compressive strengths as well as sodium and magnesium sulfate resistances of these mortars were determined. As a result, it was seen that simultaneous using of limestone and silica fume improved properties of mortars which investigate in this study.

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doi:10.1016/j.conbuildmat.2011.06.064

2. Experimental study

CEM I 42.5 type normal Portland cement, limestone and silica fume were used in the experimental study. Chemical compositions of these materials are presented in Table 1. The Blaine surface of limestone is 420 m^2/kg and specific surface of silica fume is 18,000 m^2/kg. Sixteen different cement mixtures were prepared using the above mentioned materials in various proportions as summarized in Table 2.

Flow values, compressive strengths (2, 7, 28, 90, 180 days) and sulfate resistance of mortars prepared from these 16 cements were determined. $50 \times 50 \times 50$ mm cube mortar specimens were prepared by using 450 g cement, 1350 g standard sand and 0.5 water/binder ratio for determination of compressive strength of mortars. The strength values given in this study are the average of six specimens. Flow values of mortar mixtures were determined according to ASTM C1437. The average of four measurements was used for determination of flow values.

Sulfate resistances of mortars were determined according to ASTM C1012 test procedure. $25 \times 25 \times 285$ mm prismatic specimens and $50 \times 50 \times 50$ mm cube specimens were prepared from each mortar mixtures. All specimens were cured in standard curing conditions until cube specimens gained compressive strength of 20 MPa. After reaching compressive strength of 20 MPa, prismatic specimens were separately kept in 5% sodium sulfate and 4.2% magnesium sulfate solutions. The change in length of the specimens was measured periodically. Three specimens were tested for each mortar mixture.

3. Results and discussion

3.1. Flow table test results

As it can be seen from Table 3, flow values of mortars decreased with increasing silica fume content. Silica fume, up to 5% replacement level, does not have a significant effect on the workability of mortar. Beyond this replacement level (i.e. in the mixtures containing 10% and 15% silica fume) flow values lower than that of control mixture containing no silica fume recorded. It seems that, in 5% silica fume replacement level, the circular and ultra fine silica fume

Table 1
Chemical composition of materials used in study.

%	Cement	Limestone	Silica fume
SiO_2	19.65	0.52	90.26
Al_2O_3	4.47	0.34	0.63
Fe_2O_3	3.56	0.29	0.33
CaO	62.53	54.32	3.18
MgO	2.40	0.42	0.33
SO_3	2.64	0.04	–
C_3S	55.45	–	–
C_2S	14.51	–	–
C_3A	5.82	–	–
C_4AF	10.83	–	–

Table 2
Mixture proportions.

Mixture	Cement (%)	Limestone (%)	Silica fume (%)
Control	100	0	0
5L	95	5	0
20L	80	20	0
35L	65	35	0
5S	95	0	5
10S	90	0	10
15S	85	0	15
5L5S	90	5	5
5L10S	85	5	10
5L15S	80	5	15
20L5S	75	20	5
20L10S	70	20	10
20L15S	65	20	15
35L5S	60	35	5
35L10S	55	35	10
35L15S	50	35	15

Table 3
Flow values of mortars.

Mixture	Flow value (mm)	Relative flow values (%)
Control	131	100
5L	139	106
20L	140	107
35L	147	112
5S	130	99
10S	128	98
15S	122	93
5L5S	133	102
5L10S	127	97
5L15S	125	95
20L5S	136	104
20L10S	132	101
20L15S	129	98
35L5S	139	106
35L10S	135	103
35L15S	132	101

particles enter the relatively coarse cement interparticle space, push the interparticle water outwards. Thus, the water acts as free water contributing to the workability of the mixture. On the other hand, owing to the high surface area of silica fume particles at high replacement levels, silica fume increases the water requirement of the mixture, or reduces the workability for given water content which is the case in this study [15,16].

On the contrary, flow values of mortars increased with increasing limestone content of cement. Compared to control mixture, even 5% limestone replacement affected the flow value positively.

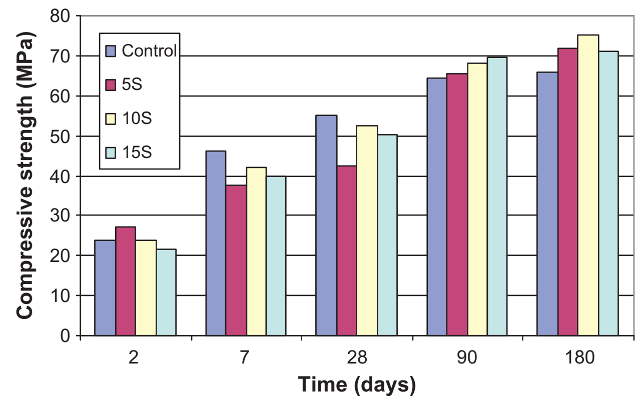

Fig. 1. Compressive strength values of cements containing only silica fume.

The effect is more pronounced in 35% limestone-incorporated cement. Since grindability of limestone is higher than that of clinker, ground limestone has a wider grain size distribution than cement. Thus, fine granulated limestone particles fill wide pores among cement particles and reduce water requirement [13,17,18].

Flow values of limestone–silica fume mortars were generally lower than flow values of mixtures containing only limestone and higher than flow values of mixtures containing only silica fume. Therefore, negative effect of silica fume on workability was compensated by simultaneous using of silica fume with limestone in cement. The effect of limestone on flow values of limestone–silica fume mortars increased with increasing limestone content. Considering with flow values of mortars, the optimum limestone–silica fume mortar is 35L5S containing 35% limestone and 5% silica fume.

3.2. Compressive strength test results

Compressive strength of mortars containing only silica fume are shown in Fig. 1. In addition, the effect of silica fume addition on relative compressive strengths is given in Table 4. Compressive strength values of silica fume mortars are generally lower than control mixtures up to 28 days. Beyond this age, compressive strengths of silica fume-incorporated mixtures are higher than that of control mixtures. As it is well known, being a highly pozzolanic material, silica fume forms additional calcium silicate hydrate by reaction with calcium hydroxide formed upon cement hydration. This results in increase in the strength of the blended cement. Since at early ages of hydration of cement sufficient amount of calcium hydroxide is not available, the early strength of blended cements is lower than that of ordinary cements.

Considering the compressive strength of mortars, it is obvious that optimum silica fume content is 10%. Compressive strength of silica fume mortars generally decreased at 15% silica fume inclusion level because of increasing water requirement and decreasing workability by high silica fume replacement. As it was mentioned earlier, 15% silica fume replacement reduced similarly the flow values of mortars.

Compressive strengths of mortars containing only limestone are shown in Fig. 2. In addition, the effect of limestone addition on relative compressive strengths is given in Table 4. Compared to control mortar mixture, limestone inclusion reduced compressive strength values and these reductions increased with increasing limestone content. The reason lies in the reduction of hydraulically active clinker fraction of cement upon the limestone replacement [17]. Cement dilution effect of limestone becomes more effective at 35% limestone replacement level especially at later ages.