History of DEF Testing and Specifications

Presented by:

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Ettrengite: The Somtimes Host of Distruction AND short for Calcium Sulfoaluminate

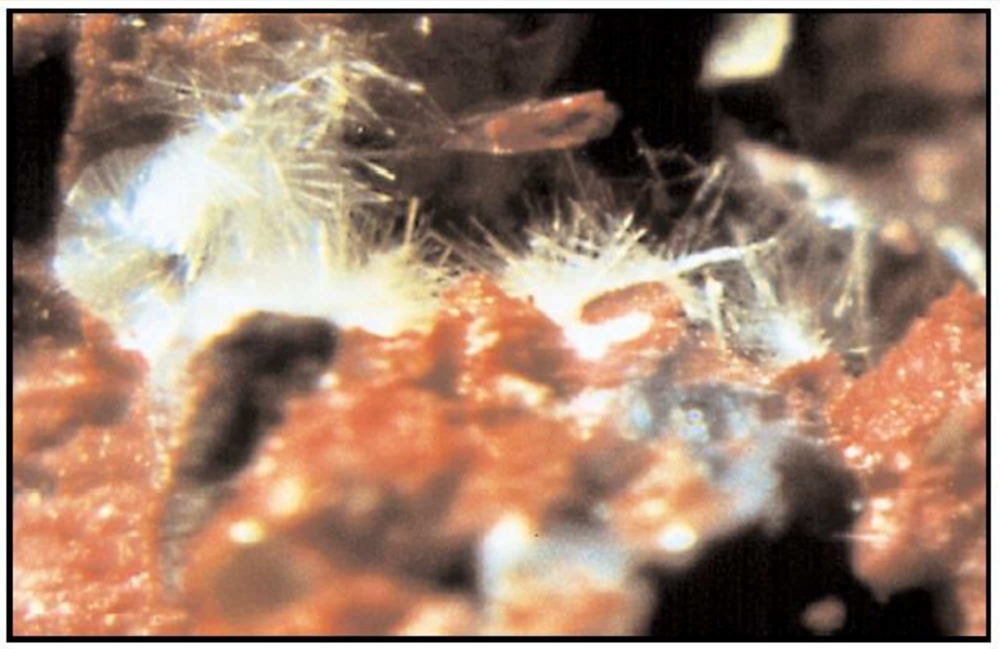
<u>Good Ettringite</u>

Introduced into Portland Cement through gypsum to regulate early age hydration reactions and prevent flash setting

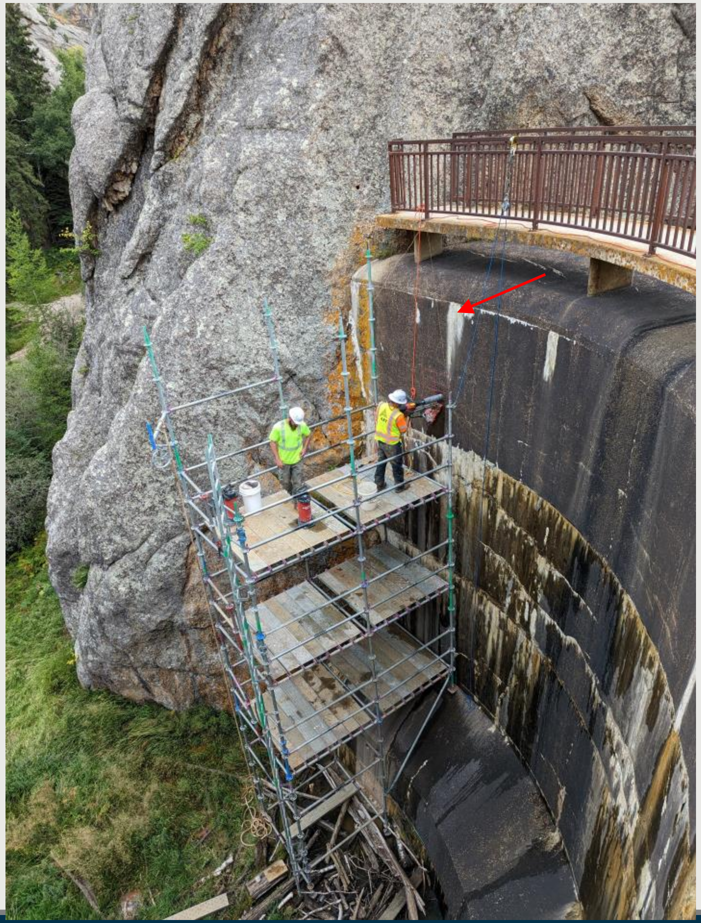
Reacts with Calcium Aluminate in cement

Stable

Ettrengite: The Somtimes Host of Distruction AND Short for Calcium Sulfoaluminate



