Construction and Building Materials 166 (2018) 916–921

Contents lists available at ScienceDirect

Construction and Building Materials

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

Effect of high temperature on strength and mass loss of admixtured concretes

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HIGHLIGHTS

- The effect of chemical admixtures on the strength and mass loss of concretes at high temperatures has been investigated.
- The admixtures used: superplasticizers, hardening accelerators, setting retarders, air entrainers and water repellents.
- The concretes are subjected to temperatures of 105 °C and 300 °C with a rate of 2 °C/min.
- The greatest losses of compressive strength and mass are those obtained for concretes with air entrainers.
- The lowest losses are those obtained for concretes with superplasticizers.

ARTICLE INFO

Article history:
Received 18 November 2017
Received in revised form 28 January 2018
Accepted 30 January 2018

Keywords:
Concrete
Chemical admixtures
High temperatures
Strength
Mass loss

ABSTRACT

Chemical admixtures are used in concretes to prove some properties at ambient temperature. The admixtured concretes may present different behaviour at high temperature than at normal conditions. In this study, five different types of chemical admixtures – Superplasticizers (SP), hardening accelerators (HA), setting retarders (SR), air entrainers (AE) and water repellents (WR) – Were incorporated with different fraction of cement mass (0.5, 1.0, 1.5 and 2.0%), to investigate their influences on the strength and mass losses of concretes under high temperature. This study concerns the behaviour of admixtured concretes at ambient temperature 20 °C (normal conditions) and those subjected to temperatures 105 °C (oven dry) and 300 °C with a rate of 2 °C/min. Compressive-strength and mass loss tests were performed on the samples $10 \times 10 \times 10$ cm^{3}which were cooled up slowly to ambient temperature. It was concluded that among the chemical admixtures used, the superplasticizer (SP) significantly increased the workability of SPC. The tests results indicated that at a temperature of 300° C, the concrete with an air entrainer admixture caused the greatest loss of strength and mass when compared with others admixtured concretes. The lowest losses are those obtained for concretes with superplasticizers at this temperature.

1. Introduction

Concrete industries often use admixtures to modify a particular property. An admixture is a product whose incorporation at low dose (less than 5% of the mass of cement) to concretes, mortars or grouts during mixing, or before the implementation, causes the desired modifications of one or the other of their properties while fresh or hardened [1].

The admixtures are classified into three main types [2]. First are those that modify the workability of concrete such as plasticizers, water reducers, and superplasticizers. Second are those which modify the setting and hardening: setting accelerators, hardening accelerators, and setting retarders. Finally, those which modify particular properties: air entrainers and water repellents.

In a fire situation, despite behaving normally at an ambient temperature, concrete can be thermally unstable beyond a certain temperature.

Examples of concrete damage under high temperature are the tunnel fires under the English Channel (in 1996 and 2008) in France; Tauern (1999) in Austria; and Gotthard (2001) in Switzerland [3]. The thermal instability of the concrete can occur in various forms [4] (explosive bursting, surface bursting, aggregate bursting, angular bursting or bursting in the cooling phase).

Water in concrete exists in various forms. It plays a dual role of hydration and allowing for workability of the mixture. It is available as free (or capillary) water, adsorbed water, and chemically bound water [3]. Due to the heterogeneity of the concrete, it is

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https://doi.org/10.1016/j.conbuildmat.2018.01.181
0950-0618/

necessary to understand the role of each of the components of the concrete in the phase of rising and/or falling in temperature. When the concrete is exposed to a high temperature it undergoes various physicochemical transformations [3].

With increasing temperature, the cementitious matrix expands and evaporates causing dehydration of hydrates formed [3]. Alonso and Fernandez [5] carried out work on the process of dehydration and rehydration of cement paste subjected to different heating-cooling cycles at a rate of 1 °C per minute.

The main transformations of the cementitious matrix described during its heating by some authors with the increase in temperature are:

- 20–120 °C: the free water starts at a marked temperature of around 100 °C, while at around 120 °C free water escapes completely [6,7]. At 100 °C, the ettringite decomposes completely [5,8].
- 120–170 °C: the endothermic reaction of gypsum decomposition is observed [9]. The destruction of the C–S–H observed before 100 °C continues until 400 °C [5,8 and 10].

During the cooling phase, Alonso and Fernandez [5] have shown rehydration process of silicates which leads to the formation of new gel C–S–H. In addition, a new formation of the portlandite is observed. These transformations are reflected in the properties of concrete as shown in previous work [11,12]. In general, the results of the literature [13] show that the compressive strength of the concrete (hot or after cooling) decreases with increasing temperature.

