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Use of diatomite as partial replacement for Portland cement in cement mortars

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Abstract

The aim of the present study is to investigate the use of diatomite as a partial replacement for cement in the production of cement mortar. Diatomite was used at 0%, 5%, 10% and 15% replacement by weight for cement while sand and water quantities were kept constant. Compressive and flexural strength, freeze–thaw resistance, sulfate resistance, water absorption and dry unit weight of the mortars were determined. The compressive and flexural strength decreased with increasing diatomite content for all curing periods. However the compressive strength of the cement mortar which was produced with 5% diatomite content complied with the minimum specified value of given in the standards. Diatomite replacement generally increased the compressive strength of the cement mortar after 25 freezing and thawing cycles. Water absorption of the mortars decreased with the increase of diatomite content except the mortar containing of 15% diatomite. Dry unit weight of the cement mortar was lower than the control mortar because of high porosity of diatomite. The expansion of the cement mortar bars immersed in 5% sodium sulfate solution decreased with increasing diatomite content and generally the sulfate resistance of the mortars was higher than that of the control mortar.

Keywords: Cement replacement; Cement mortar; Diatomite; Portland cement

1. Introduction

Diatomite is a sedimentary rock primarily composed of the skeletons of microscopic single celled aquatic plants called diatoms. The skeletons are composed of amorphous silica (silicon dioxide, SiO_2), a very durable substance. Besides its amorphous silica content diatomite rocks commonly contain carbonate and clay minerals, quartz and feldspars. Diatoms skeletons are highly porous, light in weight and chemically stable and inert [1].

Diatomite has been used in variety of applications, mainly as filtration agent and functional fillers for paints and plastics. Because of its resistant to heat and chemical action it is also used in fireproof cement, insulation materials as an absorbent in explosives manufacture [2,3].

Diatomite is used as pozzolanic additives for Portland cement and mortars and grouts. Aydin and Gül [4] studied the effect of diatomite as additive on the properties of concrete. They indicate that the increase of additive ratio results a sudden decrease in compressive strength. The pozzolanic reaction of diatomite leads to the formation of higher amounts of hydrate products, especially at the age of 28 days [5]. Stamatakis et al. [6] demonstrated that the use of diatomite rocks as cement additives has drawbacks such as higher water demand, but compressive strength of the laboratory produced cements exhibit higher values than that of the reference Portland cement. This diatomite rock had the greatest amount of silica content reflecting its high opal-A content. Fragoulis et al. [7] investigated that the addition of diatomite in cement results an increase of its specific surface (Blaine) because of their high grindability.

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The high specific surface was mainly due to the nature of the rock that was composed of very fine-grained particular such as diatom frustules, clay particles and calcareous grains. The combination of reactive silica and high Blaine results in cement with improved mechanical properties. According to Tonak [8] the main drawback of the diatomite addition to cement is the increase in water demand and fineness of produced cement. Diatomite rocks are very soft materials and grinding with clinker and gypsum has advantages in view of lower specific energy consumption. Aruntas [9] indicated that the addition of diatomite in cement has a great effect on its grain size increasing its fineness.

Due to its low thermal conductivity, diatomite could be used in bricks and other products for thermal and acoustical insulation. Unal et al. [10] studied the physical and mechanical properties of lightweight concrete produced with diatomite as lightweight aggregate. Test results indicated that lightweight concrete could be used in construction to obtain high isolation and reduce dead load of construction. Uygunoglu and Unal [11] also investigated the properties of lightweight block element produced with diatomite as divide element to reduce dead load of construction. Diatomite had been used by the ancient Greeks and Romans as an abrasive and making lightweight building bricks and stone [12].

The experimental research program outlined in this paper is designated to investigate the influence of diatomite on some properties of cement mortar, namely, compressive and flexural strength, water absorption, dry unit weight, freeze–thaw resistance and sulfate resistance.

2. Experimental study

The chemical composition and physical properties of Portland cement and diatomite used in the study are given in Table 1. The diatomite samples were crushed and air dried passing through to 0.50 mm-sieve. Diatomite is characterized as natural pozzolan (P) according to the TS EN 197-1 [13]. This standard specifies that the reactive SiO_2 content shall be not less than 25% by mass and diatomite samples used in this research satisfies this requirement.

