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Full Length Research Paper

Use of diatomite in the production of lightweight building elements with cement as binder

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Diatomite is currently being used as raw material in various industrial sectors worldwide and is also in use in the construction industry, aimed at improving characteristics of concrete and cement, and in producing heat-insulating bricks, using various binders. In this study, usage of cement as a binder, in producing diatomite-based lightweight building elements, was investigated. Diatomite rocks were ground and sifted through sieves with square-shaped apertures of 500 μm then blended with cement at ratios of 10, 20, 30 and 40% by volume. The mixtures were kneaded to plastic consistency by adding water and were placed into the moulds to obtain test sample cubes of 100 × 100 × 100 mm in dimensions. Compressive strengths and ultrasonic sound transmission values of samples were determined as basic evaluation criteria. The samples were observed to have gained strength compared to the strengths of the samples of 7 days age at the end of 28 days curing period, and no visible deformations were determined for the first 50 days. However, as the age of the samples proceeded, the samples displayed decreases in their compressive strengths due to formations of capillary fractures that expanded gradually. Finally, at the age of 150 days, non-negligible mass losses developed in the samples. These loses were thought to have sourced from the alkali aggregate reaction that took place between cement and silica constituent of diatomite. Consequently, it was concluded that it is not convenient to use cement as a binding agent in the production of diatomite-based lightweight building elements.

Key words: Diatomite, aggregate, building materials, lightweight building component, binding agent, Cement, alkali reaction.

INTRODUCTION

Diatomite and its characteristics

Diatomite is a porous, lightweight sedimentary rock resulting from accumulation and compaction of diatom remains (class Bacillariophyceae). The delicate shell or frustules of diatoms, which gives diatomite many of its useful properties, is composed mainly of amorphous opaline silica ($SiO^{2-}nH_2O$). Most diatoms fall within the 10 to 100 µm size range, although some are as large as 1 mm. It is estimated that 1 cubic inch of diatomite may contain 40 to 70 million diatoms. While the specific density of diatom frustules is nearly twice that of water, the perforations and open structure of the frustules render diatomite a considerably lower effective density (between 0.12 and 0.25 g/cm^3) and high porosity (from 75 to 85%). Diatomite is able to absorb and hold up to 3.5 times its own weight in liquid (Stoermer and Smol, 1999). Moh's hardness of natural diatomite ranges from 4.5 to 5.0 while that of calcined diatomite does from 5.5 to 6 (Ciullo, 1996).

The color of pure diatomite is white or near white, but possible impurities found with it may darken the color.

Such impurities may be other aquatic fossils such as sponge residues, sand, clay, volcanic ash, mineral aerosols, calcium carbonate, magnesium carbonate, soluble salts and organic matters. Thermal conductivity of bulk quantities of diatomite is low but increases with

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higher percentages of impurities and a higher density. The fusion point depends on the purity and averages about 1430℃ for pure diatomite. While diatomite is essentially inert, it is attacked by strong alkalis and by hydrofluoric acid but virtually unaffected by other acids (Othmer, 2010).

In the related literature, typical chemical composition of natural diatomite is given as 67.80 to 90.07% silica (SiO_2), 0.62 to 10.30% alumina (Al_2O_3), 0.20 to 6.85% iron oxide (Fe_2O_3), 0.05 to 1.21% titanium oxide (TiO_2), 0.04 to 0.21% phosphate (P_2O_3), 0.19 to 3.0% limestone (CaO), 0.11 to 1.64% magnesium (MgO), 0.13 to 0.97% sodium (Na_2O), 0.13 to 1.47% potassium (K_2O), the first values being the minimum and the second ones the maximum (Kogel et al., 2006).

Fields of use

Diatomite products are currently in use in various processes as main and intermediate material in the industry. According to Stoermer and Smol (1999), the first commercial application and perhaps the most significant use of diatomite was in the production of dynamite, as discovered in 1867 by Alfred Nobel. Contemporarily, filtration applications are the main area of use for diatomite (73%), followed by use as filler (14%). Some other fields of use can be listed as source of silica in the production of various chemical substances, as heat and electricity insulation material, as an absorbent as abrasive and surface cleaner, and catalyst carrier. Diatomite is also used in production of lightweight construction materials and fire-resistant bricks.