Day, PCA 1992, Ettringite Formation and the Performance of Concrete



Delayed Ettringite Formation

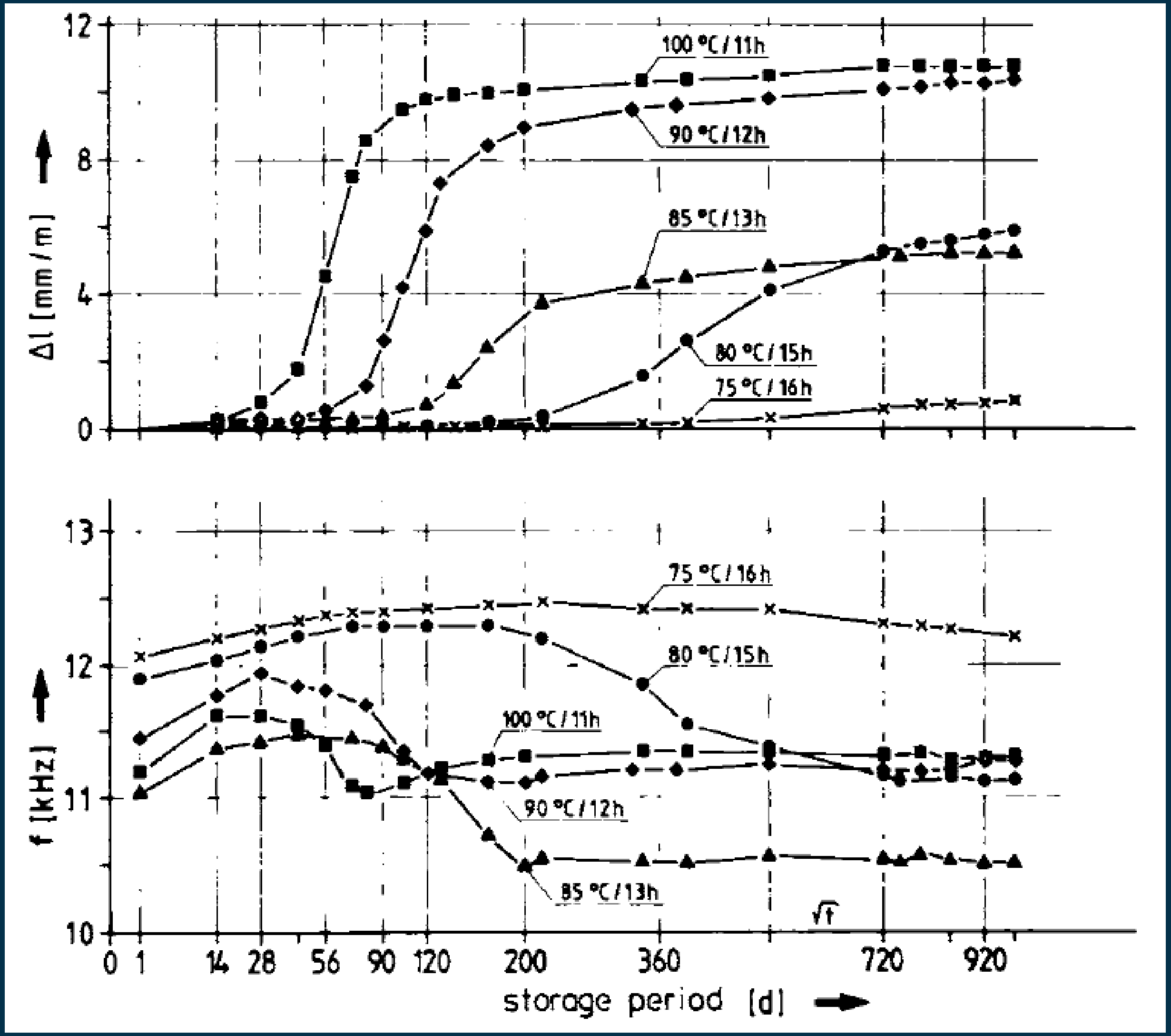
Challenging Ettringite

Exact Mechanism not fully agreed upon

Molar ratio of sulphate to aluminate

Initial curing temperature

Likes to form in ITZ



Day, PCA 1992, Ettringite Formation and the Performance of Concrete

ACI 301: Specifications for Concrete Construction-20

Section 8: Mass Concrete

Maximum temperature in concrete after

placement shall not exceed 160°F.