Ordinary Portland cement (CEM-I 42.5 N) conforming to TS EN 197-1 was used in the experimental study. The specific gravity of the cement was 3.15. Initial and final setting times of the cement were 119 and 210 min, respectively. The Blaine specific surface area was 3516 cm^2/g and C_3A content of Portland cement was 7.73%.

Sand used in the experimental study was standard Rilem Cembureau type according to TS EN 196-1 [14]. Water used in the study was tap water provided from city waterworks of Balikesir (Turkey).

The mortar mixture proportions were 1:3:0.5 by weight of cement, sand and water, respectively. Diatomite was used at 0%, 5%, 10% and 15% replacement by weight for cement while sand and water quantities were kept constant. Mortar mixture design is given in Table 2. Mixture preparation was conducted according to the TS EN 196-1 procedure. The mortar mixtures were mixed in a Hobart mixer and compacted by a vibration table operating at 12000 ± 400 rpm. The specimens were kept in moulds for 24 h at room temperature of 20 °C. For each mixture, three $40 \times 40 \times 160$ mm prisms and 50 mm cubes were prepared and covered with wet burlap and left in the casting room at 23 ± 2 °C for 24 h. The specimens were then demolded and cured in lime saturated water at 23 ± 2 °C until the time of testing. The strength tests of the specimens were conducted according to Turkish standard procedure. For flexural strength test, three prismatic specimens from each mixture were prepared and tested by one-point loading configuration with span of 10 cm. The flexural strength test was performed in ELE model testing machine with a capacity of 10 kN, the loading rate was 50 N/s. The compressive strength test was performed using six broken pieces of test prisms left flexural strength test. Compressive strength measurements were carried out using ELE International ADR 3000 hydraulic press with a capacity of 3000 kN, the loading rate was 15 N/mm^2.The flexural strengths were determined by taking the average of three test results whereas the compressive strengths were determined by taking the average of six test results. The strength values of mortar specimens are given in Table 2.

The evaluation of the water absorption (WA) and unit weight was performed on cube specimens with size of

Table 1
Physical, chemical and mechanical properties of cement and diatomite used

Chemical composition (%)	Cement	Diatomite	Physical properties of Portland cement	
SiO_2	20.04	69.20	Specific gravity	3.15
Al_2O_3	5.81	9.49	Initial setting time (min)	119
Fe_2O_3	3.62	21.74	Final setting time (min)	210
CaO	61.52	1.63	Volume expansion (mm)	1.00
MgO	1.43	0.64	Specific surface (cm^2/g)	3516
Na_2O	0.18	–	Compressive strength	
K_2O	0.94	–	of cement (MPa)	
SO_3	2.87	–	2-days	27.2
Free CaO (%)	1.41	–	7-days	42.4
Cl^-	0.01	–	28-days	52.7
LOI	2.60	2.76	C_3A (%)	7.73

Table 2
Some properties of the cement mortars

Mix	Diatomite (%)	Compressive strength (MPa)				Flexural strength (MPa)				Dry unit weight (kg/m^3)	WA (%)
		2-days	7-days	28-days	56-days	2-days	7-days	28-days	56-d		
Control	0	23.90	40.87	49.87	56.08	5.08	7.09	8.49	9.52	2214	8.73
D5	5	22.22	33.99	46.02	54.11	4.52	5.38	6.62	8.74	2208	8.67
D10	10	12.03	19.57	24.83	33.72	2.27	2.88	4.45	4.92	2146	8.57
D15	15	11.00	14.81	14.94	29.32	1.94	2.27	3.28	4.68	2098	10.11

$50 \times 50 \times 50$ mm. After 28 days hardening in water, mortar specimens were dried in an oven at 105 °C until a constant weight and then allowed to cool to room temperature. For determination of water absorption by total immersion, dry mass for each specimen was recorded and then totally immersed in water at 20 °C until achieved a constant mass. The gain in weight expressed as a percentage of the dry weight was the water absorption of the specimens. The test values of water absorption and dry unit weight are presented in Table 3.