Additionally, petroleum industry, organic and inorganic chemicals production, non-ferrous metal industry, industrial waste water treatment processes, the paper industry and swimming pools' water filtration are also included in the list of use of diatomite (Kogel et al., 2006).

The use of diatomite in the construction industry

When the literature is scanned, one is welcomed by an abundance of studies on the usability of diatomite in the construction industry.

According to Kogel et al. (2006), diatomite is used to improve characteristics of cement, being used as pozzolanic additive to improve homogeneity and plasticity of concrete and mortars by dispelling excessive water in the mixtures. Othmer (2010) stated that addition of diatomite to concrete mixtures in certain ratios makes concrete easy-to-be-processed and increases compressive and tensile strength of concrete.

Kastis et al. (2006) studied use of diatomite as puzzolanic additive in the production of cement. They stated that cements with 10% diatomite addition had the same compressive strength with the corresponding Portland cement. They also stated that addition of diatomite increased need of water of the cement paste.

Fragoulis et al. (2005) studied the effects of addition of diatomite to cement as puzzolanic material. They found that water demand of all diatomite-blended cements was higher than that of the laboratory produced ordinary Portland cement (OPC) while compressive strength of diatomite-blended cement was improved with respect to the lab OPC.

Aruntaş (1996) proposed that diatomite reserves of Ankara and Çankırı, Turkey, could be used as puzzolanic additive in cement production at the ratios of 10 and 20%, but stated that diatomite addition decreased compressive and tensile strength while it increased sulfate resistance in cementitious systems.

Aydın and Gül (2006) determined that when diatomite was added to cement in concrete production, as the diatomite ratio increased the initial setting and setting duration of concrete increased.

Ünal et al. (2005) investigated physical and mechanical properties of lightweight concretes produced with diatomite aggregates. They stated that diatomite, regarding its properties of insulation, could be used as aggregate in certain ratios (30% fine, 40% medium and 30% coarse aggregates of diatomite) in the production of lightweight concrete. But their main emphasis in the study was that scanning electron microscope (SEM) images of the samples showed that the interfacial zone between diatomite aggregates and cement was found to have been very weak.

Topçu and Uygunoğlu (2006) investigated the use of diatomite and pumice in the production of lightweight concrete, and determined that the bond interfacial zone between diatomite aggregates and the cement, developed considerably weaker than the one between pumice and cement.

Uygunoğlu and Ünal (2005) composed various granulometric series from diatomite aggregates and produced lightweight building elements with unit weights between 0.95 to 1.2 g/cm^3 and compressive strengths 2.5 to 6.0 N/mm² using cement as binder.

Fragoulis et al. (2004) stated that clayey diatomaceous rocks from Greece could be utilized for the production of lightweight aggregates on an industrial scale, but emphasized that distinct and diverse applications would require further researches as additional parameters involved had to be measured.

Bideci et al. (2009) observed that addition of diatomite to clay at the ratios of 10, 20 and 30%; at 800, 900 and 1000℃ firing temperatures, resulted in production of bricks that provided the required mechanical properties.

Yıldız (1997) showed that diatomite rocks from Seydiler (Afyon, Turkey), could be used in producing insulation bricks.

Sezgin (1997) stated that diatomite could be used in reducing unit weights of decorative plates made from gypsum.

Figure 1. Detail from diatomite reserve of Belisırma.

Table 1. Chemical composition of diatomite reserve of Belisırma.

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Cl	Cr_2O_3
%	74.37	8.416	4.435	1.9	1.455	0.177	1.7	1.311	0.267	0.01315

Table 2. Physical and mechanical characteristics of diatomite reserve of Belisırma.

Physical Property	Loose unit weight (g/cm^3)	Density (g/cm^3)	Ignition loss (%)	Moisture content (%)	Hardness (Mohs)
Value	0.50	2.97	10.56	7.60	5.00

METHODOLOGY

Material

The diatomite rocks that were used in the study were obtained from town of Belisırma in Ihlara-Selime Plain, in the western part of the Cappadocia Volcanic Province, Turkey (Figure 1). Portland cement of the type "TS EN 197-1 CEM I 42.5 R" was supplied from Niğde Cement Plantof ÇİMSA Inc., Turkey.

