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Cold and moderate ambient temperatures effects on expansive pressure development in soundless chemical demolition agents

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HIGHLIGHTS

- Small-scale experiments with soundless chemical demolition agents (SCDAs) under cold and moderate temperatures.
- Hydration heat formation and expansive pressure development under varying ambient conditions.
- Faster and higher peak hydrations and expansive pressures under warmer ambient temperatures.
- Linear relationship between ambient temperature, time to peak hydration heat, and onset of significant pressure development.

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ABSTRACT

This paper explores cool and moderate temperature (2–19 °C) impacts on hydration heat and expansive pressure development in two commercial soundless chemical demolition agents (SCDAs). Experimental results showed (1) product-specific, linear relationships between the ambient temperature and time to peak hydration heat; (2) peak hydration heats to be consistently 1.5 times the ambient temperatures at 10–19 °C; outside of this range the factor was greater; (3) a linear relationship between peak hydration heat time and the onset of expansive pressure development; (4) a largely proportional relationship between ambient temperature and volumetric expansion of 1.1–1.4 times the original volume.

1. Introduction

Demolition in urban areas is challenging due to noise and vibration limits and prohibitions against explosive agents. Yet adoption of soundless chemical demolition agents (SCDAs), which avoid these and many other problems, remains highly limited. Arguably, the highly selective uptake of this nearly 50-year old technology is an outgrowth of the proprietary nature of the products and the absence of reliable usage guidelines for their application. Nowhere is this more crucial than with respect to cooler ambient temperatures. As such, this paper explores SCDA pressure development in cold and moderate ambient temperatures for two prominent brands.

2. Background

The first non-explosive splitting of stone dates to ancient Greece where wooden wedges were inserted into cracks in marble blocks and then soaked with water. The surrounding material cracked with the wood's expansion. Chemicals were first investigated for this purpose in the 1890s, as part of Cardlot and Meaelis's discovery of ettringite in cement [1].

SCDAs were first commercially marketed in the early 1970s. The typical SCDA is a grayish, powdery dry material that is naturally hygroscopic, non-combustible, and non-explosive [2]. SCDA usage involves pouring the SCDA in a slurry form into a predrilled hole. After fracturing occurs, the materials should be removable with a sledgehammer, pick, or mechanised removal equipment.

While there are numerous proprietary SCDAs on the market, they primarily contain calcium oxide (CaO) (often over 90%) and different amounts of ferrous oxide (Fe_2O_3), magnesium oxide

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(MgO), silicon (SiO_2), aluminium oxide (Al_2O_3) and calcium fluoride (CaF_2). While CaO is the main SCDA ingredient, other materials have been added to change, postpone, enhance, or control the hydration procedure [3]. For example, a higher CaO content leads to more reaction and, thus, heightened expansive pressures [4].

When water is added to an SCDA, the hydration reaction with the calcium oxide (CaO) generates heat and calcium hydroxide under the exothermic reaction described in Eq. (1) as proposed by Goto et al. [4]:

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

The SCDA's heat of hydration can reach 150 °C, boil the mixture's free water, and cause blow outs [5]; however, during field applications heat dissipation into the surrounding environment makes this unlikely.

Eventually, hydration of the calcium oxide and formation of both calcium hydroxide and ettringite crystals generate a notable volumetric expansion. When confined, this leads to gradual stress development. If the strength of the surrounding material is less than the stresses forming inside the pre-drilled hole, cracks will initiate and propagate [2].

Within a confined hole, compressive stress begins to develop along with tensile stress (Fig. 1). Thus, fracture first occurs at the weakest section along the inside surface of the hole [4], at a point where this surface intersects the hole's opening. This is the point where surrounding confinement is lowest. The phenomenon can be described by elastic theory, even though the tensile stress in the tangential direction of the hole is caused by expansive pressure. At the opening's edge, the stress is at its maximum and reduces in proportion to the square of the distance from the edge [6]. Therefore, the tensile stress generated by the SCDA expansion is responsible for the fracturing. The applied stresses fracture the surrounding mass without producing noise, vibration, or airborne debris.

Notable expansive pressure may be generated in a few hours or across a much longer duration depending upon the SCDA type, surrounding material, and ambient temperature [3]. At an ambient temperature of 20 °C, Soeda et al. [7] recorded expansive pressure generation for more than one year when testing two types of SCDAs (one for warm and one for cold temperatures). However, in most applications cracking is desired within hours, if possible, as material removal may delay other construction activities.

