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Evidence of thaumasite formation in Southern California concrete

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Abstract

Ettringite is one of the main reaction products formed during external sulfate attack on concrete. During this process, the microstructure of the original cement paste is altered. The formation of excessive amounts of ettringite may, under some conditions, have deleterious effects leading to expansion and cracking of concrete. Depending on the severity of attack, local environmental conditions, and availability of sulfate, gypsum may be formed in the paste and at the paste aggregate interfaces. Sometimes the presence of a third mineral, thaumasite ($CaSiO_3 \cdot CaCO_3 \cdot CaSO_4 \cdot 15H_2O$) is overlooked due to its morphological similarity to that of ettringite.

Examination of concrete obtained from various structural locations of residential homes of Southern California by scanning electron microscopy (SEM) and optical microscopy revealed the presence of thaumasite in association with ettringite and/or gypsum. Morphologically, both thaumasite and ettringite have very similar structure. Analysis of the chemical composition using energy dispersive X-ray spectroscopy (EDS) shows the presence of calcium, silicon, sulfur and oxygen in thaumasite and calcium, aluminum, sulfur and oxygen in ettringite as the major components. Thaumasite deposits are usually associated with gypsum deposits in highly carbonated pastes. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Thaumasite; Concrete; Southern California

1. Introduction

The ingress of sulfates into a concrete structure by ground water containing soluble sulfates or soils laden with sulfates lead to several expansive reactions and alteration of the microstructure [1]. Ettringite is a common mineral formed during this process and may lead to expansion and cracking of concrete. Besides ettringite, gypsum is also formed in the system, depending upon the sulfate concentration. Formation of gypsum softens the cement paste and therefore leads to deterioration of the paste microstructure. Thaumasite forms in the system when limestone is present in the concrete and is subjected to sulfate attack at low temperatures (~5 °C) in an environment with high moisture [2,3]. The formation of thaumasite leads to the complete destruction of the cement paste and loss of cohesiveness [4]. The occurrences of thaumasite in field concrete in colder environment have been reported in UK, Italy, Germany, and Canada [4–8]. However, recent papers show that thaumasite can form in the warmer climatic conditions of USA [9,10]. In our recent investigation of cores taken from residential homes from Southern California, thaumasite deposits are present in association with gypsum and ettringite.

Identification of thaumasite is difficult due to its similarity in morphology and crystallographic structure to ettringite. However, careful analysis by optical microscopy can separate ettringite from thaumasite by differentiating their optical properties. Optical microscopy combined with SEM coupled with energy dispersive X-ray spectroscopy (EDS) is useful while identifying this mineral in concrete. When abundant concentrations of thaumasite are present in a system, X-ray powder diffraction (XRD) can be applied in identifying this mineral in cement paste or concrete.

In the present investigation, SEM coupled with EDS and polarized light microscopy (PLM) has been used for identifying deposits of thaumasite.

2. Experimental

2.1. Sample preparation

Concrete cores from residential homes in Southern California were cut into three sections and designated as

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top, middle and bottom. The concrete sections were cut into 40 × 40 mm blocks in order to scan large areas of the concrete. Fluorescent epoxy impregnated thin sections were made according to the procedure described in the publication [11]. The thin sections were coated with a thin layer of carbon for analysis under SEM after PLM investigation.

2.2. PLM

Optical microscopic analysis of the samples was performed on a Nikon Optiphot-2 PLM equipped for fluorescent light microscopy. The microscope is attached with a computer-controlled stage and relocation software for identification of features between the optical and electron microscopes. In order to get good quality images and to determine the optical properties of various phases of the concrete the samples were first analyzed without any conductive coating. Once the features and their coordinates were recorded by PLM, the thin sections were coated by a thin layer of carbon and subjected to SEM analysis.

2.3. SEM–EDS

Microstructures of the specimens were studied by using an Aspex personal scanning electron microscope (PSEM) with EDS capability. Backscattered electron (BSE) images were acquired for each specimen at 20 keV. Usually the images were acquired in two different modes, either as a full screen image or a composite image comprising of (a) an area imaged at lower magnification, (b) an enlarged image displayed to the right of the first image, a sub area of interest, outlined by a square, (c) an EDS spectrum taken at a point in the higher magnification image with the location marked on the right image with a small square.

