ELSEVIER

Cement & Concrete Composites 25 (2003) 1161–1164

Cement & Concrete Composites

www.elsevier.com/locate/cemconcomp

Thaumasite in Orange County, Southern California: an inquiry into the effect of low temperature

Sidney Diamond *

School of Civil Engineering, Purdue University, 1284 Civil Engineering Building, West Lafayette, IN 47907, USA

Abstract

Thaumasite has been found in ~10 year old permeable concrete exposed to sulfate-bearing ground waters in Orange County, California, an area generally associated with a warm climate. The occurrences have usually been found in carbonated zones at or near the lower surface of concrete slabs in contact with the ground. Daily records of soil temperature over the 1990–2000 decade indicate that during the early part of this decade (1990–1993) daily minimum soil temperatures dipped below 15 °C for appreciable portions of the winter months. Since 1993 a warming trend has been observed, and daily minimum soil temperatures fell below 15 °C for only a very few days. It is not clear whether the thaumasite deposits observed in the subject concretes were formed entirely during the colder pre-1994 winters, or whether the thaumasite development continued even under the warmer temperatures experienced since then.

Keywords: Thaumasite; Sulfate attack; Temperature effects; California

1. Introduction

The occurrence of thaumasite in concrete undergoing sulfate attack in residential concrete structures in Southern California has been reported by Brown and Doerr [1], and more recently, by Sahu et al. [2]. In typical cases the concrete slabs (or shallow foundations) are exposed to ground water containing sulfates, carbonates, and in some cases substantial concentrations of magnesium. Details of the field exposures have been provided in the two papers cited, and the microstructural alterations taking place within the affected concretes have been discussed by these authors, and have been illustrated in detail by Diamond and Lee [3].

The field occurrences of thaumasite reported by Brown and Doerr [1], and Sahu et al. [2], as well as other occurrences examined by the present writer, all occur within Orange County, California, an area noted for its mild climate. Thaumasite is generally considered to require low temperatures to form at appreciable rates, although different authors vary in their assessments of this point. The report of the Thaumasite Expert Group [4] stated that "Fairly low temperatures, generally less than 15 °C, are needed for vigorous formation of thaumasite in concrete exposed to sulfate attack". Bensted [5] indicated that "Thaumasite is formed very slowly below ca. 15 °C... Once the temperature rises above 15 °C, thaumasite stops forming, but starts up again once the temperature falls below this level". Crammond and Halliwell [6] indicated that "deterioration (associated with thaumasite formation) has been observed in test specimens exposed to a range of different sulfate solutions, and is more rapid in the samples stored at cold temperatures below 15 °C".

Accordingly, the formation of thaumasite in field concrete in the generally warm climate of Orange County, California, was initially considered surprising. The question naturally arises as to whether the prevailing concept that low temperatures were needed for appreciable thaumasite development was violated in these cases.

To provide some evidence for the temperatures that might be associated with these occurrences, the writer sought, and eventually succeeded in obtaining long-term temperature records for Santa Ana, California (the county seat of Orange County); the significance of these records are discussed in this paper.

* Tel.: +1-7654945016; fax: +1-7654961364.
E-mail address: diamond@ecn.purdue.edu (S. Diamond).

0958-9465/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/S0958-9465(03)00138-0

2. The location and geography of Orange County, California

Orange County is located immediately south and east of Los Angeles County, California, and, as mentioned previously it is known to possess a benign climate in which freezing temperatures are almost never encountered. As its name indicates, prior to its recent urbanization it was the California center for the production of oranges, a crop very sensitive to low temperatures.

Fig. 1 provides an outline map of California and indicates the general location of the Orange County; it is bordered on the north by Los Angeles County, and on the south by San Diego County.

The soils of most areas of Orange County are typically derived from Tertiary marine deposits; and ground waters typically contain significant concentrations of sulfate, and also contain substantial contents of chloride and carbonate. The anions present are commonly calcium, sodium, and to some extent, magnesium. The area is arid, with typical annual rainfall only about 280 mm (11 in.). In residential areas, much of the water actually present in the soil is derived from irrigation by homeowners, lush tropical plantings being the norm. The municipal water used for this irrigation is also fairly rich in sulfate.