Freeze and thaw (FT) resistance was tested on the water saturated cube specimens after 28 days of initial moist curing. In this test the specimens were put in deep freezer at −20 °C for 4 h during freezing and in water at room temperature for 4 h during the thawing period. The freeze and thaw test cycle was repeated for 25 times and then compression test was conducted. Also three specimens from each mixture were kept in water at 20 °C during the freeze–thaw test of the other specimens and all specimens were tested at the same age. The results with or without 25 freeze–thaw cycles are shown in Table 3.

For the determination of sulfate resistance, the expansion of cement mortars containing diatomite were measured by using specimens having a cross-section of 25×25 mm and 285 mm in length. The sulfate exposure testing procedure was conducted by immersing mortar specimens after the specified initial curing in a water tank containing 5% sodium sulfate solution. After 28 days of curing in tap water, three specimens from each mixture were immersed in 5% sodium sulfate solution for 8 weeks. The aggressive solutions were made by dissolving regent-grade chemicals in tap water and test solutions were renewed every two weeks. Test solution was maintained at 23 ± 2 °C during the test period. The test solution was kept in plastic containers with space between the mortar specimens. Test specimens were kept covered throughout the testing period to minimize evaporation. The expansion of mortar specimens were measured every week until eight weeks of exposure. Average values were calculated from the measurements of three replicates.

Table 3
The compressive strength of the cement mortar after freeze–thaw (FT) test

Mix	Compressive strength after 25 FT cycles (MPa)	Compressive strength without FT cycles (MPa)
Control	44.87	44.43
D5	43.42	44.51
D10	44.04	43.39
D15	31.62	29.45

3. Test results and discussion

Diatomite was used as 0%, 5% 10% and 15% replacement by weight for cement while sand and water quantities were kept constant. The cement, sand and water mixing proportions were 1:3:0.5, respectively. The compressive strength of the mortar was determined at 2, 14, 28 and 56 days, and the test results as a function of age are presented in Fig. 1. As expected the compressive strength increased with age. The rate of increase depended upon the level of diatomite replacement and age. The results show that the compressive strength decreases with the increasing diatomite content at all ages. As seen in Table 2, it is observed that the compressive strength of control mortar (D0) achieved a compressive strength of 23.90 MPa at the age of two days, 40.87 MPa at the age of seven days, 49.87 MPa at the age of 28 days, and 56.08 MPa at the age of 56 days. The compressive strength of the mortars (D5, D10, D15) containing diatomite ranged from 22.00 MPa to 11.00 MPa at the age of two days, 33.99 MPa to 14.81 MPa at the age of seven days, 46.02 MPa to 14.94 MPa at the age of 28 days, and 54.11 MPa to 29.32 MPa at the age of 56 days. When these values compare with the control mortar, it can be seen that the mortars containing diatomite have lower compressive strength than that of the control mortar. The mortars con-

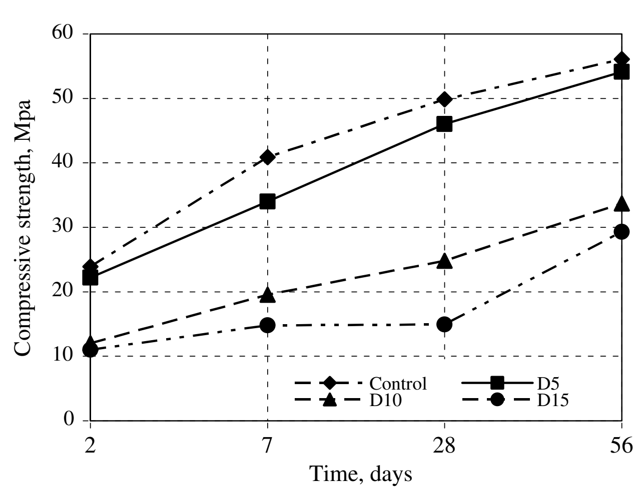

Fig. 1. Compressive strength of the cement mortars versus time.

taining 5% diatomite have higher compressive strength and the mortars with 10% and 15% diatomite content have lower compressive strength than the minimum values given in Turkish Standards. The mortars containing 5% diatomite showed the 8% decrease in compressive strength compared to control mortar at the age of 28 days. The compressive strength of the mortar (D5) containing 5% diatomite was obtained as 46.02 MPa at 28 days. This value complied with the specified value of 42.50 MPa at 28 days given in TS EN 197-1.