During SEM analyses the features identified as thaumasite were relocated according to the procedure described earlier [12]. After relocation, the features are

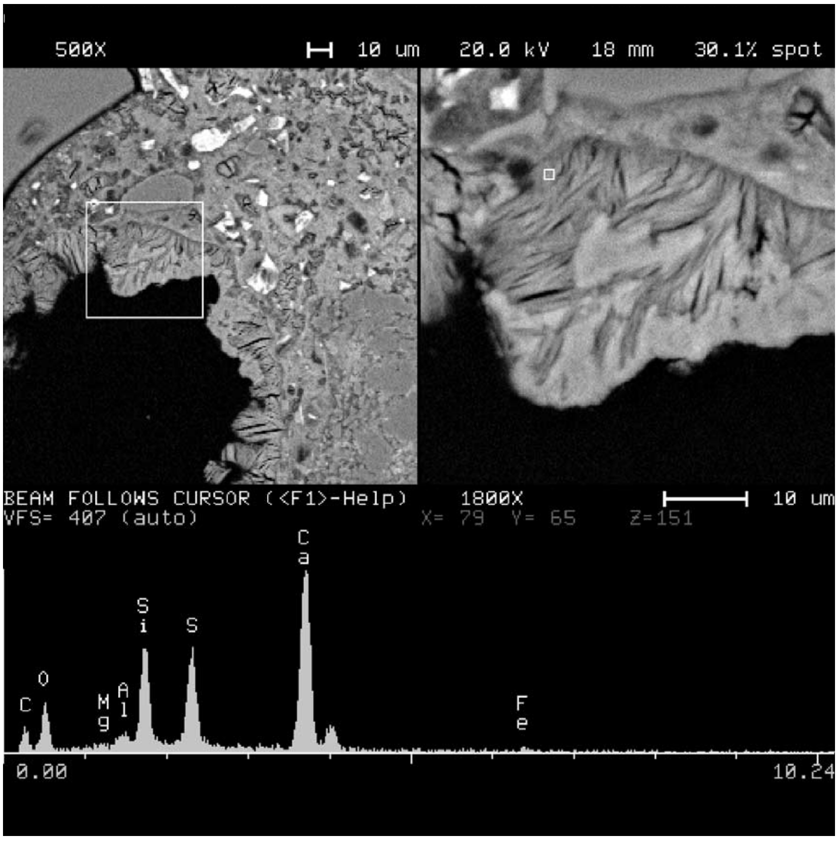

Fig. 1. BSE image showing thaumasite deposits in association with gypsum.