3. Development of thaumasite in field concrete in Orange County

Orange County has undergone massive urbanization over the last 10–12 years, and continues to be one of the most rapidly growing areas in the United States. Most of the new population is housed in tracts of single-family or sometimes multifamily homes, employing concrete slab on grade construction with shallow concrete footings. Typically the garage slabs and the shallow foundations are directly exposed to the ground water, without intervening barriers.

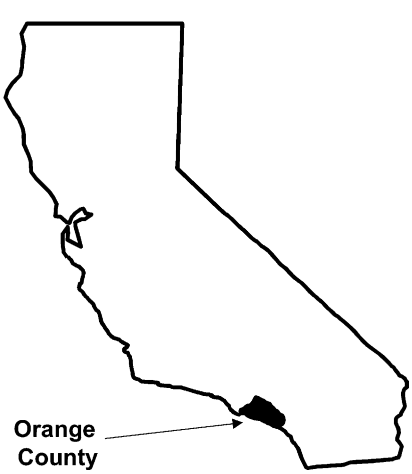

Fig. 1. Location of Orange County, California.

The concretes used for the slabs and foundations are typically placed at high water:cement ratios and are accordingly highly permeable. Deposits of sodium sulfates and other salts that have penetrated through the garage slabs and appeared on their upper surfaces are common. As detailed in Refs. [1,2], symptoms of sulfate attack rarely extend uniformly through the concrete. Rather, they are commonly found to be concentrated in the lower part of the section and to a lesser degree in the upper part of the section near the evaporative surface; the central portion of the cross section is commonly less affected. As described by Sahu et al. [2] a zone of carbonation is found below the upper surfaces of slabs and also not uncommonly above the lower surfaces of the slabs. The latter is presumably induced by bicarbonate dissolved in the ground water. Thaumasite is found only in this lower zone, and is usually found in local association with gypsum and ettringite.

An illustration of one such thaumasite deposit, taken from Diamond and Lee [3] is shown as Fig. 2. The identification as thaumasite rests on the EDS spectrum and the morphology, both of which are virtually identical to those of thaumasite formed in laboratory sulfate attack specimens as reported by Jallad et al. [7]. The identity of the thaumasites studied by these authors was confirmed by near-infrared Raman spectroscopy. The peaks of thaumasite in the Raman spectra obtained were identical to those reported for mineral thaumasite and to thaumasite from various field sources as recently reported by Brough and Atkinson [8].

4. Temperature records

The University of California, Davis, maintains a series of permanent weather stations at several sites in California. At a few of them, not only are air temperatures measured, but a daily record is maintained of maximum and minimum soil temperatures. These soil temperatures are measured at a fixed position 15 cm below the ground surface. One of these sites is in Santa Ana, California, the county seat of Orange County; the soil there is indicated as being a sandy loam. The writer believes that the temperatures recorded at this location are at least reasonably close to the temperatures experienced by concrete slabs on grades and by shallow footings buried at modest depths.

These soil temperature records are available on a web site maintained by the university [9]. The writer has succeeded in downloading the daily records for the entire decade of 1990–2000, roughly the period during which the subject concretes were exposed.

Fig. 3 is a plot showing daily maximum and minimum soil temperatures for the year 1995, a typical year