Town of Belisırma is located between the longitudes 33º to 36º and latitudes 36º to 38º. It is 33.0 km far from Province of Aksaray, 67.2 km from Province of Niğde and 88.6 km from Province of Nevşehir.

The data on chemical and physical characteristics of the diatomite obtained from the reserve area are shown in Tables 1 and 2. From Table 1, the percentage of SiO_2 is read to have been as 74.37%. Al_2O_3 and F_2O_3 follow SiO_2, respectively as the second and third most abundant minerals in the composition of the rocks. Loose unit weight of the ground diatomite was measured to be 0.5 g/cm^3 while the density was obtained as 2.97 g/cm^3. Moisture content was found to be 7.60% and ignition loss as 10.56%. Furthermore, a SEM image of 8.000 times magnification of the rocks is shown in Figure 2 to give an idea about the morphology of the rocks.

The data for the chemical composition and physical characteristics of the cement used in the study are shown in Tables 3 and 4, respectively. The data were obtained from the laboratory of the above-mentioned cement plant.

Experimental work

The material obtained from the reserve was ground by a ball mill of horizontal axis at a speed of 60 rpm for a period of 25 min. The ground material was sieved through a sieve with openings of 500 µm square mesh and stored. The particle size analysis of diatomite aggregate that was used for the production of samples is shown in Figure 3.

All samples produced for the study were cast at the dimensions of 100x100x100 mm. In the production of samples, piles of diatomite representing the same properties were prepared by measuring the loose volumes of diatomite. The Portland cement ratio to diatomite by volume was chosen as 10, 20, 30 and 40% (Table 5).

The most important parameter observed in the previous studies was that the bond interface between cement and diatomite aggregates formed very weakly suggesting that the diatomite aggregates did not sufficiently adhere with cement paste (Ünal et al., 2005; Topçu and Uygunoğlu, 2006).

For this reason, the diatomite that was ground and sifted through a sieve with openings of 500 µm square mesh were chosen as aggregate. Thus, it was aimed to evaluate the performance that diatomite would exhibit when used if ground to 500 µm in size as

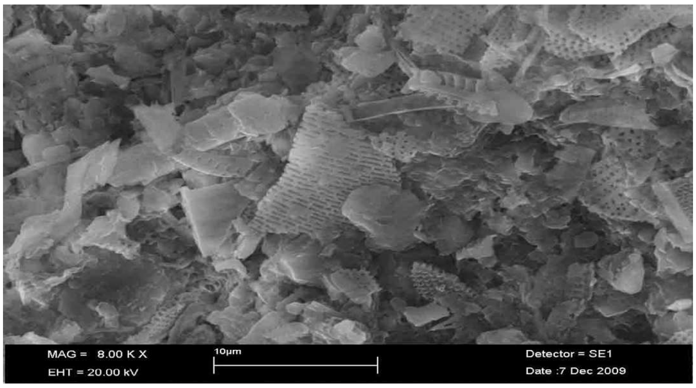


Figure 2. SEM image from diatomite rocks of the reserve area (x 8.000).

Table 3. Chemical composition of the cement used in the study.

Component	SO_3	Loss of ignition	Cl^-	S.CaO	Total additive	Trass	Limestone	Gypsum
%	3.50	3.30	0.0097	0.80	0.00	0.00	5.00	4.00

Table 4. Physical and mechanical characteristics of the cement**,** TS EN 197-1 CEM I 42,5 R.

Class of strength	Compressive strength (N/mm^2)			Beginning of setting (h)	End of setting (h)	Expansion of volume (mm)	Specific surface (cm^2/g)	Density (g/cm^3)
	1 day	2 days	28 days					
42.5R	14.0	23.0	52.8	02:15	03:25	1.0	3300	3.15