Where did this 160°F (formerly 158°F because 70°C = 158°F) come from?

[25] D. Heinz, U. Ludwig, Mechanism of secondary ettringite formation in mortars and concretes subjected to heat treatment, J.M. Scanlon (Ed.), Concr. Durability, Katharine and Bryant Mather Int. Conf., SP 100, American Concrete Institute, Detroit, 1987, vol. 2, pp. 2059–2071.

SP 100-105

Mechanism of Secondary Ettringite Formation in Mortars and Concretes Subjected to Heat Treatment

by D. Heinz and U. Ludwig

Heinz & Ludwig

Precast, heat-treated members exposed to moisture

Prisms, storage for 2 h at 70 °C followed by 12 h at 60°C (140°F) to 100°C (212°F)

Investigated Sulfate to Aluminate Humidity at elevated temps. 60-100%

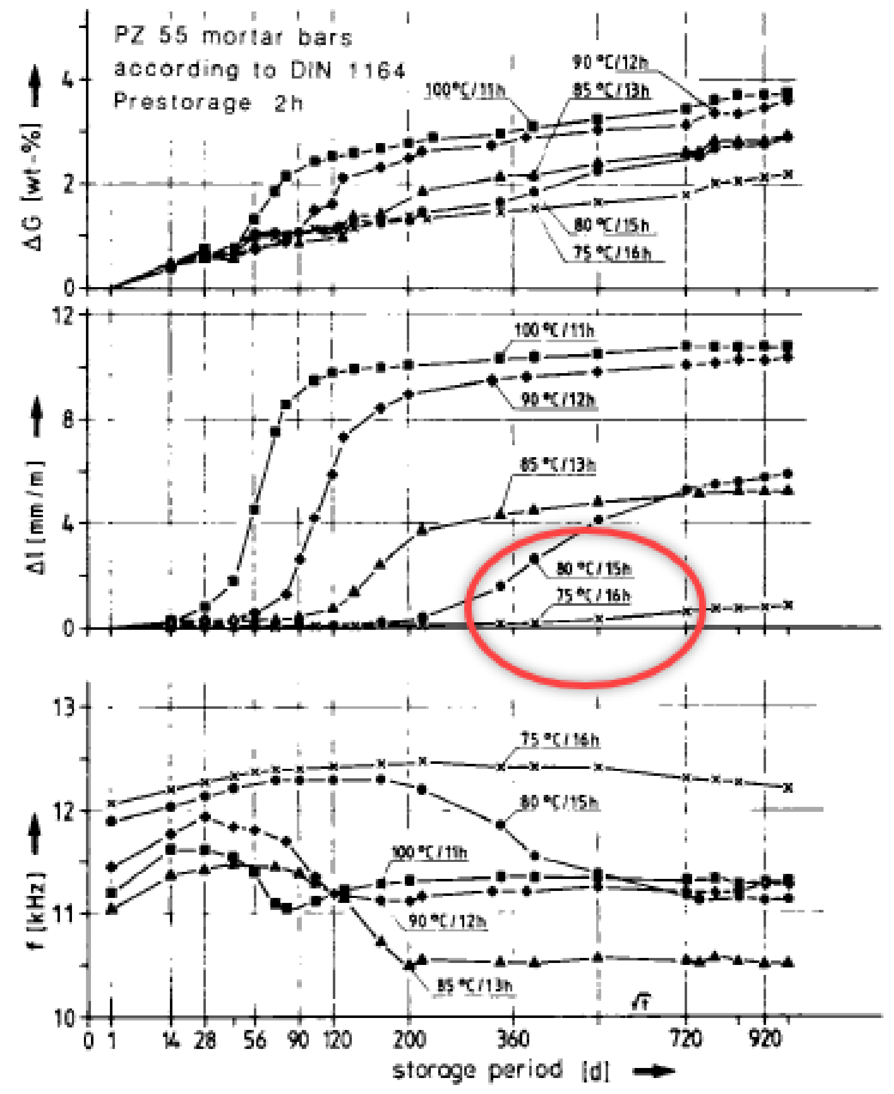


Fig. 1--Influence of the treatment temperature on weight, length, and resonance frequency of mortars with PZ 55