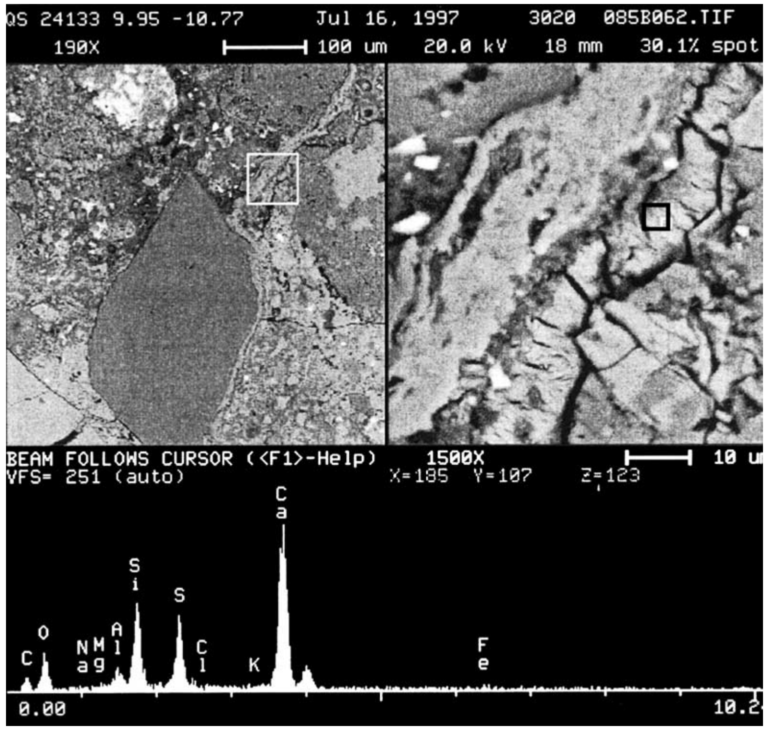

Fig. 2. Backscatter SEM images and EDS spectrum for an occurrence of thaumasite in Orange County, California. The layer of thaumasite extends along the full length of the right hand side of the sand grain in the upper left image shown above.

for the latter part of the decade. The minimum temperatures are shown using a bolder line for emphasis. There are some interruptions in the daily record, but the pattern is obvious. Except for a few days in January 1995, the daily minimum soil temperature at the site was never below 15 °C, and from April through October of 1995 was always above 20 °C.

It is of interest to note that the *maximum* soil temperature for a given day is only a few degrees warmer than the *minimum* soil temperature for the same day. This holds true throughout the data set.

If the 1995 record were typical for the decade, a strong argument could have been made that thaumasite formation in field concrete is not limited to low temperatures. However, the records show that this is not quite the case.

Fig. 4 is a plot of the daily minimum temperatures for the 1990–2000 decade. It appears that the daily minimum temperatures shown in Fig. 3 for 1995 are more or less typical of each year since 1994; since 1994 soil temperatures dipped below 15 °C only for a very brief period during the winter of 1997–1998.

However, a very different soil temperature pattern emerges from the records for 1990–1993, and especially for 1990 and 1991. Minimum temperatures during January and February of these years were much colder, and descended to about 6 °C at the lowest point in 1990; and 8 °C in 1991. Subsequently, as seen in Fig. 4, the winter

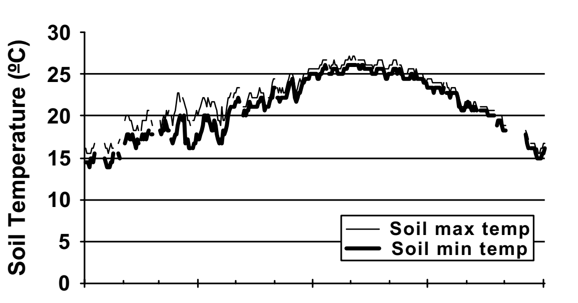

Fig. 3. Plot of daily maximum and minimum soil temperatures, Santa Ana, California, for 1995.

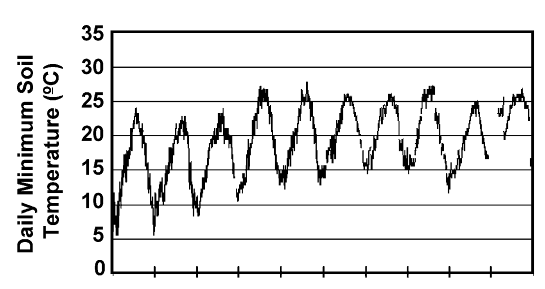

Fig. 4. Plot of daily minimum soil temperatures, Santa Ana, California, for the decade 1990–2000.

minimum soil temperatures grew progressively more mild, and after 1993 remained well above 15 °C for most of the winter months.

5. Interpretation

Several factors need to be mentioned before attempting to interpret thaumasite formation in the light of these temperature records.

