AIR VOID SYSTEMATICS of HARDENED CONCRETE

100th Annual Meeting of the
Northeastern States Materials Engineers' Association

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Air Void

A small space enclosed by the cement paste in hardened concrete and occupied by air.

Types of Voids in Concrete

Capillary < 5μm

Entrained >5μm - 1mm (head of a pin = 1.5mm; 10^6 air voids/in^3)

Entrapped > 1mm

Types of Voids in Concrete

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- Irregularly-shaped; form around and by hydrating cement particles
- Originally filled with water or air
- Higher w/c paste = more capillary voids
- Not counted in air void analysis of hardened concrete

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- Air that is retained and trapped within the cement paste via the use of surfactants or admixtures to increase the % air in concrete.
- Spherically-shaped

Entrapped > 1mm

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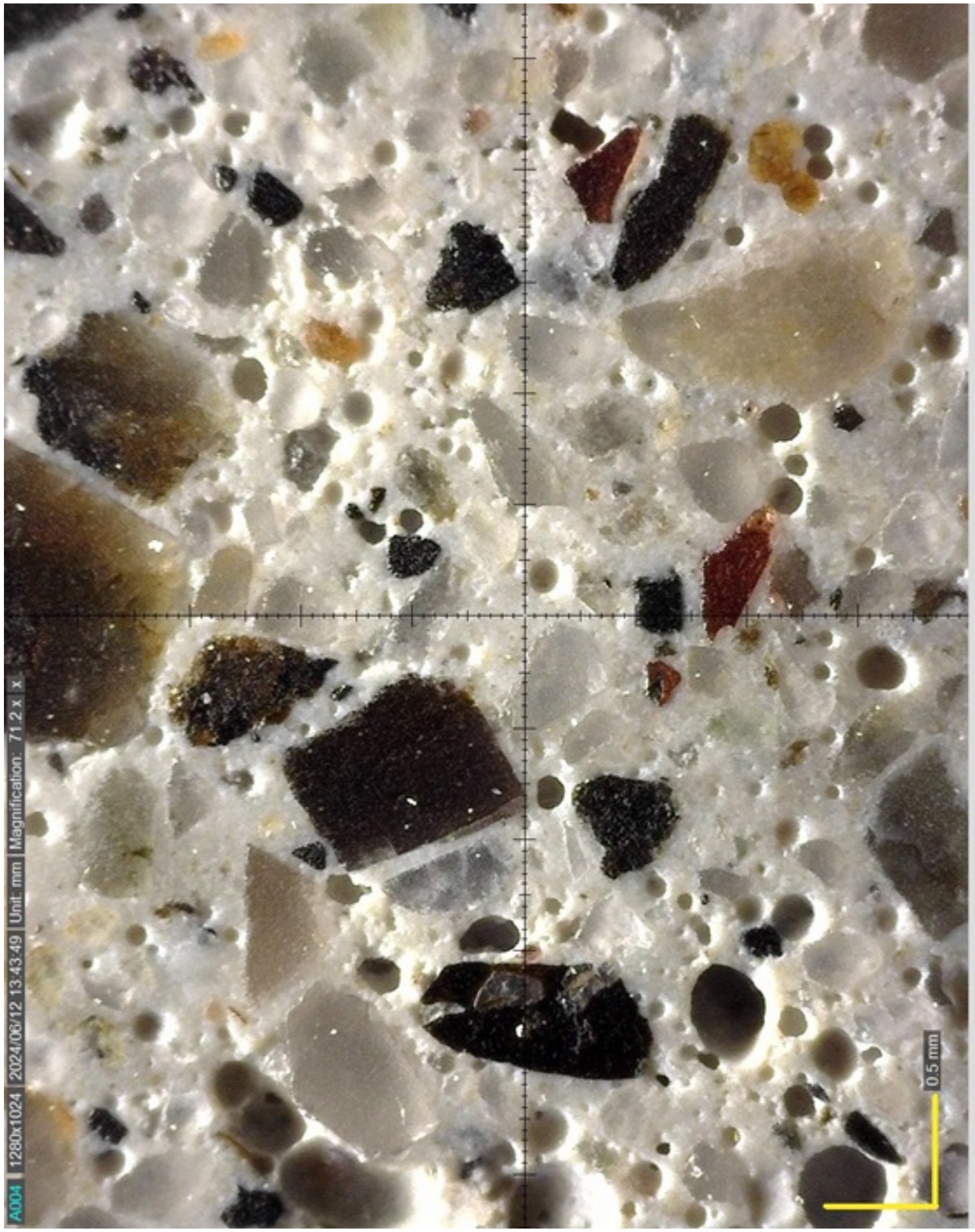
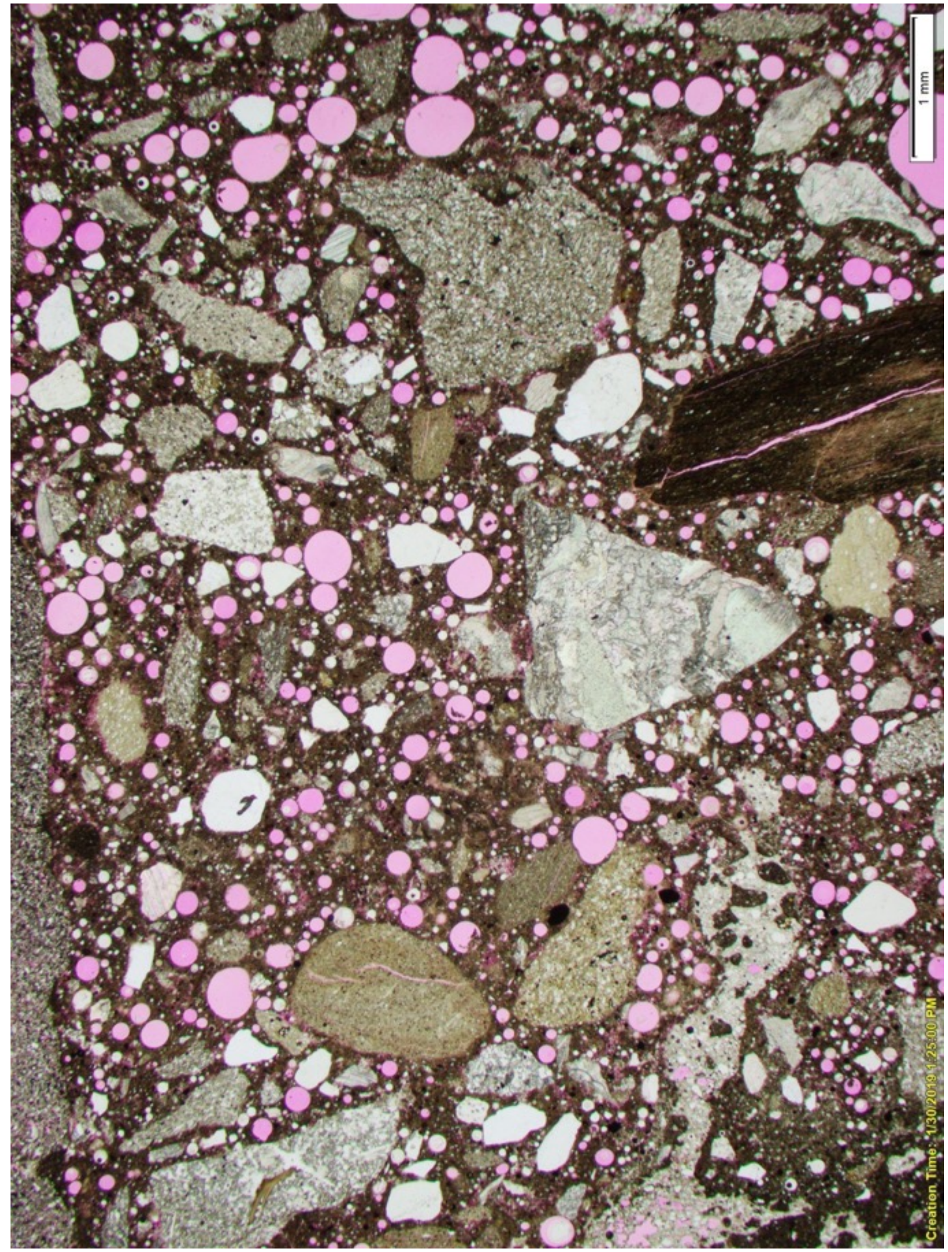
Entrapped > 1mm