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160°F limit acceptable for most Type I/II Cements

Divet, L. and Pavoine, A. International RILEM TC 186-ISA Workshop on Internal Sulfate Attack and Delayed Ettringite Formation, 4-6 September 2002, Villars, Switzerland (Estimated max. sustained temp = 80°C = 176°F)

PRC-201.2-23: Durable Concrete—Guide

able 6.2.2.2—Recommended measures for reducing potential for DEF in concrete exposed to elevated mperatures at early ages*

laximum concrete temperature T	Prevention required
$T \leq 158°F$ (70°C)	No prevention required
$158°F < T \leq 185°F$ ($70°C < T \leq 85°C$)	Use one of the following approaches to minimize the risk of expansion: 1. Any ASTM C150/C150M portland cement in combination with the following proportions of pozzolan or slag cement: (a) Greater than or equal to 25% fly ash meeting the requirements of ASTM C618 for Class F fly ash (b) Greater than or equal to 35% fly ash meeting the requirements of ASTM C618 for Class C fly ash (c) Greater than or equal to 35% slag cement meeting the requirements of ASTM C989/C989M (d) Greater than or equal to 5% silica fume (meeting ASTM C1240) in combination with at least 25% slag cement (e) Greater than or equal to 5% silica fume (meeting ASTM C1240) in combination with at least 20% Class F fly ash (f) Greater than or equal to 10% metakaolin meeting ASTM C618 2. An ASTM C595/C595M or ASTM C1157/C1157M blended hydraulic cement with the same pozzolan or slag cement content as listed in Item 1
$T > 185°F$ (85°C)	The internal concrete temperature should not exceed 185°F (85°C) under any circumstances.

Assembled from Ghorab et al. (1980), Ramlochan et al. (2003), Thomas (2001), and Thomas et al. (2008b).

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Ramlochan 2003

- Mortar prisms with Type III Portland Cement
- Cement replaced with pozzolans and/or slag as partial replacement by mass.
- Metakaolin, slag, and fly ashes--F and C.