Flexural strength of the mortars was determined at the age of 2, 7, 28 and 56 days, and the results are presented as a function of age in Table 2 and Fig. 2. In general flexural strength of the mortars decreased with increasing diatomite content. The control mortar (D0) achieved a flexural strength of 5.08 MPa at the age of two days, 7.09 MPa at the age of seven days, 8.48 MPa at the age of 28 days, and 9.52 MPa at the age of 56 days. The flexural strength of mortars (D5, D10, D15) containing diatomite varied between 4.52 MPa and 1.94 MPa at the age of two days, 5.28 MPa and 2.27 MPa at the age of seven days, 6.62 MPa and 3.28 MPa at the age of 28 days, and 8.74 MPa and 4.68 MPa at the age of 56 days. The mortars containing 5% diatomite showed the 22% decrease in the flexural strength compared to control mortar at the age of 28 days.

The compressive strength of mortar specimens after 25 freeze–thaw (FT) cycles and without freeze–thaw cycles are given in Table 3 and Fig. 3. Generally diatomite replacement increased the compressive strength of the mortar except 5% diatomite content after 25 FT cycles. 5% diatomite replacement for cement caused the reduction in compressive strength after freeze–thaw test. The mortars containing 10% and 15% diatomite showed higher durability resistance to freezing and thawing damage. This result may be attributed to the effect of diatomite filler packing of the mortar.

Water absorption and dry unit weight of the mortar mixtures containing diatomite are given in Table 2 and Fig. 4. The results indicate that dry unit weight decreases with an increase in diatomite content. Dry unit weight changed between 2098 kg/m^3 and 2214 kg/m^3 for mortar specimens aged 28 days. The dry unit weight of the mortars containing diatomite was lower than the control mortar because of high porosity and the low specific gravity of diatomite compared to the cement. Water absorption of the mortars decreased with the increase of diatomite content except the mortars containing of 15% diatomite. The porous nature of diatomite is the main reason for such behavior. Water absorption changed between 8.57% and 10.11% for the mortars aged 28 days.

The effect of diatomite replacement on the variation of sulfate expansion is shown in Fig. 5. The mortar samples were exposed sulfate environment after 28 days of initial moist curing. In general, the sulfate resistance of the mortars was higher than that of the control mortar (D0). Additionally, the sulfate resistance of the mortar containing diatomite increased with increasing the diatomite replacement level. The control mortar showed less durability to sulfate attack reaching maximum sulfate expansion value after 8 weeks of exposure of 0.018%. The mortars containing 10% and 15% diatomite content showed excellent durability to sulfate attack and they reached maximum sulfate expansion after 8 weeks of sulfate exposure of 0.013% and 0.012%, respectively. The mortars containing 5% diat-

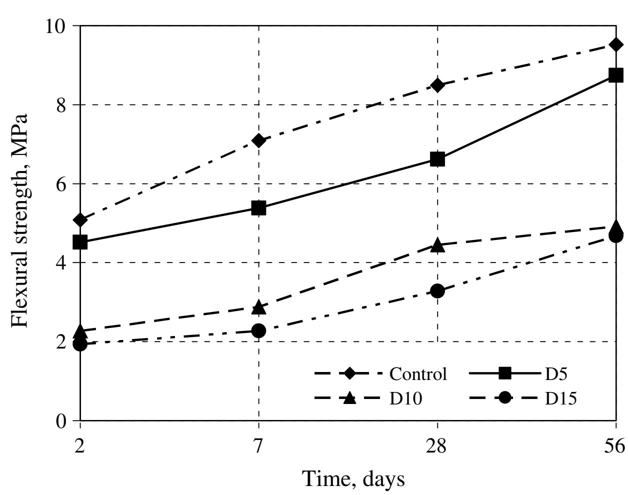

Fig. 2. Flexural strength of the cement mortars versus time.