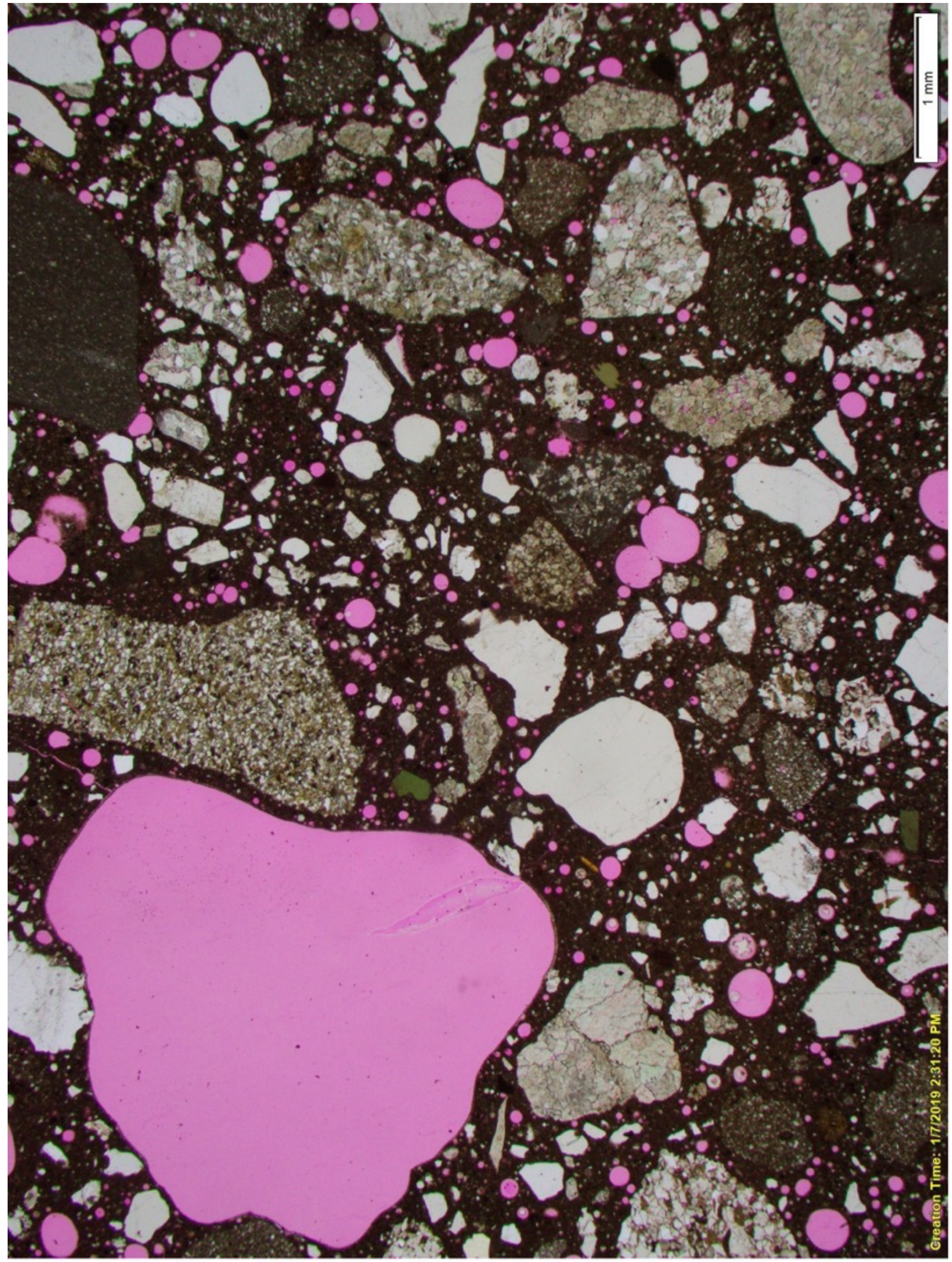
- Air: Spherically-shaped
- Water: Irregularly-shaped
- Boundary: Flat-shaped; located along aggregate-paste boundaries

Entrained Air






Face
Entrapped Air
Petro
CP-2
8"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AIR VOIDS in CONCRETE …

The Good, the Bad, and the Ugly

Good

1. **Entrained air voids help hardened concrete resist freeze/thaw damage*;**

AIR VOIDS in CONCRETE …

The Good, the Bad, and the Ugly

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2. **Reduce the overall weight of the concrete;**

AIR VOIDS in CONCRETE …

The Good, the Bad, and the Ugly

Good

1. Entrained air voids help hardened concrete resist freeze/thaw damage*;
2. Reduce the overall weight of the concrete;
3. Increase workability which allows for a lower w/c to be used = stronger concrete = concrete less susceptible to sulfate attack, ASR damage;

AIR VOIDS in CONCRETE …

The Good, the Bad, and the Ugly

Good

1. **Entrained air voids help hardened concrete resist freeze/thaw damage*;**
2. **Reduce the overall weight of the concrete;**
3. **Increase workability which allows for a lower w/c to be used = stronger concrete = concrete less susceptible to sulfate attack, ASR damage;**
4. **Improve cohesion and reduce bleeding in fresh concrete.**