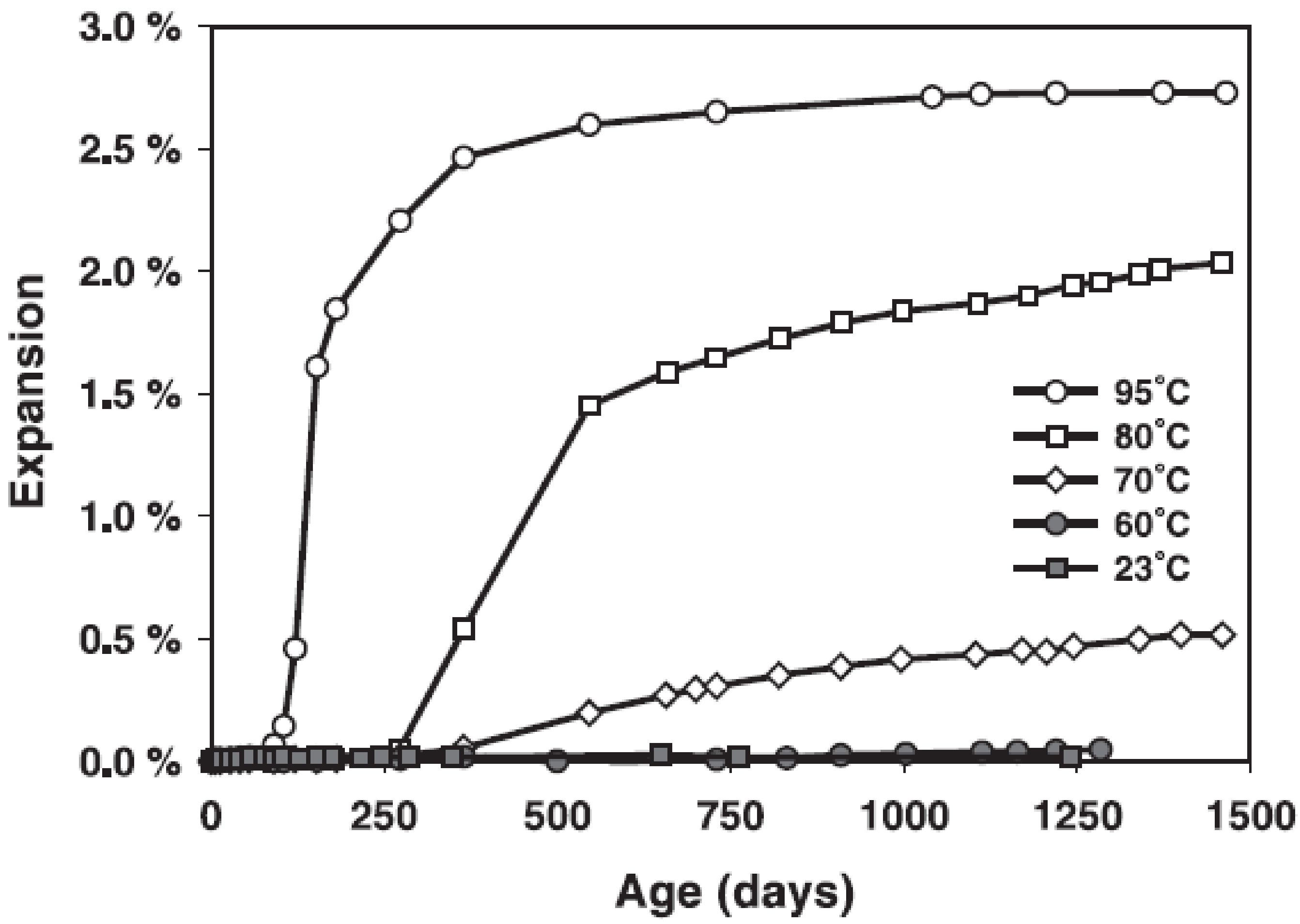

Fig. 1. Expansion of Portland cement mortars made with cement A cured at different temperatures.

Ramlochan 2003 cont...

Mortar--w/c 0.48. Same sand.

Cement--Type III high in sulfate, alkali, C3A, and fineness

Metakaolin--commercially available Georgia

Kaolin--natural pozzolan

Slag--Grade 100

Silica fume--undensified powder

Ramlochan 2003 cont...

Fly Ash--

(5) Class C

- C1--low alkali and sulfate
- C2, C4, C5--high sulfate
- C3--moderately high alkali content
- C5--high alkali content.

(2) Class F--both had low alkali and sulfate

Ramlochan 2003 cont...

- Heat cured with relative humidity of 100%
- 4hr at 23C
- Increase temp at 20C/hr until 60, 70, 80, or 95C was reached.
- Max temp maintained for 12 hours
- Specimens cooled to 23C at 20C/hr.
- Samples demolded at stored in lime water. Length change measured

Ramlochan 2003 Conclusions

- Metakaolin--8% or greater replacement--suppresses DEF
- Silica Fume--8% replacement--not effective in suppressing DEF
- Slag--at least 25% replacement
- Fly Ash
  - Low lime fly ashes more effective at suppressing DEF--15-25%
  - High lime fly ashes more effective at suppressing DEF--25-35%
- The sulfate and alkali content may be important

Thomas 2008

- Concrete bridge piers constructed in 1980 showed extensive cracking by 1990
- 450 kg/m^3 cement (760 lb/yd^3)
- Estimated curing temp. 80°C