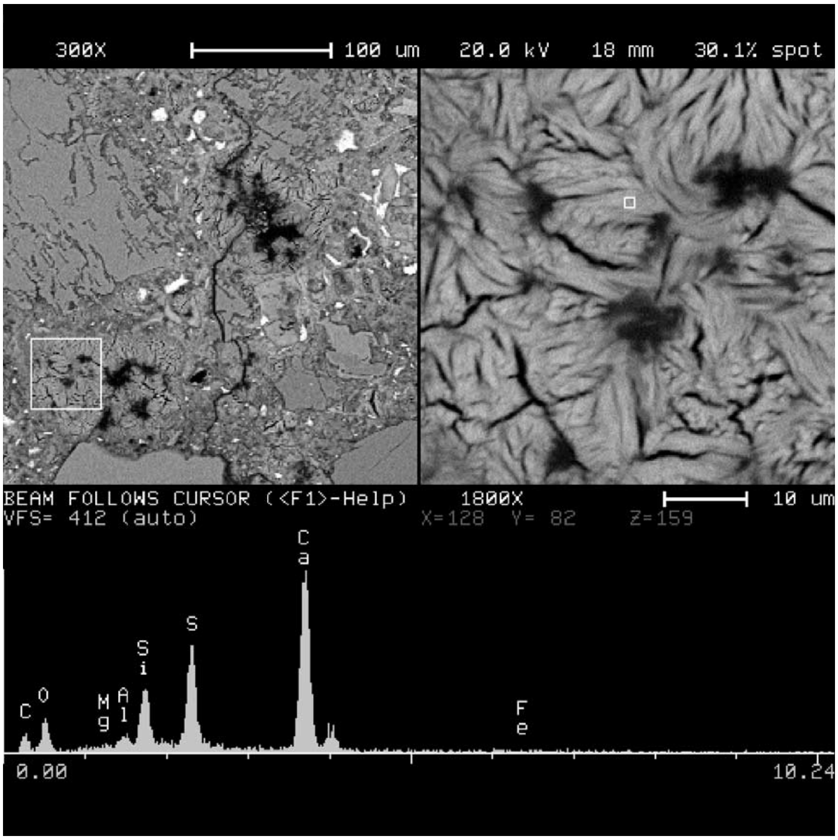

Fig. 2. BSE image of thaumasite deposits in an entrapped air void.

viewed at higher magnification and the elemental analysis was carried out by using EDS.

3. Results and discussion

Sulfate attack was diagnosed in most of the cores analyzed. Thaumasite was identified only in few cores obtained from garage slabs. This concrete did not contain ground carbonaceous (limestone, dolomite) material as filler or as aggregates. Severe carbonation was observed at the bottom as well as at the top of the concrete. The depth of carbonation was measured to a 20–30 mm thickness. Though carbonation was observed at the top and bottom of the concrete, thaumasite deposits were observed only in the bottom portion of the cores. A backscattered electron (BSE) image of thaumasite deposits in an entrapped air void is shown in Fig. 1. Thaumasite is associated with gypsum as a lining. The deposits are just above the bottom carbonation zone of the core. Fig. 2 shows a BSE image of thaumasite deposits in another entrapped air void in the same core. The entire deposit in the air void is thaumasite. The other deposits in the air voids in the left image are also thaumasite. A band of thaumasite deposited in a crack next to an aggregate is shown in Fig. 3. The thaumasite band is similar to that of ettringite bands as commonly found in deteriorated concrete. Gypsum deposits were also found parallel to the thaumasite deposits.

Fig. 4 shows a polarized light optical micrograph of ettringite deposits in association with thaumasite in an entrapped air void. Thaumasite differentiated from ettringite by its high birefringence and feather-like morphology. Figs. 5 and 6 are BSE images of the same location as shown in the optical micrograph in Fig. 4. Fig. 5 shows the composition of ettringite in the air void. Though the composition is quite consistent with ettringite, there is a significant amount of silica in the structure. Silica in ettringite has been described in the literature [13,14]. The other portion of the deposit is consistent with thaumasite. The morphology of ettringite is clearly different from that of thaumasite in the same air void. Ettringite has a needle-like structure, whereas thaumasite has a feather-like morphology and finer in structure. The occurrence of thaumasite and ettringite together and silicon-rich composition of ettringite suggests that ettringite is transforming into thaumasite or