First, the location of the weather station from which the temperature records were obtained, Santa Ana, is about 10–15 miles from the actual locations where thaumasite was found. Santa Ana is an old established urban location on flat terrain; in contrast most of the field sites were on somewhat elevated, hilly terrain. Accordingly they may have experienced winter minimum temperatures several degrees lower than those recorded at the Santa Ana weather installation.

Second, there are several findings reported in recent literature that indicate that under the right conditions, thaumasite might form extensively at temperatures higher than that usually considered optimal. For example, Hooton and Brown [10] indicated that thaumasite was found (in association with ettringite and gypsum) in carbonated areas of 21-year old concrete cylinders undergoing sulfate attack. These concrete specimens were said to have been maintained at "room temperature" throughout their lifetimes. Sibbick and Crammond [11] recently described an occurrence of rapid thaumasite formation within a Portland cement mortar undercoat beneath a gypsum plaster layer in the wall of a repaired residence; the thaumasite had developed within a period of 18 months. The mean internal temperature of the residence "was felt to be 16–22 °C", although it was not clear whether there might have been periods when residents were on holiday, during which periods the heating of the residence might have been interrupted or reduced. Interestingly, the residual mortar itself was heavily contaminated with gypsum, and was heavily carbonated.

It appears to the writer that thaumasite may be expected to develop at least occasionally in carbonated zones in field concrete undergoing sulfate attack, even in what are generally considered to be warm climates. Partly this may be due to occasional short-term incidences of exposure to low temperatures, as illustrated in the present data. However, it may also be that some thaumasite may be produced in field exposures even at 'normal' temperatures.

Finally, it would appear that once formed, thaumasite in field concrete seems to be stable and to remain in the concrete regardless of subsequent temperature changes.

Acknowledgement

I thank Norah Crammond and Paul Brown for helpful discussions.

References

[1] Brown PW, Doerr A. Chemical changes in concrete due to the ingress of chemical species. Cem Conc Res 2000;30(3):411–8.
[2] Sahu S, Badger S, Thaulow, N. Evidence of thaumasite formation in southern California concrete. Cem Concr Comp, in press.
[3] Diamond S, Lee RJ. Microstructural alteration associated with sulfate attack in permeable concretes. In: Marchand J, Skalny JP, editors. Materials science of concrete—sulfate attack mechanisms. Westerville, OH: American Ceramic Society; 1999. p. 123–74.
[4] The Thaumasite Expert Group. The thaumasite form of sulfate attack: risks, diagnosis, remedial works, and guidance on new construction. Construction Directorate Department of the Environment, Transport, and the Regions, London, 1999.
[5] Bensted J. Mechanism of thaumasite sulfate attack in cements, mortars, and concretes. ZKG Int 2000;53(12):704–9.
[6] Crammond N, Halliwell, MA. The thaumasite form of sulfate attack in concretes containing a source of carbonate ions—a microstructural overview. In: Malhotra VM, editor. Proceedings of the CANMET/ACI International Symposium on Advances in Concrete Technology, Las Vegas, 1995. p. 357–80.
[7] Jallad KN, Santhanum M, Cohen MD, Ben-Amotz D. Chemical mapping of thaumasite formed in sulfate attacked cement mortar using near infrared Raman imaging microscopy. Cem Concr 2001;31(6):953–8.
[8] Brough AR, Atkinson A. Micro-Raman spectroscopy of thaumasite. Cem Concr Res 2001;31(3):421–4.
[9] www.ipm.usdavis.edu/WEATHER/wxretrive.html, accessed August 25, 2001.
[10] Hooton RD, Brown P. Microscopic examination of sulfate-resistant concrete exposed to sulfate solutions for 21 years. In: Proceedings of 8th Euroseminar on Microscopy Applied to Building Materials, Athens, September 2001. p. 147–57.
[11] Sibbick RG, Crammond N. Microscopical investigation into recent field examples of the thaumasite form of sulfate attack (TSA). In: Proceedings of 8th Euroseminar on Microscopy Applied to Building Materials, Athens, September 2001. p. 261–9.