Construction and Building Materials 66 (2014) 403–409

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Assessment of early-age autogenous shrinkage strains in concrete using bentonite clay as internal curing technique

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HIGHLIGHTS

- Bentonite clay usage to impart internal water reservoir during autogenous shrinkage.
- Concrete prisms prepared with variable dosage of bentonite clay.
- Linear shrinkage strains computed with the help of sensitive dial gauge.
- Microstructural evaluation conducted to ascertain the behavior of bentonite clay.

ARTICLE INFO

Article history:
Received 7 January 2014
Received in revised form 22 April 2014
Accepted 18 May 2014

Keywords:
Shrinkage
High-performance concrete
Humidity

ABSTRACT

This research paper addresses the controlling methodology of autogenous deformation, which occurs as an essential attribute of high-performance concrete. The amount of cement present in concrete mix is the main cause of triggering the autogenous shrinkage in high-performance concrete. To reduce this shrinkage, the replacement of cement with bentonite clay was studied. Bentonite clay was used as 5%, 10%, 15% and 20% replacement of cement and the linear shrinkage strain in plain cement concrete beams, of selected dimensions, was monitored. The relative humidity was constantly monitored while the specimens were sealed. The beams prepared in 10% replacement of cement with bentonite showed the most encouraging results among all other mixes. Differential Thermal Analysis (DTA) and Thermo-Gravimetric Analysis (TGA) ensured that bentonite clay possesses stability to withstand high temperature gradients and the Scanning Electron Microscope (SEM)/Energy Dispersive X-ray tests (ED-XRF) showed that bentonite clay imparts certain amount of siliceous and aluminous compounds to the mixes.

1. Introduction

The recent era is shifting towards the use of High-Performance Concrete (HPC) and utilizing its capabilities altogether. Owing to its beneficial role in reducing the weight and increasing the strength, the HPC is widely accepted as replacement of ordinary cement concrete. The HPC is prepared using lower water to cementitious material proportion and may incorporate some additional ingredients in the form of mineral and chemical admixtures i.e. fly ash, silica fume, High Range Water Reducing Admixtures (HRWRAs), etc. [1]. The resulting HPC is stronger in strength but at the cost of higher cementing material content. This increased amount of cementitious content leads to the phenomenon of volumetric shrinkage in the concrete membrane [2]. Change in the volumetric proportions of concrete gives way to cracking of the concrete members which is not desirable in engineering design.

A freshly mixed concrete undergoes early-age cracking when placed in the form of a restrained member. Such restrained specimen does not find directions for dissipating the stresses induced in them due to the expansion caused by the changes occurring in the internal chemistry of the hydrating cement structure [6]. Predominantly, in the cases of high strength concretes, this phenomenon of early-age cracking has remained a matter of great concern to researchers [2].

It is the intrinsic property of HPC to have lower porosity level which is achieved by minimizing the water to binder ratio. The lower water to binder ratio is generally obtained by adding some

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http://dx.doi.org/10.1016/j.conbuildmat.2014.05.051
0950-0618/

supplementary cementing materials to the concrete batch and workability modifying agents such as silica fume, fly ash and superplasticizers. These types of concrete show a higher tendency for autogenous deformation and change in the relative humidity of concrete [6].

The creation of micro-cracks within the pore structure of HPC leads to the decrease in the tensile strain capacity of concrete and bears a stress equalizing effect [7]. Moreover, the micro-cracks created as a result of autogenous shrinkage within a restrained system may add up to a continuous crack pattern and lead to the formation of macro-cracks [8]. The overall effect of the concrete member is a loss in strength, loss to the sustainable durability and a bad impression on the overall aesthetics of the concrete member [9].

The autogenous shrinkage strains occurring in plain cement concrete beams of constant dimension has been presented in this study. In order to observe the role of bentonite clay in providing internal curing to concrete, the beams were kept covered in polythene sheet to prevent moisture transfer with the environment.

2. Materials

2.1. Cement

ASTM Type-I cement (Ordinary Portland Cement) was incorporated in the study and by following the ASTM standard procedure [3] the fineness of cement was ensured.

2.2. Aggregates

The fine and coarse aggregate used in the study were obtained from local quarries. The material properties were computed by adopting the ASTM standard procedure [4,5].