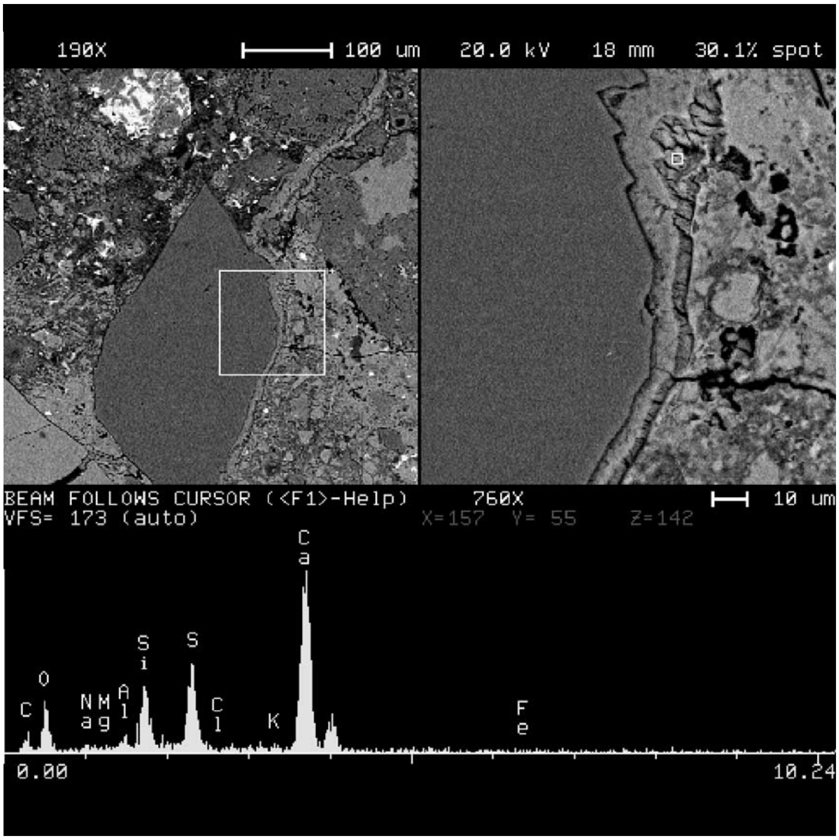

Fig. 3. BSE image of a band of thaumasite deposit.

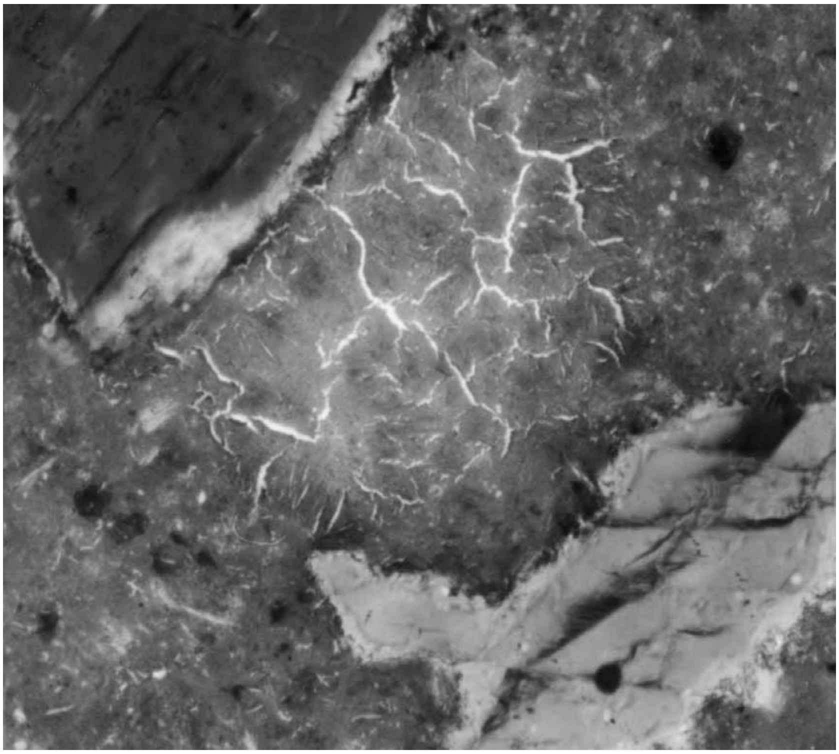

Fig. 4. Optical micrograph showing deposits of thaumasite in association with ettringite (crossed polarized light, 200X).