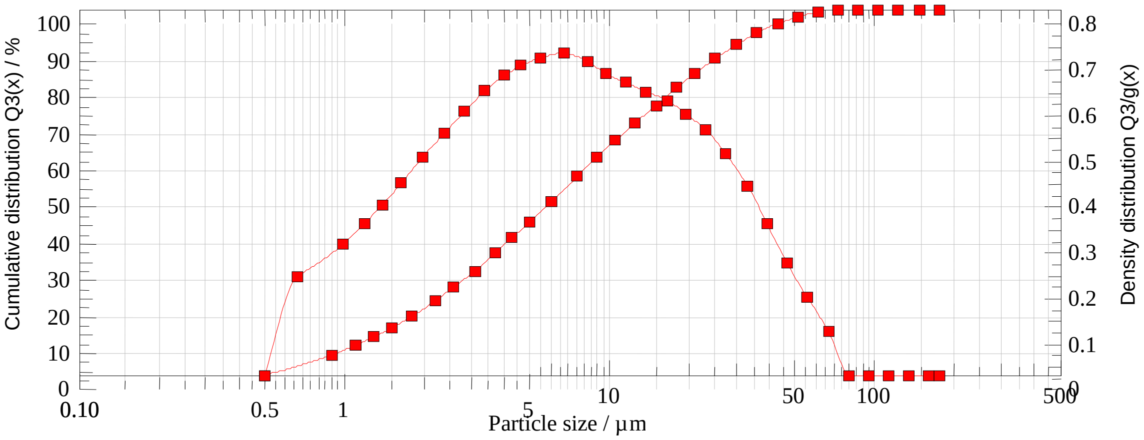


Figure 3. Particle size analysis of the ground diatomite aggregate.

the maximum, remembering that diatomite did not form a sufficient bond interface with cement in larger granulometric sizes. The compositions of mixtures were arranged on the basis of volume.

The diatomite and cement were drily mixed in a desktop-type mixer for 3 min then pastes of samples were prepared by gradually adding water and kneading the mixtures for 5 min until they acquired plastic consistency. The slump values of pastes were constantly measured and tried to be kept around 7.

The mixtures, of which slump values were measured, were filled into the square formed moulds of 100×100×100 mm in dimensions.

Table 5. Mixture compositions by volume.

Cement quantity (cm^3)	Diatomite quantity (cm^3)	Water quantity (cm^3)	Slump value (Slump)
100	1000	700	7
200	1000	740	7.1
300	1000	770	7.1
400	1000	870	7.2

Table 6. Measured values of samples for 7, 28, 60 and 150 days.

Sample age (Days)	Cement ratio (%)	Unit weight (g/cm³)	Ultrasonic sound transmission (km/s)	Compressive strength (N/mm²)	Porosity (%)
7	10	1.25	1.00	0.90	58.00
	20	1.27	1.22	1.42	51.00
	30	1.33	1.22	2.32	42.00
	40	1.37	1.22	2.43	38.00
28	10	1.24	1.22	1.25	59.00
	20	1.24	1.22	2.56	54.00
	30	1.31	1.22	4.08	49.00
	40	1.35	1.22	4.95	42.00
60	10	0.75	155.00	0.89	65.00
	20	0.91	63.70	3.18	59.00
	30	0.98	64.30	4.01	52.00
	40	1.08	56.40	5.31	45.00
150	10	0.63	-	0.62	65.00
	20	0.71	100.70	1.65	59.00
	30	0.83	83.40	3.45	52.00
	40	0.95	61.30	4.29	45.00

The moulds were filled in 2 layers, each layer being compressed by applying 25 strokes with a tamping rod. The samples were kept in the moulds for 24 h.

Twelve (12) samples were produced for each cement ratio and for each testing period, namely for testing periods of 7, 28, 60 and 150 days. Thus, 192 samples were produced, 9 of each group being used in the tests and remaining 3 samples being spared for any possible use in the future.

After 24 h, the samples were taken out from the moulds and were kept in a curing pool for 28 days in which the ambient temperature was set to 20±2°C. At the end of curing period, unit weights, compressive strengths, ultrasonic sound transmission values and apparent porosities were determined for each group of samples. Then, arithmetic means of the measured values for each group of samples were calculated.

Unit weights of the samples of 7 and 28 days of ages were determined by weighing the samples after getting them out of the curing pool and having them kept in open air conditions in laboratory environment for 24 h. The samples of 60 and 150 days of ages were also kept in an open air conditions in laboratory environment following the curing period, thus were brought to air-dry condition before the tests.

