Construction and Building Materials 121 (2016) 659–663

Contents lists available at ScienceDirect

Construction and Building Materials

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

Influences of bacteria-based self-healing agents on cementitious materials hydration kinetics and compressive strength

Mian Luo, Chunxiang Qian *

College of Materials Science and Engineering, Southeast University, Nanjing 211189, China
Research Institute of Green Construction Materials, Southeast University, Nanjing 211189, China

HIGHLIGHTS

- The hydration kinetics of bacteria-based cement paste was studied.
- The compressive strength of bacteria-based cement mortar was tested.
- The compatibility of bacteria-based cementitious materials was evaluated.

ARTICLE INFO

Article history:
Received 29 October 2015
Received in revised form 2 June 2016
Accepted 14 June 2016

Keywords:
Bacteria
Self-healing agent
Rheology
Hydration heat
Setting time
Compressive strength

ABSTRACT

Bacterially induced calcium carbonate precipitation has been proposed as an alternative and environmental technique to develop self-healing cementitious materials system in recent years. This study investigated the influences of bacteria-based self-healing agents on the rheology, hydration kinetics and compressive strength of cementitious materials to further verify the feasibility of bacteria-based self-healing agents for crack repairing. The results showed that the rheology of cement mortar was significantly improved by the addition of bacteria-based self-healing agents. Incorporation of bacteria-based self-healing agents in cement greatly influenced the hydration kinetics. The self-healing agent RB could delay the hydration of cement resulting in final setting time increase, however the self-healing agents JB and NB accelerated the hydration resulting in initial and final setting time decrease. In addition, compressive strength test results showed that incorporation of RB in cement mortar resulted in early age compressive strength decrease, but the 28 d compressive strength increased compared to control. Incorporation of JB in cement mortar enhanced compressive strength, however incorporation of NB in cement mortar could result in unwanted compressive strength loss. Furthermore, MIP test results indicated that the pore size distributions were different between cement paste samples with and without bacteria-based self-healing agents. The addition of bacteria-based self-healing agents increased the porosity between 100 and 1000 nm. The porosity between 100 and 1000 nm of the sample with NB increased the most compared to the samples with RB and JB. The incorporation of JB increased the porosity between 100 and 1000 nm, but at the same time the small pores with a diameter under 10 nm increased. These results could be used to explain the compressive strength development.

1. Introduction

Bacterially induced calcium carbonate precipitation has been proposed as an alternative and environmental technique to develop a self-healing cementitious materials system in recent years [1–7]. In this system, the bacteria-based self-healing agent which consists of the alkali resistance spore-forming bacteria and a specific substrate should be added into cementitious materials in the mixing process. The bacteria can form dormant spores in extreme environments of cementitious materials. When the concrete cracks, the dormant spores could be activated by the water and oxygen entering through the cracks. Then, the substrate in the crack migrating from cementitious materials matrix could be metabolized by the activated bacteria to produce calcium carbonate precipitation after a series of biochemical reactions and achieve the purpose of crack self-healing. A large number of studies on this topic have been carried out, mainly focusing on the effect of crack self-healing [8,9], permeability test [10,11], the mechanism of

* Corresponding author at: College of Materials Science and Engineering, Southeast University, Nanjing 211189, China.
E-mail addresses: cxqian@seu.edu.cn, cquluomian@163.com (C. Qian).

http://dx.doi.org/10.1016/j.conbuildmat.2016.06.075
0950-0618/

mineralization [12], optimization of nutrients [5,13], bacteria species and carrier selection [14–16]. The results showed that bacteria-based self-healing agents could improve the ability of cementitious materials crack self-repairing and reduce the possibility of erosion media through the cracks into the matrix resulting in improvement of the material durability. However, the prerequisite for achieving this goal is the need to introduce bacteria-based self-healing agents as a new component into cementitious materials. Cementitious materials is a kind of complex multi-component composite material and anyone new component introducing could have adversely affected its performance. So, it is very important to investigate the compatibility between bacteria-based self-healing agents and cementitious materials. Jonkers et al. [17] investigated the effect of bacteria and organics additions on paste strength. Incorporation of a high number of bacterial spores in the paste resulted in about 10% decrease in compressive strength compared to controls. Additions of different organic compounds (0.5% of cement weight) also affected splitting-tensile strength of the paste. The study results of Zeynep Basaran Bundur et al. [18] indicated that hydration kinetics and compressive strength behavior of mortar were highly influenced when *Sporosarcina pasteurii* cells were vegetatively inoculated.

In our previous studies, three types of bacteria-based self-healing agents were developed. The crack self-healing capacity of bacteria-based concrete in different conditions has been widely researched and the results showed that the bacteria-based self-healing agents could be used to achieve the goal of concrete crack self-healing [19]. This study investigated the influences of three types of bacteria-based self-healing agents on the rheology, hydration kinetics and compressive strength of cementitious materials to further verify the feasibility of bacteria-based self-healing agents for crack repairing. Moreover, the influence mechanism of bacteria-based self-healing agents on cementitious materials was discussed in detail.