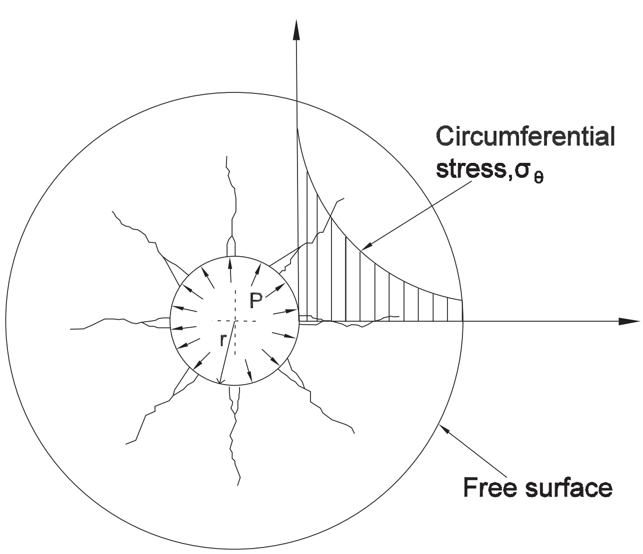

Fig. 1. Deformation mechanism of drillhole by demolition agent [23].

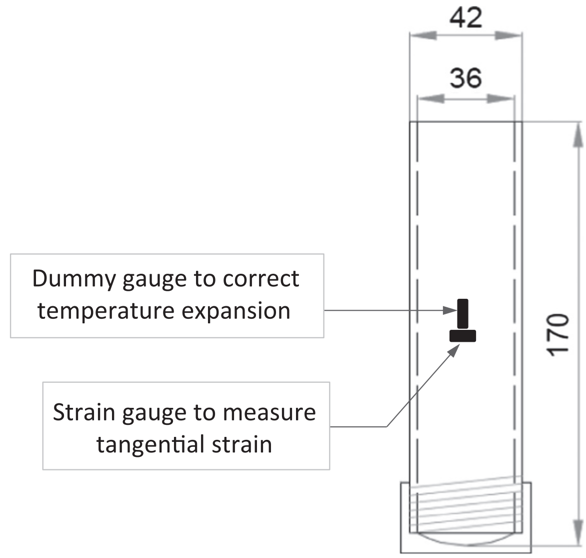

Fig. 2. Steel pipe dimensions and strain gauge orientations.

SCDAs are designed to be used over a wide range of ambient temperatures, with most manufacturers confining application to environments of 0–40 °C, although some claim applicability in temperatures as low as −8 °C or as high as 50 °C [8]. Notably, some manufacturers recommend a specific product within particular temperature ranges, with selection based on the lowest temperature likely to be encountered. As most applications are outdoors, temperatures can change significantly over 24 h [9].

Ambient temperature has been shown to significantly influence a variety of SCDA performance factors. For example, Huynh and Laefer [10] demonstrated that the Time to First Crack (TFC) and the Minimum Demolition Time (MDT) [moment at which there is sufficient cumulative cracking width for non-percussive, mechanical material removal] occurred sooner under warmer temperatures. Laefer et al. [11] showed specifically that for 0.67 m^3 concrete blocks with small aggregate that increasing the ambient temperature from 24 °C to 38 °C decreased the MDT by 4 h and the TFC by 13 h. When Hinze and Brown [3] increased ambient temperatures from 20 °C to 30 °C in samples in steel tubes, a doubling in the expansive pressure was documented. Similarly, Onada [12] demonstrated in thin-walled steel cylinders with Bristar that under a 10° temperature reduction (from 25 °C to 15 °C), a 30% decrease in expansive pressure at 24 h and a 10% decrease at 48 h were observed. Additionally, research by Laefer et al. [11] demonstrated that products designed for colder temperatures could be used in warmer environments to accelerate cracking and that heating the mix water was another approach to hastening the cracking process.

Soeda and Harada [13] provided a basis for this when they found that higher ambient temperatures contributed more to the exothermic reaction of the hydration reaction, thereby increasing $Ca(OH)_2$ generation. They also observed that a lower water/SCDA ratio resulted in less $Ca(OH)_2$. Subsequent experimental work by Soeda et al. [7] directly linked greater hydration level formation increases to expansive pressure development.

However, expansive pressure generation cannot be explained exclusively by CaO hydration. Performance can vary widely depending upon the product, confinement geometry, and percentage and temperature of the mix water [11], with ambient temperature arguably the controlling factor. Thus, SCDA users have to date been unable to estimate demolition time based on manufacturers' information and the published literature. This paper aims to begin to overcome this knowledge gap.