Construction and Building Materials 187 (2018) 348–359

Contents lists available at ScienceDirect

Construction and Building Materials

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

Impact of thermal transfer on hydration heat of a Soundless Chemical Demolition Agent

Debra F. Laefer [a,b,*], Atteyeh S. Natanzi [b], S.M. Iman Zolanvari [b]

[a] Center for Urban Science and Progress and the Department of Civil and Urban Engineering, Tandon School of Engineering, New York University, 370 Jay St., 12th Fl., Brooklyn, NY 11201, USA
[b] Urban Modelling Group, School of Civil Engineering, University College Dublin, Belfield, Dublin 4, Ireland

HIGHLIGHTS

- Ambient temperature effects on SCDAs were explored for 3 pipe diameters.
- Samples were tested in a water bath and/or a constant temperature chamber at 10 °C.
- The largest pipe showed peak hydration heat 50% greater than the water temperature.
- The smallest pipe showed peak hydration heat 22% greater than the water temperature.
- Traditional pipe tests fail to account for the influence of thermal transfer.

ARTICLE INFO

Article history:
Received 23 May 2017
Received in revised form 18 July 2018
Accepted 22 July 2018

Keywords:
Soundless Chemical Demolition Agent
Expansive cement
Ambient temperature
Borehole diameter
Non-expansive demolition agent
Thermal transfer
Bristar
Heat of hydration
Volumetric expansion
Expansive pressure

ABSTRACT

This paper explores thermal transfer effects in Soundless Chemical Demolition Agents (SCDA). In a 10 °C water bath, quadrupling the volume of SCDA in a pipe accelerated peak hydration onset and resulted in a 700% increase in expansive pressure and a 20% increase in volumetric expansion. An equivalent sample in a constant temperature chamber showed an almost 5 °C greater hydration heat than in the water bath, which resulted in a six-fold expansive pressure difference after 4 days of testing and an order of magnitude more pressure in the first 24 h, thereby demonstrating limitations of previous SCDA experimental work and providing a temperature-based reason for discrepancies between large-scale testing and manufacturers' predictions. Since most construction projects have scheduling requirements, understanding how to achieve sufficiently high pressures within a single work shift is important for evaluating the field viability of SCDAs on a particular project.

1. Introduction

Building standards and environmental policies demand a high level of control when undertaking structural demolition. Consequently, use of heavy demolition equipment and explosives has been restricted in urban areas due to their unwanted side effects of noise, debris, and vibrations. Soundless Chemical Demolition Agents (SCDAs) offer an alternative by means of chemically-based selective material removal. However, to date, there has not been a full understanding of the development of the hydration heat and its subsequent expansive pressure gains due to several competing factors including ambient temperature, thermal transfer mechanisms, and SCDA volume. As such, this paper explores SCDA hydration heat and expansive pressure development in various pipe diameters for a commercial product under a temperature common for fieldwork with a control mechanism for thermal transfer.

2. Background

SCDAs or Non-Explosive Materials (NEEMs) were first identified in the 1890s by Cadlot and Micheaelis [1] but not commercialized until 1979 in Japan [2]. In 1981, study of SCDAs started in China resulting in a highly efficient soundless cracking agent with

---

[*] Corresponding author.
E-mail addresses: debra.laefer@nyu.edu (D.F. Laefer), atteyeh.natanzi@ucdconnect.ie (A.S. Natanzi), iman.zolanvari@ucdconnect.ie (S.M.I. Zolanvari).

https://doi.org/10.1016/j.conbuildmat.2018.07.168
0950-0618/

expansive pressures of 60–90 MPa only 2 years later [3]. By 1985, a fast acting commercial SCDA was produced in Japan that developed expansive pressure in only 3 h and was sufficient for cracking small concrete samples ($600 * 600 * 600\ mm^3$) [2]. Today's market includes many commercial SCDA products that promise initial cracking within a few hours including Dexpan (http://www.dexpan.com/), Bristar (http://www.taiheiyo-m.co.jp/), Betonamit (http://www.betonamit.net/), Cevamit (http://cevamit.cz/), and S-Mite (http://www.soc.co.jp/). The environmental conditions under which such cracking can be expected, however, are not fully described by the manufacturers and are often difficult to replicate in lab conditions, as previously demonstrated by Laefer et al. [4] and Huynh et al. [5] where cracking times were significantly slower than advertised. In those tests, the large concrete blocks ($0.67\ m^3$ – $1.0\ m^3$) surrounding the embedded SCDA were likely to have served as heat sinks and to have interfered with the rate and possibly the maximum level of thermal development within the SCDA.

Generically, SCDAs can be described as powdery materials, similar in texture and appearance to Portland cement [6]. These are mixed with water to be introduced as a slurry into a series of predrilled holes. SCDAs mainly consist of calcium oxide (CaO). Other components may include ferrous oxide (Fe_2O_3), magnesium oxide (MgO), aluminium oxide (Al_2O_3), silicon (SiO_2), sulfur trioxide (SO_3) and calcium fluoride (CaF_2) and are designed to delay, accelerate, or just generally control the hydration rate of the slurry [7], as described in further detail below. The water initiates the hydration process. The reaction of the CaO generates heat and calcium hydroxide ($Ca(OH)_2$), as described by Goto et al. [8]:

$$CaO + H_2O \rightarrow Ca(OH)_2 + 15.2 \uparrow (kCal/mol) \tag{1}$$

If not properly controlled, this SCDA hydration heat may reach temperatures in excess of 150 °C, causing the mix water to boil and resulting in the SCDA mixture being expelled from the hole into which it was inserted [9]. Hydration of CaO and formation of $Ca(OH)_2$ are considered the main reactions in this process that generate notable expansive stresses. The formation of ettringite is a secondary contribution in expansive pressure development. Other cementing materials such as calcium silicate (in the form of belite or alite) and calcium aluminates (which is generated by calcium oxide and aluminium oxide – the main SCDA components) are present in the SCDA mixture. For example, calcium silicate (in the form of belite) was reported by Soeda and Harada [14], and the SCDA manufacturer's product literature used herein (Bristar 150) reports the presence of calcium silicate in the forms of both alite and belite (10–20% by weight) [15]. When the SCDA-generated stresses exceed the tensile strength of the surrounding materials, cracks will form and then propagate over time [10].