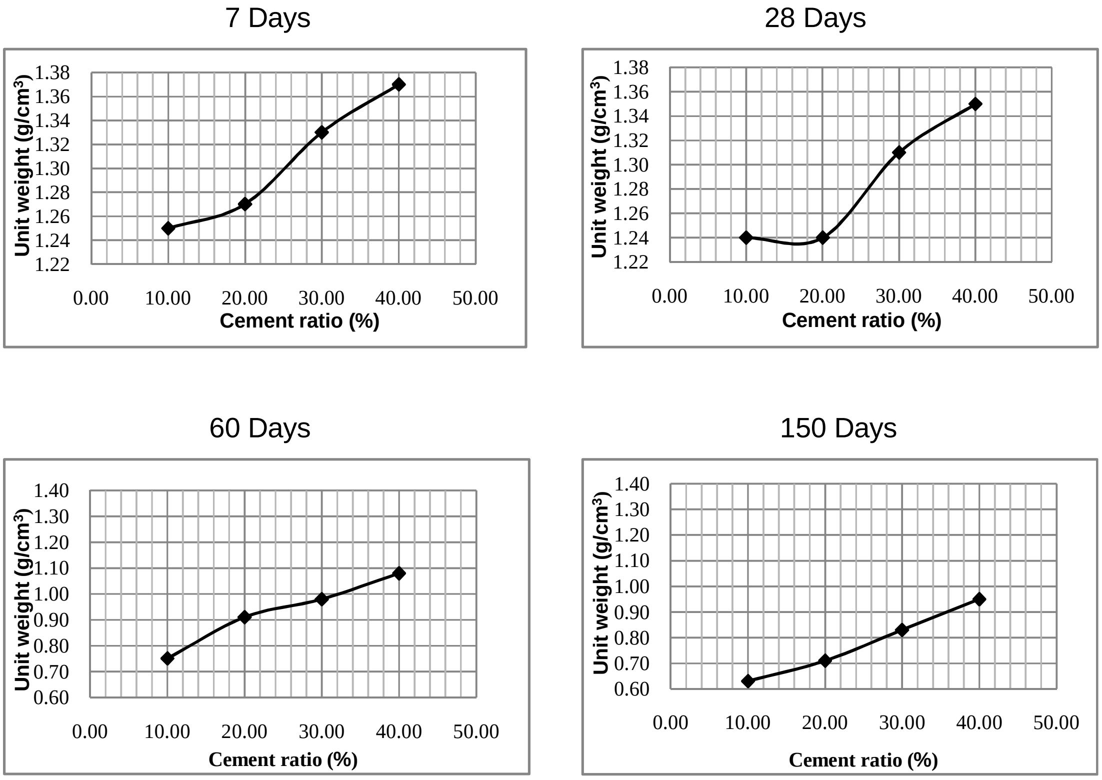
The compressive strengths of the samples were determined according to TS-EN 1354, with a press equipment complying with the standards.

Ultrasonic sound transmissions of the samples were determined using an ultra-sound device, with trade mark and model “CONTROLS E 48”, by applying direct measuring method from two mutual surfaces.

RESULTS

The results of the tests are shown in Table 6. The course of the unit weights of the samples, depending on the age is shown in Figure 4.

According to Table 6 and Figure 5, it is understood that decrease in the unit weights of the samples are directly proportional to their ages. To give some examples, the samples with 10% cement ratio gave an average unit weight of 0.63 g/cm^3 for the age of 150 days while they gave an average of 1.25 g/cm^3 for the age of 7 days.