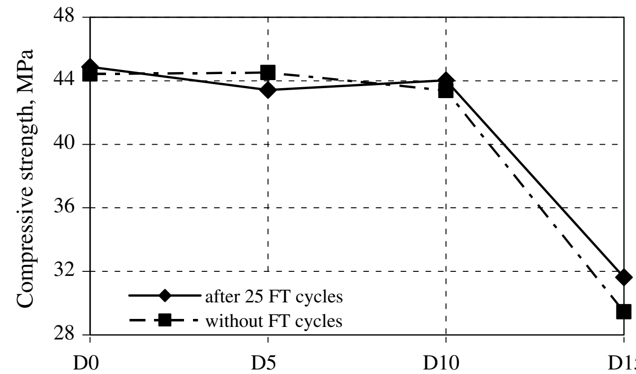

Fig. 3. Compressive strength of the cement mortars after freeze–thaw (FT) test.

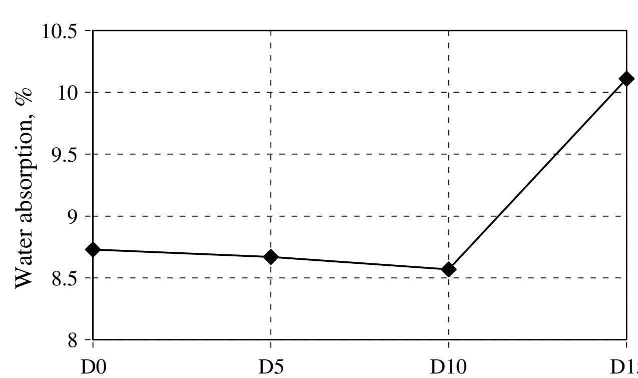

Fig. 4. Water absorption of the cement mortars.

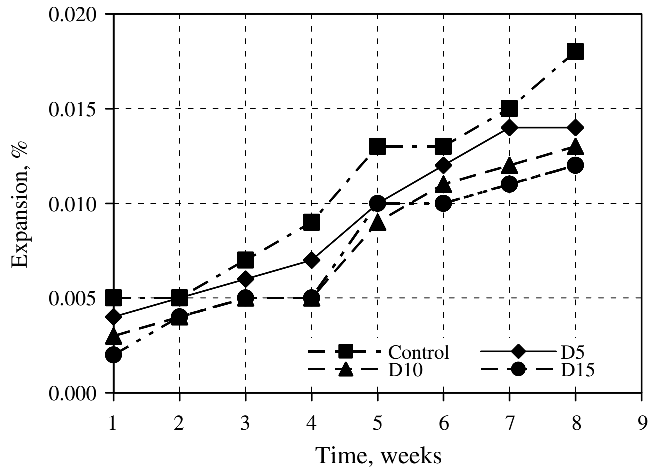

Fig. 5. Expansion of the cement mortars cured in 5% sodium sulfate solution.

omite showed intermediate durability to sulfate attack reaching maximum sulfate expansion value of 0.014%. The increase in sulfate resistance can be explained that replacement of a portion of Portland cement with diatomite reduces the total amount of tricalcium aluminate hydrate in cement paste.

4. Conclusions

The possibility of using diatomite as a replacement of cement has been investigated in the present study and the following conclusions can be drawn from the study:

- The strength of the mortar decreased with increasing diatomite content. The mortar containing up to 5% diatomite exhibited comparable results with the minimum values given in Turkish Standards.
- Diatomite replacement generally increased the compressive strength of the mortar except 5% diatomite content after 25 freeze–thaw cycles. 10% and 15% diatomite replacement showed higher durability resistance to freezing and thawing damage. This result may be attributed to the effect of diatomite filler packing of the mortar.
- The dry unit weight of the mortars containing diatomite was lower than the control mortar because of high porosity and the low specific gravity of diatomite compared to the cement.
- Water absorption of the mortars decreased with the increase of diatomite content except the mortar containing 15% diatomite. The porous nature of diatomite is the main reason for such behavior.
- In general, the sulfate resistance of the mortars was higher than that of the control mortar. The sulfate resistance of the cement mortar containing diatomite increased with increasing the diatomite replacement level. The mortar containing 10% and 15% diatomite showed excellent durability to sulfate attack.

According to test results, it is suggested that diatomite can be used up to 5% as a replacement of Portland cement in production of cement mortar.

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