As will be discussed below, SCDAs can be highly influenced by temperature-related factors. Manufacturers recommend SCDA selection based on the lowest ambient temperature likely to be encountered, and specific SCDAs are designed for particular ambient temperature ranges as low as -8 °C and as high as 50 °C [11]. A higher ambient temperature will result in earlier and greater expansive pressures. This was demonstrated by Laefer et al. [4] in tests on $0.67\ m^3$ concrete blocks with small aggregate. That study also demonstrated that the time to first crack (TFC) was reduced by 13 h and the minimum demolition time (MDT) [time when the sample can be mechanically dismantled] was decreased by 4 h, when the ambient temperature was increased by 14 °C (from 24 °C to 38 °C). Unfortunately, direct pressure gains could not be measured in that experimental set up. Similar work by Huynh et al. [5] in $1\ m^3$ unreinforced concrete blocks showed that increasing ambient temperature by almost 3 °C decreased the TFC by almost 4 h and accelerated MDT by almost 5 h. Notably, in those two studies, the surrounding concrete blocks served as large thermal sinks, as opposed to most SCDA research, which has been conducted in steel pipes (to facilitate direct pressure measurement).

For example, in the work by Hinze and Brown [7] in 100 mm high, 43 mm diameter, thick walled, steel pipes there was a doubling of expansive pressure when the ambient temperature was increased from 20 °C to 30 °C. Similarly, in the work by Natanzi et al. [9] on the impact of cold and moderate ambient temperatures, SCDA expansive pressure in 170 mm high, 36 mm diameter steel pipes increased by 350% when the temperature was raised from 2 °C to 19 °C. Onoda [12] reported less dramatic gains in thin-walled, steel cylinders of indeterminate size with a 30% pressure rise in the first 24 h and only a 10% difference after 48 h when the ambient temperature was increased from 15 °C to 25 °C.

Ambient temperature also affects the rate and magnitude of expansion due to the impact on ettringite formation during hydration [13]. Additionally, higher ambient temperatures result in faster exothermic hydration reactions, thus increasing $Ca(OH)_2$ generation [14]. Experimental work by Soeda et al. [16] showed a direct relationship between greater hydration level formation and increased expansive pressure development. Experimental results by Natanzi et al. [9] also demonstrated faster exothermic reactions at higher ambient temperatures, which hastened peak hydration heat and, in turn, generated greater and earlier expansive pressure development.

While this linkage has been definitively established, the issue of borehole size and its effect, if any, on expansive pressure development has been less clear. Hinze and Brown [7] investigated borehole diameter variation with a Chinese SCDA in 100 mm high steel cylinders of 4 different diameters (25 mm, 38 mm, 43 mm and 50 mm) at an ambient temperature 33 °C and a water/SCDA ratio of 32%. After 8 h, the 25 mm diameter hole reached an expansive pressure of only 2 MPa, while the 38 mm and 43 mm diameter holes generated pressures of 3 MPa and 4.5 MPa, respectively. Furthermore, the 50 mm diameter specimen reached 7 MPa. However, the authors concluded that specimen diameter was not a significant factor based on the fact that all of the specimens had nearly identical expansive pressures after 24 h.

In laboratory tests by Dowding and Labuz [17], the product Bristar 100 was poured into 100 mm high, thick-walled, steel cylinders of different diameters (102 mm and 172 mm). After 48 h, the expansive pressures were highly similar to each other. These results seemed to contravene their field tests on dolomite blocks (unconfined compressive strength of 165 MPa), where wider boreholes (38.0 mm vs. 12.7 mm) developed faster expansive pressures, as would be expected due to the larger amount of material available for hydration. After 18 h in the field, the 38 mm borehole block cracked and reached approximately 40% of the size of the borehole after 90 h. In contrast, the 12.7 mm borehole did not crack until 42 h and only managed a crack width of 3% of the borehole, implying that larger boreholes exhibit both a more rapid development of expansive pressure and ultimately more pressure overall, although this was not measured directly.

Schram and Hinze [18] stated that for effective rock fracturing both hole diameter and configuration were critical. For large granite rocks and boulders, they recommended a minimum effective borehole diameter of 38 mm. They also stated that a borehole diameter range of 44–50 mm provided the maximum amount of rock fracturing per pound of SCDA. In research by Gambatese [6], Betonamit Type S was poured into small-scale ($152.4\ mm * 152.4\ mm * 76.2\ mm$) reinforced concrete blocks (20.7 MPa concrete mix design) with boreholes of different diameters (3.18 mm, 4.76 mm, and 6.35 mm) but of the same lengths. Those tests showed that small borehole diameters were still sufficient to generate enough expansive pressure for cracking relatively strong concrete, although direct pressure measurements were not made.