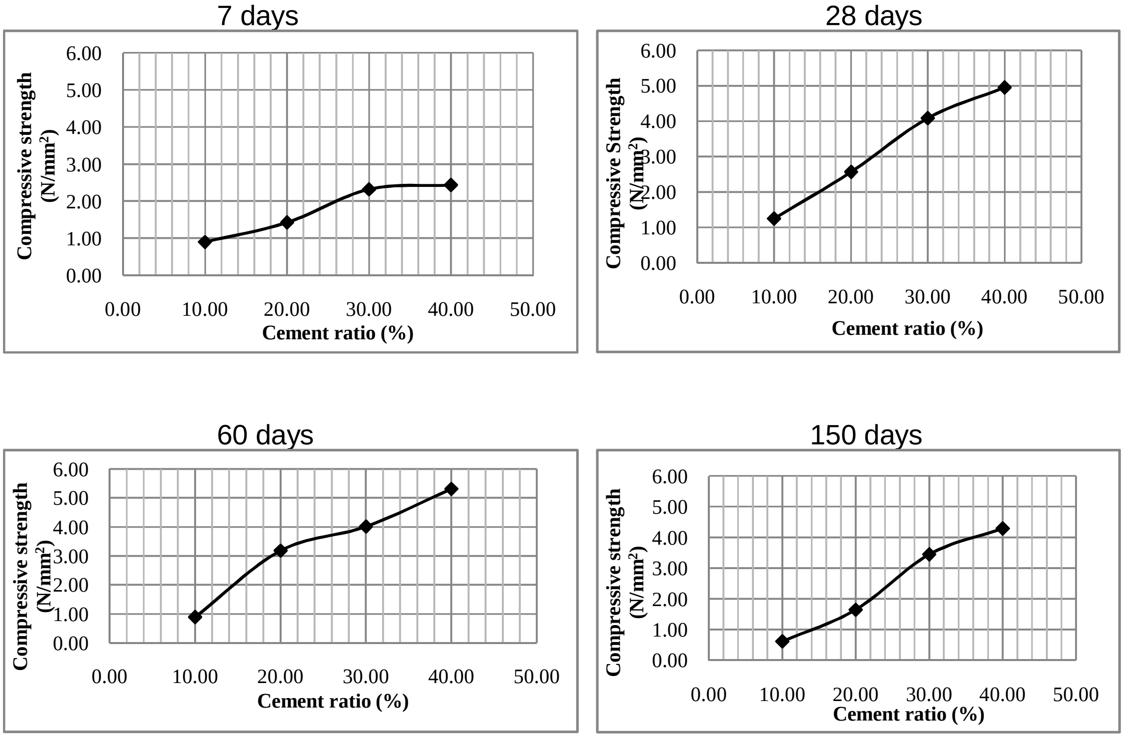

7 Days

28 Days

60 Days

150 Days

Figure 4. Relationship between the unit weights and the ages of samples.


7 days

28 days

60 days

150 days

Figure 5. Relationship between compressive strengths and ages of the samples.

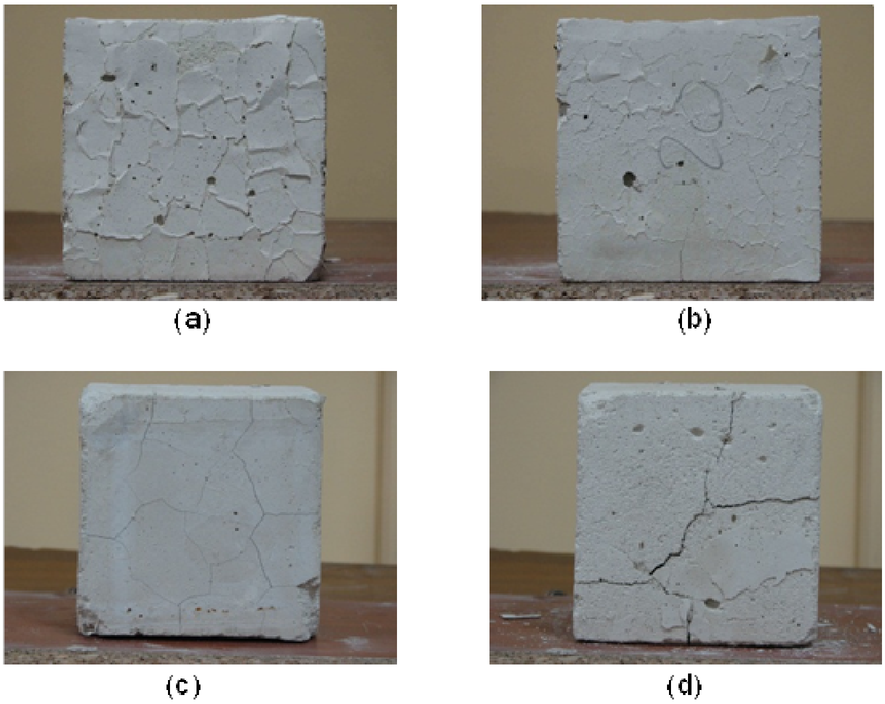


Figure 6. Relationship between physical appearances and ages of the samples. a, Sample of 10% cement and 60 days age; b, sample of 20% cement and 60 days age; c, sample of 40% cement and 150 days age; d, sample of 10% cement and 150 days age.