2. Materials and methods

2.1. Bacteria-based self-healing agents preparation

Three types of bacteria-based self-healing agents (RB, JB and NB) were used in this study. RB agent was consisted of calcium lactate (R) and bacteria spores powder (B), JB agent was consisted of calcium formate (J) and bacteria spores powder (B) and NB agent was consisted of calcium nitrate (N) and bacteria spores powder (B). Spore-forming alkali-resistant bacteria were used for this study. The bacteria were cultured in liquid medium containing 5.0 g peptone and 3.0 g yeast extract per liter of distilled water (pH = 7.0), which was autoclaved at 121 °C for 25 min. After inoculation on laminar flow, the medium was incubated at 30 °C on a shaker at 170 rpm for 72 h. Bacterial cells were harvested by centrifuging the 48 h old grown culture and were re-suspended in distilled water. Then the bacteria cells suspension liquid was kept in 80 °C water baths for 20 min to get bacteria spores suspension liquid. The concentration of bacterial spores in the suspension was 10^8 cells/mL. The bacteria spore powder was obtained by drying of bacteria spores suspension liquid.

2.2. Preparation of cement mortar specimens

Cement mortar specimens with dimensions of 40 × 40 × 160 mm were prepared by mixing ordinary Portland cement, river sand, self-healing agent and tap water. The mixing proportion is shown in Table 1. The self-healing agent to cement ratio is 0%, 1%, 2% and 3%. The cement mortar fluidity was measured before casting according to the Chinese standard (GB/T 2419-2005). After 24 h curing specimens were unmolded and kept in standard curing room for further curing. In order to determine the influences of bacteria-based self-healing agents on compressive strength of cement mortar, sets of 3 replicate specimens were tested after1, 3, 7 and 28 days curing.

2.3. Setting time

The initial and final setting times were measured by the technique for determining the time of setting of hydraulic cement using a Vicat needle according to Chinese standard (GB/T 1346-2011).

Table 1
Mixing proportion of cement mortar.

Code	Cement (g)	Sand (g)	Water (g)	Self-healing agent types	Self-healing agent contents (wt%)
C	450	1350	225	/	0
RB1	450	1350	225	RB	1
RB2	450	1350	225	RB	2
RB3	450	1350	225	RB	3
JB1	450	1350	225	JB	1
JB2	450	1350	225	JB	2
JB3	450	1350	225	JB	3
NB1	450	1350	225	NB	1
NB2	450	1350	225	NB	2
NB3	450	1350	225	NB	3

The initial and final setting times of the cement paste with and without self-healing agents RB, JB and NB in various contents from 1% to 3% were tested, respectively. In order to reveal the influence mechanism of setting time, the effects of each component of self-healing agents on setting time were researched.

2.4. Hydration heat

A constant temperature gauge TAM Air (Swedish Leite La Ltd) was used to measure the rate of heat evolution and the total heat evolution during 72 h of cement hydration, the experimental temperature is kept at 20 °C. The cement paste mixing was performed by water to cement ratio of 0.5. The hydration heat evolutions of the cement paste with and without self-healing agents RB, JB, NB, R, J, N and B in contents of 2% were investigated, respectively.

2.5. Mercury intrusion porosimetry (MIP)

In order to explain the influences of bacteria-based self-healing agents on the properties of the cement mortar, the pore size distribution test of cement paste (water to cement ratio of 0.4) with different self-healing agents (RB, JB and NB) was performed using MIP. MIP tests were made with a Micrometrics AutoPore IV 9500 (American Michael Instruments Corp., USA), which has a pore measuring range between 0.0036 and 400 μm diameters. After curing for 28 days, the samples were broken and dried for 3 days in the oven.

3. Results and discussion

3.1. Rheology of cement mortar

The fluidity test results of cement mortar with bacteria-based self-healing agents RB, JB and NB in different dosages are presented in Fig. 1. It can be seen that cement mortar fluidity had been improved after the incorporation of bacteria-based self-healing agents. However, various improvement trends were found in

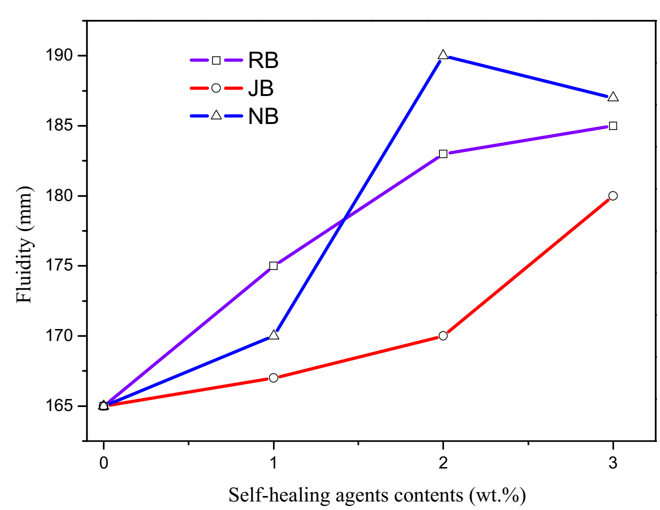

Fig. 1. Results of the fluidity test of cement mortar.