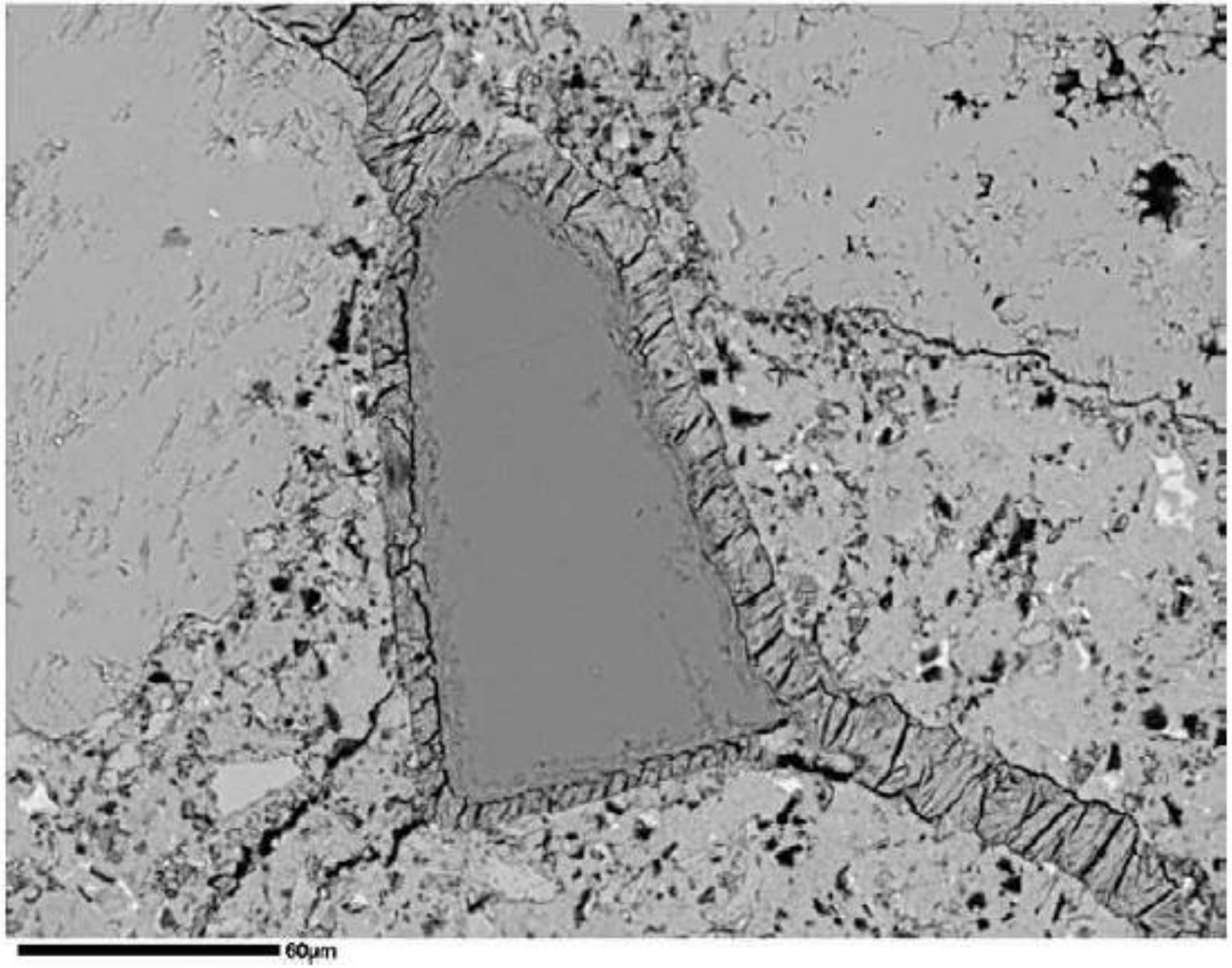

Fig. 7. BSE image of polished sample from Column A showing ettringite-filled gap around aggregate particle.

Thomas 2008 cont...

- ASR/DEF often seen together but DEF was observed independently from ASR
- 4 bridge piers highlighted (of many)
  - A. DEF—sole cause of Distress
  - B. DEF + ASR observed
  - C. No distress, fly ash in the concrete mixture
  - D. DEF + ASR Observed.

