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The effect of high temperature on lightweight concretes produced with colemanite coated pumice aggregates

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HIGHLIGHTS

- Pumice aggregates were coated by cement and colemanite mixture.
- Usage of colemanite coated aggregates prevents concrete from strength loss.
- Unit weight of concrete with colemanite coated aggregates increases.
- Weight loss of concrete with coated aggregates increases under high temperature.

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ABSTRACT

Concrete is a non-combustible material. But it is known to have serious changes in its physical, chemical and mechanical properties when exposed to high temperatures. In this study, the surface of large pumice aggregate was coated with cement + colemanite (CLM) dual mixtures (0%, 7.5%, 12.5% and 17.5%). Lightweight concretes were produced by using coated aggregates. Then by exposing to temperatures at 20 °C (Control), 200 °C, 400 °C and 600 °C, the unit weight, compressive strength, ultrasonic pulse velocity and weight loss of concrete samples were determined. Also, in order to identify the internal structural properties of the samples, DTA-TGA and SEM-EDS analysis were performed. As a result of the study, the optimum value was obtained from 12.5-CLM samples. It is determined that the lightweight concretes that would be produced with pumice aggregates coated with cement + colemanite dual mixture would have a high performance against high temperature.

1. Introduction

Since 1940s, the effect of high temperature on mechanical properties of lightweight concretes has been inspected by many researchers in order to produce fire-resistant materials [1]. High temperature, which is one of the main physical effects that causes durability problem in constructions, might cause the construction to be out of service or loss of life and property by making permanent damages to the constructions. Getting these damages under control is possible by removing the effect or having protective measures against the effect [2]. The changes that might occur in physical, chemical and mechanical properties of materials under high temperature effect should be known beforehand [3].

When concrete is exposed to high temperatures, its chemical composition and physical structure changes considerably. Also as a result of the high temperature effect that causes micro-structural changes, the concrete loses its strength and durability [4]. According to EN 13501-1 [5], regarding fire resistance classes of construction materials, the concrete is present in class A1. Factors that effect high temperature resistance of mortar cements and concretes are divided into two main groups as material-related factors and environmental factors. Material-related factors can be specified as aggregate characteristics, the bond between aggregate and cement paste, thermal compliance of constituents and characteristics of cement paste [6]. In addition to this, the mechanical properties of the concrete are also affected by the temperature increase. The deterioration in mechanical strength of concrete is low at 200 °C, whereas it becomes more significant over 400 °C [7]. To show high performance at high temperatures, proper aggregate selection for produced concrete is very important. The type, porosity and mineralogy of the aggregate have an important effect on the behavior of the concrete that is exposed to high temperatures. For example, the mineralogy of the aggregate determines the different thermal expansions between aggregate and cement paste and the maximum strength of the intermediate zone [8].

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Table 1
Chemical analysis of the pumice aggregate and colemanite.

Chemical composition	B_2O_3	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	SO_4	As (ppm)	Loss on ignition
Pumice	–	74.10	13.45	1.40	1.17	0.35	4.10	3.70	–	–	–	1.54
Colemanite	40.09	4.98	0.15	0.029	26.95	2.37	–	0.09	0.26	0.31	11.36	0.27

Table 2
The chemical and physical analysis of CEM I 42.5/R cement.

Component (%)	CEM I 42.5R	TS EN 197-1	Physical analysis			TS EN 197-1
CaO	63.92	C + S ⩾ %50	Setting time (min.)	Start	145	Min. 60
SiO_2	19.55			Finish	195	–
Al_2O_3	5.12	–	Density (g/cm^3)		3.11	–
Fe_2O_3	2.52	–	Specific surface (cm^2/g)		3912	–
MgO	1.02	Lim. ⩽ %5	Total volume Expansion (mm)		1	Max.10
SO_3	2.96	Lim. ⩽ %4	Over 40 μ sieve residue		23.1	–
Na_2O	0.27	–	Over 90 μ sieve residue		2.4	–
K_2O	0.67	–	Compressive strength (N/mm^2)	2 days	25.9	Min. 20
Cl^-	0.0089	Lim. ⩽ %0.10		7 days	45.1	–
Loss on ignition	4.08	Lim. ⩽ %5		28 days	-	Min. 42.5 Max.62.5
Res. solution	0.36	Lim. ⩽ %5				

Table 3
The codes of coated pumice aggregates.

Colemanite addition	Codes
0%	0-Control
7.5%	7.5-CLM
12.5%	12.5-CLM
17.5%	17.5-CLM

Table 5
Dry unit weight test results.

Samples	Unit weight (kg/m^3)			
	20 °C	200 °C	400 °C	600 °C
0-Control	1666	1601	1573	1541
7.5-CLM	1867	1795	1746	1719
12.5-CLM	1845	1746	1703	1675
17.5-CLM	1858	1750	1709	1685

Bingöl and Gül (2004), determined that for lightweight and semi-lightweight concretes, compressive strength is decreased by increasing temperature and although between 150 and 300 °C temperatures no significant loss is observed in compressive strength of concretes, the minimum compressive strength was obtained at 750 °C [9]. Karakoç (2013) determined that for concretes with expanded perlite and pumice aggregate which are exposed to high temperatures, the compressive strength of the concrete decreases with the increase of perlite and pumice aggregate amount and a significant strength loss is observed at 700 °C [10].

Boron minerals are natural compounds containing different amounts of boron oxide (B_2O_3) in their structures. In nature, there exists more than about 230 boron minerals. Commercially important main minerals are; tincal, colemanite, kernite, ulexite, pandermite, boracite, szajbelyite and hydroboracite [11]. The simplest form of boron compounds are boron oxide (B_2O_3) and boric acid (H_2BO_3) and when it is found with calcium, it is called as colemanite, with calcium-sodium it is called as ulexite and when it is bonded with sodium, it is called as "borax" [12]. Colemanite mineral is monoclinal. It has typical colors as white-grey or greenish grey. Its hardness is 4–4.5 and its specific gravity is 2.52, although it is hardly soluble in water, it readily dissolves in acid. When heated over 400 °C, it is scorched as powder by cracking (decrepitation) [13].

About usability of boron in construction materials, studies were performed by Volkman and Bussolini (1992) [14] about the effect of boron products with fine particles on concretes, by Gencel et al. (2009) [15] about characteristics of concretes containing colemanite and by Çelik et al. (2014) [16] about lightweight brick production from boron added perlite mixtures. Aggregate coating methods were developed in order to enhance some physical properties of pumice aggregate as water absorption and strength [17–19].

In this study, the surface of pumice aggregate was coated with cement + colemanite mixture (0%, 7.5%, 12.5% and 17.5%). With obtained aggregates, lightweight concrete samples with 400 dose were produced and their behaviors at high temperatures were examined. Before and after high temperatures (200 °C, 400 °C and 600 °C), the unit weight, compressive strength, ultrasonic pulse velocity and weight loss of samples were determined. Also, DTA-TGA and SEM-EDS analysis of samples were performed.

Table 4
Concrete mixture design.

Components		Unit	Mixing amount (400 dosage)			
			0-Control	7.5-CLM	12.5-CLM	17.5-CLM
Lightweight aggregate	8–16 mm	kg	169.67	163.99	175.10	167.16
	4–8 mm	kg	278.56	275.75	281.69	268.63
Sand	0–4 mm	kg	914.25	914.25	914.25	914.25
Water		kg	207.00	205.00	204.00	208.00
Cement		kg	400.00	400.00	400.00	400.00