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Strength and fresh properties of borogypsum concrete

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HIGHLIGHTS

- The effect of borogypsum on the strength and fresh properties of concrete was investigated.
- Fifteen different mixtures were prepared to determine the effect of borogypsum on the compressive strength.
- Borogypsum can be used as a set retarder additive for Portland cement.
- According to strength test results, it was determined that 5–10% borogypsum can be used as a concrete additive.

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ABSTRACT

This paper reports on a comprehensive study on the properties of concrete containing borogypsum. Properties studied include setting time and volume expansion of paste, unit weight and consistency of fresh concrete, compressive and splitting tensile strength of hardened concrete. Potential use of borogypsum as a concrete admixture is discussed. Borogypsum contents of 0%, 3%, 5%, 10% and 15% by mass are used in the study. The strength results show that concrete mixtures containing 3% and 5% borogypsum developed higher strength values than those of control concrete mixtures. Based on strength properties, it is determined that 5–10% borogypsum may be used as a concrete additive. On the other hand, inclusion of borogypsum as a cement replacement reduced the consistency. Moreover, test results also showed that borogypsum delays setting time of paste made with cement and borogypsum. Thus, the use of borogypsum as a set retarder of Portland cement is recommended.

1. Introduction

Natural resources have a significant impact on the social-economic development of countries. There is a direct relationship between utilization of natural resources and economical development. For the developed countries, the amount of resources used is far greater compared to those of the others. Boron is one of the most important ores in Turkey which possesses 72% of the world boron reserves. Boron is used in different areas i.e., industry, energy and medicine. Turkey is second after the USA in boron mineral and compound production by 1.72 million tons.

The most important boron minerals in Turkey are colemanite, ulexite and tinkal. These minerals are subjected to concentration at production sites to produce boric acid and borates. Borogypsum, a byproduct, is collected from filters after the colemanite reacts with sulphuric acid in the production of boric acid and the filtration. The amount of this waste is approximately 550,000 tons per year [1]. Obviously, this waste material creates a significant environmental concern. However, due to its positive effects on concrete properties borogypsum has recently drawn attention by some researchers.

There are a number of studies in the literature which investigated the use of borogypsum as a cement additive [1–4]. Some studies focused on the use of borogypsum in mortar production as a cement replacement [5–8]. On the other hand, some researchers studied leaching kinetics of borogypsum by leaching with water [9–11]. However, only a few studies investigated the effect of borogypsum on the properties of concrete specimens [12]. It is believed that the effect of borogypsum on the strength and consistency properties of concrete warrants further research.

The primary objective of this study is to investigate the usability of borogypsum in cement-based materials as a mineral additive and its effect on setting time, volume expansion, compressive strength, splitting tensile strength, unit weight and consistency. It should be also mentioned that the main goals of using borogypsum in concrete are to achieve cost-effective and green environment friendly concrete.

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Table 1
Chemical composition of cement and borogypsum.

Oxide	PC	Borogypsum
SiO_2	19.55	7.35
Al_2O_3	5.31	0.61
Fe_2O_3	4.15	0.53
SO_3	2.55	46.24
CaO	62.30	27.55
MgO	3.14	2.50
B_2O_3	–	0.99
NaO	0.36	–
K_2O	0.88	–
SrO	–	1.48
Undissolved solid	0.42	–
CaO free	0.31	–
LOI	1.73	12.38

Table 2
Mineralogy of the borogypsum sample (wt.%).

Mineral	%
Anhydrite	2.2 (0.22)
Bassanite	13.0 (0.47)
Gypsum	84.8 (0.49)
Global χ^2	4.07

2. Materials

2.1. Cement

Standard Portland cement CEM I (PC 42.5 N/mm^2) with a specific gravity of 3.15 g/cm^3 was used in the study. Initial and final setting times of the cement were 160 min and 320 min, respectively. The blaine specific surface area was 3230 cm^2/g. The remaining of the cement on 90 and 45 μm sieves were 0.3% and 5.2%, respectively. The chemical compositions of cement are presented in Table 1.

2.2. Borogypsum

Borogypsum was obtained from the Etibor Emet Boric acid factory in Turkey. The specific gravity of Borogypsum was 2.37 g/cm^3. Blaine specific surface area was 8830 cm^2/g. The remaining of the borogypsum on 90 and 45 μm sieves were 3.5% and 8.5%, respectively. Borogypsum is the solid part on filter press in boric acid production. This damp waste was dried in air and then ground in mills. Elemental analyses of samples were carried out by X-ray fluorescence (XRF) spectrometry technique. Quantitative X-ray diffraction (XRD) analyses were carried out using an interactive data processing system (SIROQUANT^{TM})[1] based on Rietveld interpretation methods [13]. Diffractograms of the samples were obtained using a Philips diffractometer system with Cu Kα radiation. Samples were run from 5° to 65° 2θ with a step of increment of 0.02° and counting time of 2 s/step.