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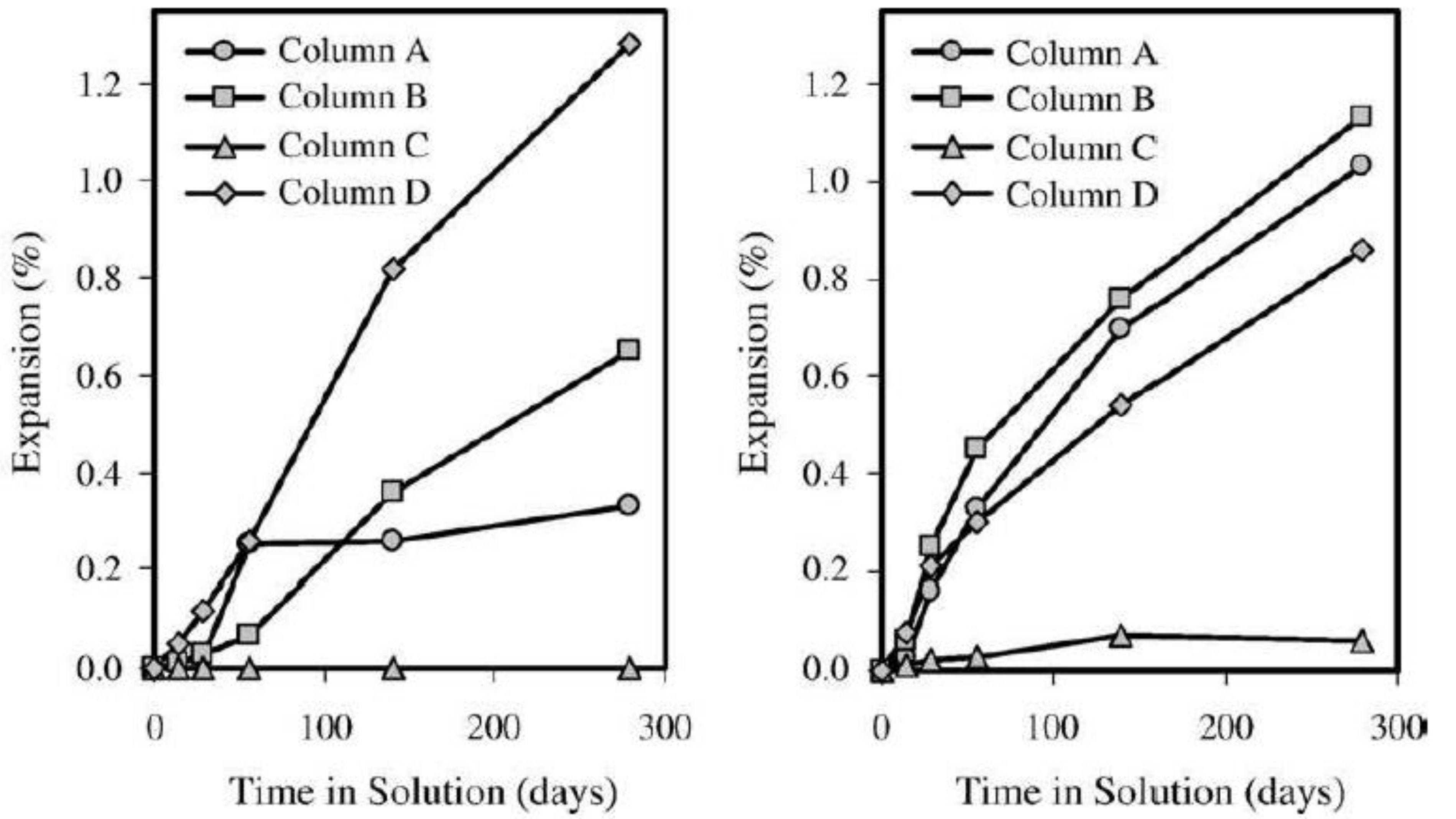

Fig. 3. Expansion of 50-mm cores cut from concrete columns and stored in limewater (left) and NaOH solution (right).

