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Influence of High Temperature on Concrete Produced from Portland Cement with Boron Additives

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The boron compounds have been widely used as additives in the production of cement and concrete to enhance their engineering properties. In this study, three series of concrete specimens were produced using B_2O_3 additive materials, boron modified active belite cement and Portland cement. After 28 days of curing period the specimens were exposed to temperatures of 250, 500 and 750 °C. Mass loss and compressive strength were determined and recorded after the specimens were cooled to room temperature. It was concluded that the effect of the boron becomes more apparent at high temperatures.

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1. Introduction

Concrete is the most used construction material due to its easy shaping, low cost, durability, low energy usage in its production and its aesthetic quality. Durability can be expressed as the quality of long lasting of a building through its service-life under present and future environmental effects [1].

Boron compounds have been used as additives in the production of cement and concrete, for enhancing such engineering properties as fire resistance and radiation shielding [2–4]. The improvements and additional features (neutron shielding, fire resistance, antibacterial properties, etc.) provided by boron compounds to concrete and other cementitious composites are very closely related to B_2O_3 concentrations [5]. During the service period, concrete is exposed to various effects, such as erosion, freezing-thawing, chemical environments and dynamic loads [6].

In the critical cases the high temperature effect also plays an important role, since concrete exposed to the high temperatures loses significantly its strength [7, 8]. When construction materials are heated to 1200 °C the wood burns up, steel softens and loses its resistance, concrete or stones are broken into pieces [9, 10]. None of the construction materials can resist such high temperatures. However, in comparison with the other construction materials, concrete is more durable and brakes into pieces during a longer period [11].

In the present study, three series of concrete specimens were produced using B_2O_3 additive materials, boron modified active belite cement and Portland cement. Finally, the effects of boron additive on temperature resistance of concrete materials were examined.

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2. Materials and methods

2.1. Materials

In the present study, three different types of concrete were manufactured. Portland CEM I 42.5R and boron modified active belite (BAB) cements were used in the produced samples. These two types of concrete series were employed for quality control. Portland CEM I 42.5R type of cement was used in the production of the third sample, containing anhydrous boric acid $B[OH]_3$ (BA), as well as sodium aluminate $NaAlO_2$ (SA), which was used for extending the duration of the concrete setting. The physical and chemical properties of PC and BAB cements, which were used as the binding materials, are given in Table I.

Aggregates forms CT1 (coarse 22.4–8 mm), CT2 (medium 8–4 mm), CT3 (fine 4–2 mm) and CT4 (sand stone 2–0 mm) groups and grain sizes of this groups were analyzed. Values of $D_{\max} = 22.4$ mm and 15–18 cm were aimed for aggregate mixture and slump value, respectively. For reducing the ratio of w/c, slump was fixed and hyper plasticizer was employed in proportion with the weight of cement. Besides, fly ash was included into the mixture as a mineral additive, for reducing the dosage of cement, ensuring the activity of the plasticizer and for enhancing the workability, while keeping the strength constant. The amounts of the components added to 1 m^3 mixtures in the manufacturing process of concrete are presented in Table II.

2.2. Methods

In the study, concrete mix calculations have been made using TS802 standard and concrete class has been also determined by TS500 standard. Because it is commonly used in concrete production in the region, the limestone aggregate was used in ordinary and high-performance concrete production. The maximum aggregate size used was 22.4 mm. After one day of setting the samples were kept in water for 21 days. Samples were kept at 23 °C and 65% relative humidity until the time of the experiment. The specimens were 28 days old at the time of the tests. Obtained samples were exposed to temperatures of 250 °C, 500 °C, 750 °C.

TABLE I

The physical and chemical properties of PC and BB cements.

Clinker components [%]			Cement physical properties		
Component	PC	BAB		PC	BAB
SiO_2	20.52	20.37	Volumetric expansion [mm]	1	0
Al_2O_3	4.00	4.45	Fineness [90 μ]	0.1	0.1
Fe_2O_3	3.45	3.27	Slightness [200 μ]	1.1	1.8
CaO	64.28	58.19	Specific surface area [cm^2/g]	3340	3560
MgO	1.63	4.70	Initial setting time [min.]	185	220
SO_3	2.53	3.08	Final setting time [min.]	240	265
Na_20+K_2O	1.35	1.50	Specific gravity [g/cm^3]	3.12	2.98
B_20_3	0.00	1.12	Flexural strength [MPa, 2 days]	4.5	2.5
CaO [Free]	1.81	0.63	Flexural strength [MPa, 7 days]	5.8	4.1
L.O.I.	2.72	4.02	Flexural strength [MPa, 28 days]	7.2	6.0
Clinker phases [%]			Pressure strength [MPa, 2 days]	11.7	11.7
C_3S	–	56.66	Pressure strength [MPa, 7 days]	39.3	23.2
C_2S	66.23	17.65	Pressure strength [MPa, 28 days]	51.0	38.6
C_3A	7.86	6.33	Other properties		
C_4AF	14.01	12.03	Cl^-	0.000	0.006

TABLE II

Amount of the concrete components added to 1 m^3 of mixture.