The chemical composition of Borogypsum is provided in Table 1. The results of the quantitative XRD analysis (Table 2) represent the final output from each task, when the best possible fit had been achieved between the observed and calculated XRD patterns (Fig. 1). Table 2 also shows the error associated with each individual component, from the estimated standard deviation (e.s.d). The error is expressed in each case as an absolute percentage with respect to the last digit; thus, a determination of 13.0 (0.47)% refers to 13.0% with an error of ±0.47%. An estimate of the overall goodness of fit of each analysis is also provided, expressed as the relevant global χ^2 value derived as indicated by Taylor [14]. This value should approach 1.0 for a perfect fit between the measured and interpreted patterns.

2.3. Aggregate

Dry and clean natural river sand was used with a maximum size of 4 mm. The absorption value and relative density at saturated dry (SSD) condition of sand were 2.1% and 2.65, respectively. The methylene blue value of sand was 0.25 g/kg. Two sizes of crushed dolomite aggregate were used in the concrete mixtures. The first one was 5–12 mm size with 0.8% water absorption value and 2.67 relative density at the saturated surface (SSD) condition. The Los Angeles abrasion value and flakiness index of this aggregate were 21.9% and 8.7%, respectively. The second aggregate size was 12–20 mm. The water absorption and the relative density at SSD condition measured were 0.6% and 2.69, respectively. This aggregate has 20.5% Los Angeles abrasion value and 7% flakiness index.

[1] Registered Trademark, CSIRO.

3. Mixture proportions and sample preparation

The compositions of each concrete mixtures are illustrated in Table 3. The mixtures were prepared according to the absolute volume method given by Turkish Standard, TS 802 [15]. In the beginning of mixture design, a binder content (300, 400 kg/m^3) and a water–cement ratio (0.50, 0.60) were chosen as constants, and then the volume of aggregate was determined for each control PC concrete. It should be emphasized that the volumes of aggregate were used to determine the aggregate weights.

For the purpose of evaluating the influence of the borogypsum on the strength properties of concrete, borogypsum concretes were produced using borogypsum as cement replacement at the levels of 3%, 5%, 10% and 15% by mass.

Cube samples with 150 mm sides were prepared for the compressive strength measurements. The cylinder samples with a diameter of 150 mm and a height of 300 mm were prepared for the splitting tensile strength. The compressive and splitting tensile strengths of each specimen were determined using ASTM C 39 and ASTM C 496 standards [16–17]. The compressive strength was measured at the 7, 28, and 90 days. The splitting tensile strength was measured at 28 days. Compressive and splitting represent average results obtained from three representative samples.

Experimental investigation of fresh mix properties of borogypsum NPC concrete was conducted based on ASTM C143 standard [18] using a slump cone, V–B time by ASTM C1170 standard [19] and unit weight ASTM C138 standard [20].

One mixture of cement paste and four mixtures of cement–borogypsum paste were prepared to evaluate the setting time and volume expansion. Cement–borogypsum pastes were prepared using borogypsum as cement replacement at the level of 3%, 5%, 10% and 15% by mass, respectively. Setting time was determined according to ASTM C191 [21] by Vicat Needle. Volume expansion of each specimen was determined by Le Chatalier apparatus according to TS EN 196-3 standard [22]. This TS-EN standard is derived from the European Norm (EN).

4. Results and discussion

4.1. Setting time and volume expansion

The influence of borogypsum on setting time is shown in Fig. 2. It can be seen in Fig. 2 that the setting time increases proportionally with respect to borogypsum ratio. For example, the initial and final setting time of mixture containing 15% borogypsum increases to 43.75% and 29.70%, respectively, as compared to that of the control Portland cement paste. The reason behind this behavior can be that the presence of boron which accelerates Portlandite solubility [5,23].

Results in Fig. 3 illustrate the effects of borogypsum on the volume expansion of cement paste. The results show that, except for mixture containing 15% borogypsum, all borogypsum–cement pastes had lower volume expansion compared to the control mix. Nonetheless, all mixtures produced reasonable volume expansion values as defined in the TS EN 196-3 standard [22].

4.2. Unit weight and consistency

Unit weight, V–B time and slump value consistency measurements were carried out on fresh borogypsum-NPC concrete. The results of unit weight, V–B time and slump test are presented in Table 4. The results indicate that the replacement of borogypsum by NPC has no remarkable effect on the unit weights of fresh concretes.