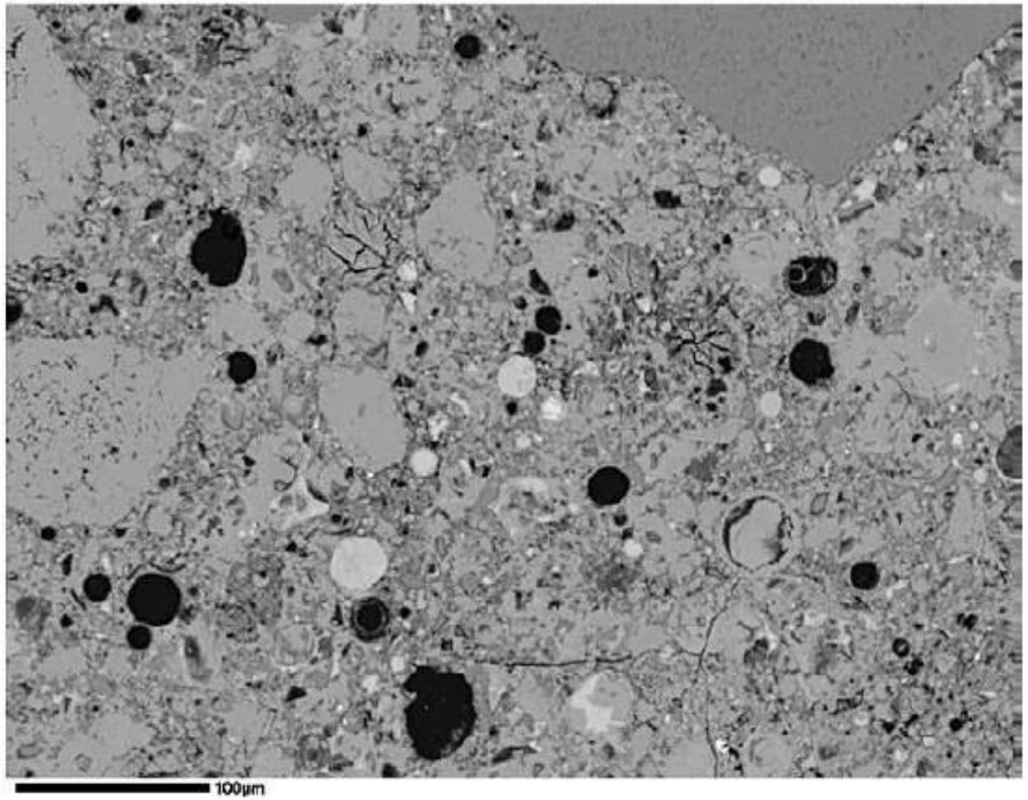

Fig. 6. BSE image of polished sample from Column C.

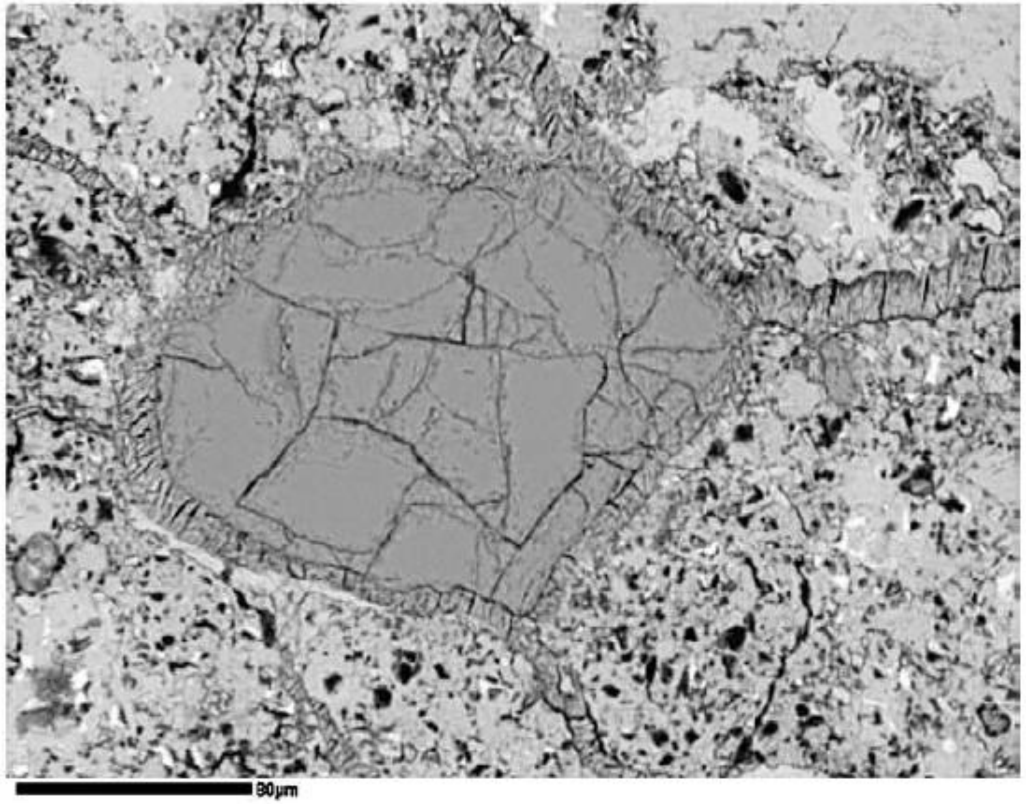

Fig. 8. BSE image of polished sample from Column B showing ettringite-filled gap around reacting aggregate particle.


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