2.3. Bentonite

The research work aimed at exploring newer sites of bentonite, present in different areas of the region of Khyber Pakhtunkhwa, Pakistan. The bentonite selected for this research, shown in Fig. 1, was obtained from Takht Bhai, which is located at about 15 km from District Mardan, Khyber Pakhtunkhwa at 34°19′15″N 71°56′45″E. The lump of bentonite excavated from the site was ground to fineness level of sieve # 200. The elemental composition of the bentonite sample was determined by X-ray Fluorescence (XRF) testing.

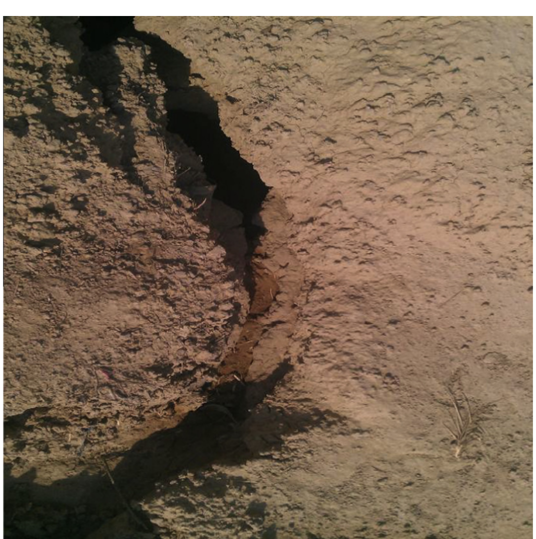

Fig. 1. Site photograph of bentonite deposit.

Table 1
Energy dispersive X-ray fluorescence test results of the bentonite clay from the selected source.

Chemistry	Percentage
SiO_2	53.08
Al_2O_3	12.38
Fe_2O_3	9.10
CaO	12.92
K_2O	2.46
Na_2O	0.00
MgO	2.64
P_2O_5	0.17
TiO_2	1.01
MnO	0.14
LOI	6.09

A pozzolan, having cementitious properties in the presence of lime or cement, should include Silicon dioxide (SiO_2), Aluminum oxide (Al_2O_3), and Iron oxide (Fe_2O_3) not less than 70% by weight of unit sample [10]. Table 1 presents the elemental composition of the bentonite clay which was in compliance to ASTM specification [10].

2.4. Superplasticizer

High Range Water Reducing Admixture (HRWRA) was used in this study in order to achieve the desired workability. The technical data as supplied by the manufacturer is shown in Table 2. Trial mixes were prepared in order to finalize the dosage of superplasticizer in the preparation of HPC mix according to the desired slump.

3. Methodology

The mix proportion of concrete was finalized using ACI 211; Absolute Volume Method. The technical data obtained from conducting test on concrete ingredients according to ASTM specifications is presented as shown in Table 3.

The mix design procedure yielded mix proportions of 1:1.64:2.33 with *w*/*c* as 0.40. A series of trials were conducted to confirm the proper mixture proportion that would result in strength of 6000 psi or more. The final mixture proportions obtained after testing ten concrete cylinder specimens and their average 28 days strengths are presented in Table 4.

The mix proportion for the control mix was 1:1.2:2.1 and that for the concrete mix with bentonite was 1:1:2, with water–cement ratio of 0.35. The finely ground bentonite clay was over-dried prior to batching. The dosage of superplasticizer increased with

Table 2
Technical data of superplasticizer.

Chemical base	Naphthalene sulfonate
Density	1.17 kg/l at 20 °C
pH value	6
Freezing point	−5 °C
Total chloride ion content	Max.% 0.1, chloride-free
Equivalent sodium oxide as% Na_2O	Max. 8%

Table 3
Mix design parameters.

S. no.	Design parameter	Result	Units
1	Specified compressive strength (28 days)	6000	Psi
2	Nominal maximum size of coarse aggregate	1	Inch
3	Fineness Modulus (F.M)	2.85	Nil
4	Rodded unit weight of coarse aggregate	96.7	lb/ft^3
5	Bulk specific gravity of coarse aggregate	2.68	Nil
6	Moisture absorption of coarse aggregate	1.43	%
7	Bulk specific gravity of fine aggregate	2.63	Nil
8	Moisture absorption of fine aggregate	1.07	%