The drop in resistance is observed around 100 °C to 150 °C. This slight decrease in strength is related to the departure of the water which, during the rise in temperature, it expands and causes spacing between the sheets of the gel. This gap causes a reduction in cohesion forces. Until temperatures of 300–400 °C, a gain in resistance is noticed [3]. The departure of water can lead to an increase in the binding forces between the hydrates with an increase in surface energies [12,14].

Water, present in concrete in free, bonded or adsorbed form, gradually escapes and represents the main cause of mass loss of the concrete. The evolution of the loss of mass is grouped into three domains: from 20 to 150 °C, a small loss of the order of 3% was observed; between 150 and 300 °C a rapid loss; and then above 300 °C, a slowing down of mass loss. The main physicochemical transformation undergone by concrete heated between 150 and 300 °C is the dehydration of C–S–H [3].

According to another study [15], the results obtained by crushing tests carried out after cooling show a progressive degradation of the compressive strength of concrete as a function of temperature. At 200 °C, a 4% decrease in the compressive strength of the concrete was recorded.

The variation in the temperature of the concrete may influence the adsorption of the superplasticizer on the cement grains [16,17].

J. Pan [18] has shown the efficiency of the superplasticizer is related to the adsorption of the superplasticizer on the cement grains, so the temperature has a significant effect on this efficiency and thus influences the properties of the concretes with superplasticizers. According to other works [19,20], some superplasticizers are very sensitive to the evolution of temperature.

2. Materials and methods

2.1. Materials

An ordinary concrete with a water/cement ratio of W/C = 0.56 is used in this study. The cement used is a Portland cement composed of CEM II-A conforming to the European norm EN-197/1 produced locally and whose physical and mechanical characteristics are: an absolute density of 3100 kg/m^3, a bulk density of 1100 kg/m^3 and a specific fineness of 3200 cm^2/g.

A silico-calcareous sand crushed 0/5 and two gravels silico-calcareous of classes 8/15 and 15/25 were from the region Oum el Bouaghi, Algeria.

The chemical admixtures which have been used come from an Algerian company and are in conformity with standard NF EN 934-2 [1]. The setting retarder (SR) present in the form of a yellow liquid with a density of 1.175, a pH of 8.5.The hardening accelerator (HA) present in the form of a brown liquid with a density of 1.313, a pH of 6.0.The superplasticizer (SP) present in the form of a light brown liquid with a density of 1.06 ± 0.01, a pH of 6.0 ± 1. The mass water repellent (WR) present in the form of a white liquid with a density of 1.02, a pH of 6.5 to 9.5. Finally, the air entrainer (EA) present in the form of a dark brown liquid with a density of 1.03, a pH of 10.5 to 12. The dosage of chloride contained for all types of chemical admixtures used, is lower than 0.1% [(Cl^-) <0.1%].

2.2. Experimental study

To evaluate the effect of temperature on the residual strength and mass losses of admixtured concretes, tests were carried out on cubic specimens 10 × 10 × 10 cm. In addition to the composition of the control concrete (CC) with an W/C = 0.56 ratio, four dosages (0.5, 1.0, 1.5 and 2.0%) of each admixture were adopted for the composition of the studied concretes (Table 1). These concretes are called concretes with: setting retarders (SRC), hardening accelerators (HAC), superplasticizers (SPC), water repellents (WRC) and air entrainers (AEC).

The prepared specimens were kept in water for 28 days and then were taken out of water and dried at ambient temperature. The specimens were divided into three groups. The specimens of each group were subjected to a different temperature regime (20, 105 and 300 °C). An electric furnace was used to reach temperatures of 105 and 300 °C (Fig. 1). A rate of temperature rise of 2 °C/min was used, followed by a plateau of 3 h at each target temperature for homogenization of the temperature in the specimen.

Compression tests were carried out on the ambient air-cooled test specimens by a press of 2000 kN capacity with a velocity of 0.5 MPa/s (Fig. 2.). Three specimens were tested for each composition.

3. Results and discussions

3.1. Workability

The incorporation of admixtures into concrete resulted in modification of the workability, depending on dosage and chemical properties (Fig. 3). Increase of the slump was proportional to dosage, except for HAC admixtured concrete for which there was a slight decrease of the slump (Table 2). Maximum values occur at the maximum dosage.

All concretes showed greater slump than the control concretes except the concretes HAC and WRC (Fig. 3). This was valid for the four HA dosages (0.5, 1.0, 1.5 and 2%) and for three WR dosages (0.5, 1.0, and 1.5%).

Table 1
Composition of Concrete (kg/m^3).

Components	Sand (0/5)	Gravel (8/15)	Gravel (15/25)	Cement	Water
Dosage (kg/m^3)	650	723	434	350	196