Similarly, the samples with 40% cement ratio gave an average of 0.95 g/cm^3 for the age of 150 days while they gave 1.37 g/cm^3 for the age of 7 days. The other samples exhibited similar behaviors as well. Thus, at the end of 150 days of age, the average unit weights of the samples with 10% cement ratio decreased as low as 49%, and those of the samples with 40% cement ratio did decrease as low as 30% of their initial values.

Furthermore, ultrasonic sound transmission values of the samples of ages of 60 and 150 days proved to have increased compared to those of the samples of ages of 28 and 7 days.

Both cases were thought to have been sourced from the fact that the samples of younger ages kept the kneading and curing waters within their bodies while samples with older ages released them as the time passed.

As shown in Table 6 and Figure 5, the compressive strengths of the samples of 7 days ages were obtained as good as 0.90, 1.42, 2.32 and 2.43 N/mm^2 for 10, 20, 30 and 40% cement ratios, respectively.

The compressive strengths of the samples of ages of 28 days rose expectedly depending on the cement ratios and were determined as 1.25, 2.56, 4.08 and 4.95 N/mm² for 10, 20, 30 and 40% cement, respectively.

For the ages of 60 days, the average compressive strength of the samples with 10% cement ratio, showing a sharp decrease of 28.8%, declined from 1.25 to 0.89 N/mm² while those of samples with 20 and 40% cement ratios exhibited limited increases. Furthermore, a limited decline was observed in average compressive strength of samples with 30% cement rate resulting in 4.01 N/mm².

After 150 days, compressive strengths showed sharp falls and were 0.62, 1.65, 3.45 and 4.29 N/mm² for the samples with 10, 20, 30 and 40% cement ratios, respectively. These sharp falls suggested that the decreases that were observed in samples with 10 and 30% cement ratios on the 60th day, also started in other samples and continued to rise.

In naked-eyed inspections on the samples, no deformations were observed since the bodies of the samples were saturated with water for the 28 days of curing period. However, once the curing stage completed, the samples were taken out of water and were kept under open air conditions in laboratory environment, it was witnessed that capillary cracks, that progressively enlarged, occurred on the surfaces of the samples as shown in Figure 6. Furthermore, deformations that were easily noticeable by naked-eye occurred on the edges. Especially, the samples with 10% cement ratio experienced considerable flaking formations on their surfaces on as early as the 60th day. The deformations on the edges of the 60 days old samples became clear. On the 150th day, deformations became more apparent and mass losses from the samples were observed while 10% cement-rated samples completely decomposed.

DISCUSSION

The following results were derived from the experimental study on the production of diatomite-based lightweight building elements using cement as binder:

1) The unit weights of the produced samples were found reasonably low. 2) Increase in the amount of cement in the mixtures led to increases in compressive strengths.
3) Until the end of the 28 days curing period, compressive strengths of samples exhibited a rising trend. But after this period, losses in compressive strengths started to develop. The trend of decrease in the compressive strengths continued in course of time.
4) It was observed that the samples did not exhibit any deformation as long as they were held subject to curing in water. However, as they were kept in an open air in the laboratory environment, cracks started to form. The cracks gradually enlarged in course of time and reached to the depth of disintegration in most of the samples.
5) The cracks decreases in compressive and resulting decomposition of the samples are thought to have sourced from alkali reactivity that took place between silica, the main component of diatomite, and cement.
6) The basic result of this study is that a diatomite-based lightweight building element is not possible to be produced when cement is used as binder. But, aiming to reduce unit weight of a product, diatomite aggregates can be added to cementitious systems within limited amounts such as 10 to 20% as referred previously.

Further researches should be conducted in order to bind diatomite more sustainably and benefit more from this unique mineral in the construction industry.

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