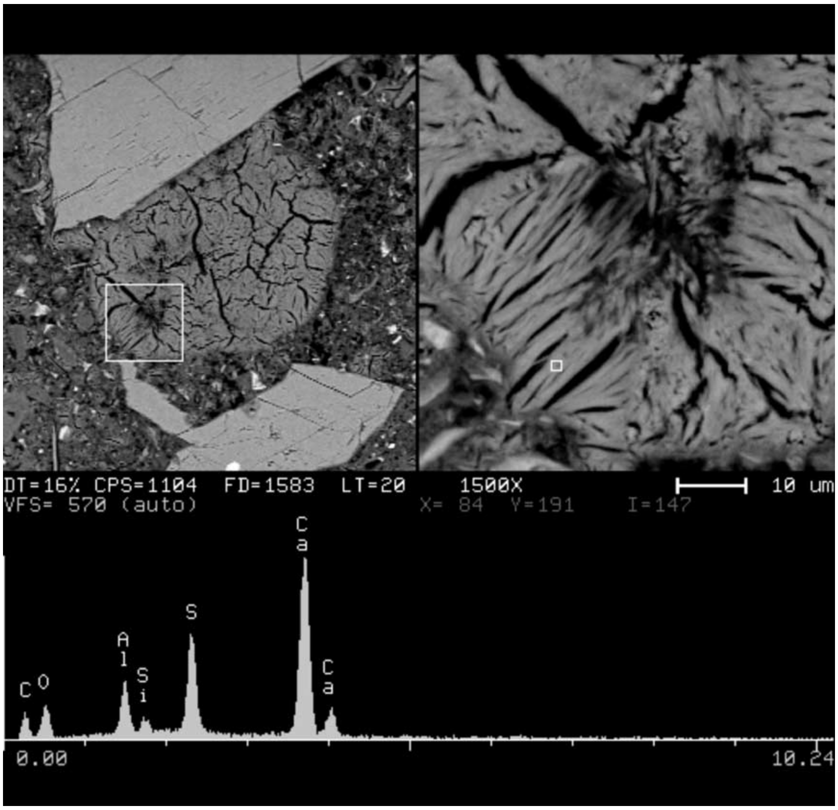

Fig. 5. BSE image showing deposits of ettringite in association with thaumasite in an entrapped air void (same area as Fig. 4).

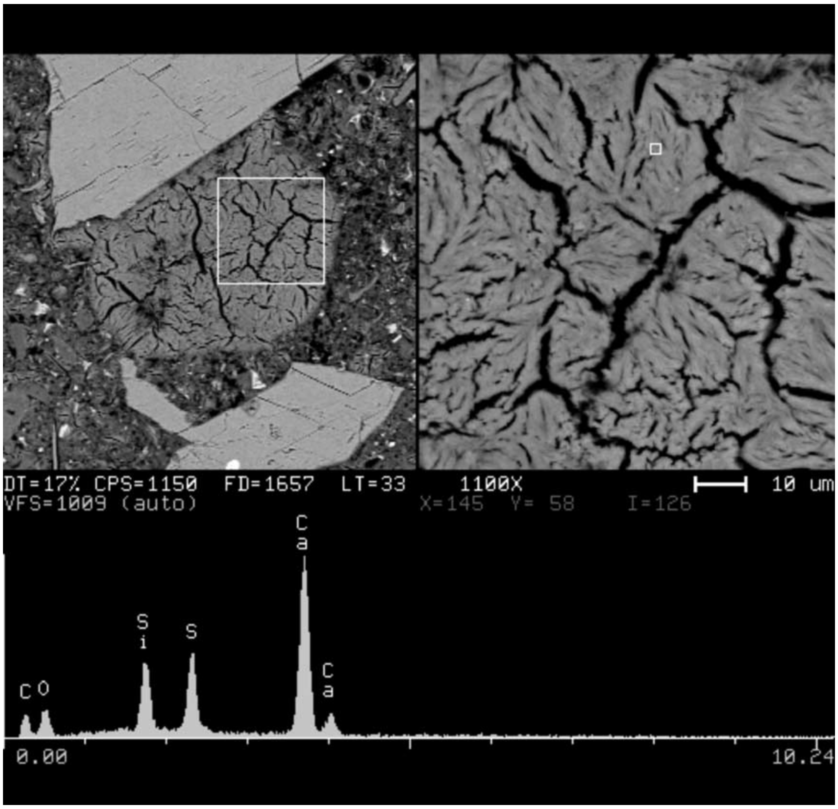

Fig. 6. BSE image showing deposits of thaumasite in association with ettringite in an entrapped air void.

that a limited solid solution series exists between the two minerals. This observation is consistent with the earlier hypothesis that ettringite is destroyed or ettringite is the nucleating site for thaumasite formation [15].

4. Conclusions

Analyses show deposits of thaumasite in addition to ettringite and gypsum in the concrete. The observed symptoms are consistent with concrete suffering from external sulfate attack. There were no internal sources of carbonates in the investigated concrete. Thaumasite formation potential is high when there are adequate carbonates available in addition to sulfates in the ground water. Thaumasite formation is another indicator of concrete distress. The formation of thaumasite consumes the C–S–H binder. The general notion that thaumasite formation from sulfate attack occurs only in cold environments is not true, although thaumasite may form in higher amounts in lower temperatures.

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