Components		PC		BAB		BSA	
		Weight [kg]	Volume [dm^3]	Weight [kg]	Volume [dm^3]	Weight [kg]	Volume [dm^3]
Cement		321.00	117.52	321.00	125.49	321.00	125.49
Fly ash		123.00	59.13	123.00	59.13	123.00	59.13
Aggregate	CT1	446.88	163.10	440.96	160.93	438.09	159.89
	CT2	297.37	108.53	293.43	107.09	291.52	106.40
	CT3	253.01	92.34	249.66	91.12	248.04	90.52
	CT4	645.68	235.65	637.12	232.52	632.98	231.01
Mixing water		200.15	200.15	200.15	200.15	200.15	200.15
Water in the aggregate		3.72	0.00	3.67	0.00	3.65	0.00
$B[OH]_3$		0.00	0.00	0.00	0.00	4.44	1.28
S. aluminate		0.00	0.00	0.00	0.00	8.88	2.57
Hyper plasticizer		3.70	3.22	3.70	3.22	3.70	3.22
Air		0.00	19.00	0.00	19.00	0.00	19.00
Total		2294.52	1000.00	2272.69	1000.00	2275.45	1000.00

After removal from the furnace the samples were first weighted and the weight difference at the end of the heat treatment was determined; then to avoid getting the lost moisture back, samples were wrapped in aluminum foil and stored in secure bags. Concrete samples, exposed to thermal processing and reference samples were subjected to compressive strength and ultra sound tests in the laboratories.

3. Results

The variation of mass loss of the concrete with processing temperature is given in Fig. 1.

Mass loss changes according to the temperature of processing of the concrete samples. At 250 °C it is 1.7% for BAB concrete samples, while it is only 0.1% for BSA samples. The mass loss is not observed in the PC samples. In addition, the mentioned effect is reversed at 500 °C.

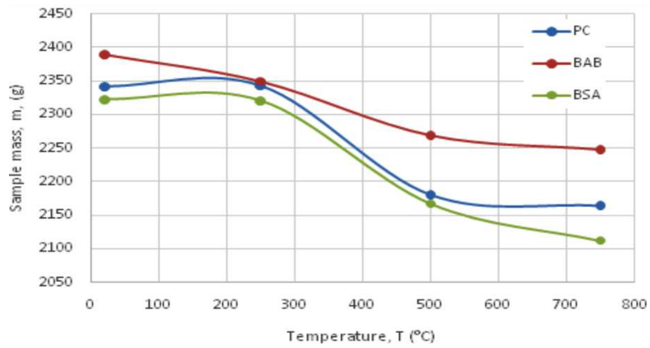

Fig. 1. The variation of mass loss of the concrete with processing temperature.

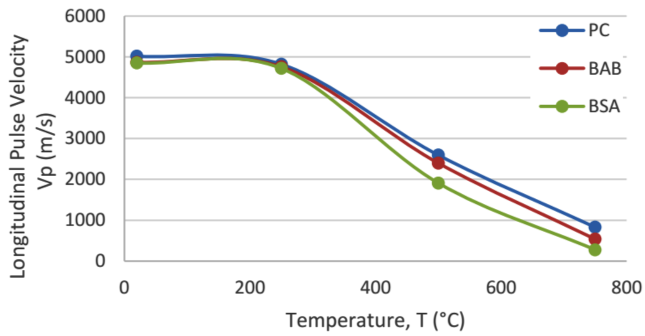

Fig. 2. The variation of longitudinal pulse velocity with processing temperature.

At 750 °C the minimum observed mass loss is 5.9% for BAB concrete samples and the maximum one of 9% is observed in BSA concrete samples. The influence of the processing temperature on longitudinal pulse velocity of concrete is presented in Fig. 2.

When Fig. 2 is examined, the same behavior is observed in all concrete samples. Ultra sound waves velocity does not change after treatment at 250 °C in all concrete samples and after treatment at 500 and 750 °C, the change is very sharp. In PC, BAB and BSA samples the longitudinal sound wave velocity decreases with increasing processing temperature. The variation of the compressive strength with the processing temperature is presented in Fig. 3.

After processing at 250 °C the compressive strength of concrete samples of PC series increases by 11%, while it decrease by 27% in BAB sample. After processing at 500 °C the compressive strength decreases in all concrete samples. However, at 750 °C the mentioned decrease is very sharp. Compressive strength of PC concrete is decreased from 52.2 MPa to 15.4 MPa due to the effect of high temperature. It is seen that high temperature has the smallest influence on the PC samples and the greatest influence on the BAB samples.

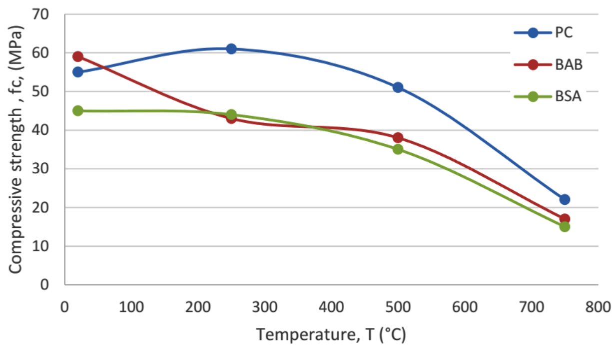

Fig. 3. The variation of compressive strength with processing temperature.

4. Conclusions

According to the results, the BAB concrete samples have the smallest mass loss and the smallest compressive strength after processing at high temperature. A decrese of longitudinal sound waves velocity with the increasing processing temperature has been observed in all samples. It was seen that high temperature has the smallest effect on PC samples while it has the greatest effect on BAB samples. Finally, it is concluded that the boron additive has no positive effect on the strength of concrete subjected to the high temperatures.

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