AIR VOIDS in CONCRETE …

The Good, the Bad, and the Ugly

Bad

1. **Increase porosity and permeability of the concrete;**

AIR VOIDS in CONCRETE …

The Good, the Bad, and the Ugly

Bad

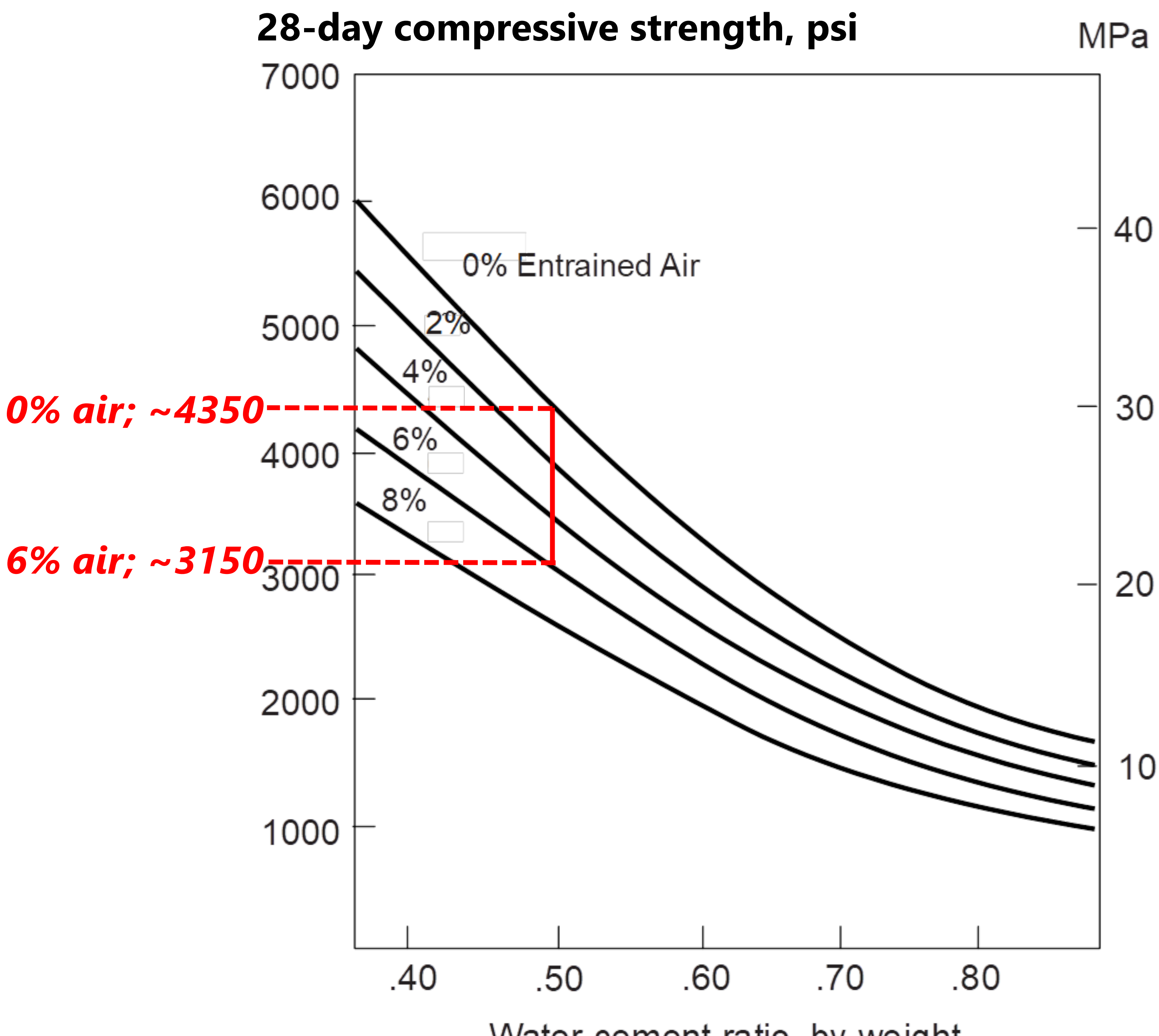
1. **Increase porosity and permeability of the concrete;**
2. **Increase the susceptibility of the concrete to chemical damage via infiltration of harmful chemicals;**

AIR VOIDS in CONCRETE …

The Good, the Bad, and the Ugly

Bad

1. **Increase porosity and permeability of the concrete;**
2. **Increase the susceptibility of the concrete to chemical damage via infiltration of harmful chemicals;**
3. **Decrease the overall strength of the concrete.**



An increase in air content will decrease the compressive strength of concrete.

Walker and Bloem (1955)

% Total Air in Concrete

% total air = % entrapped air + % entrained air

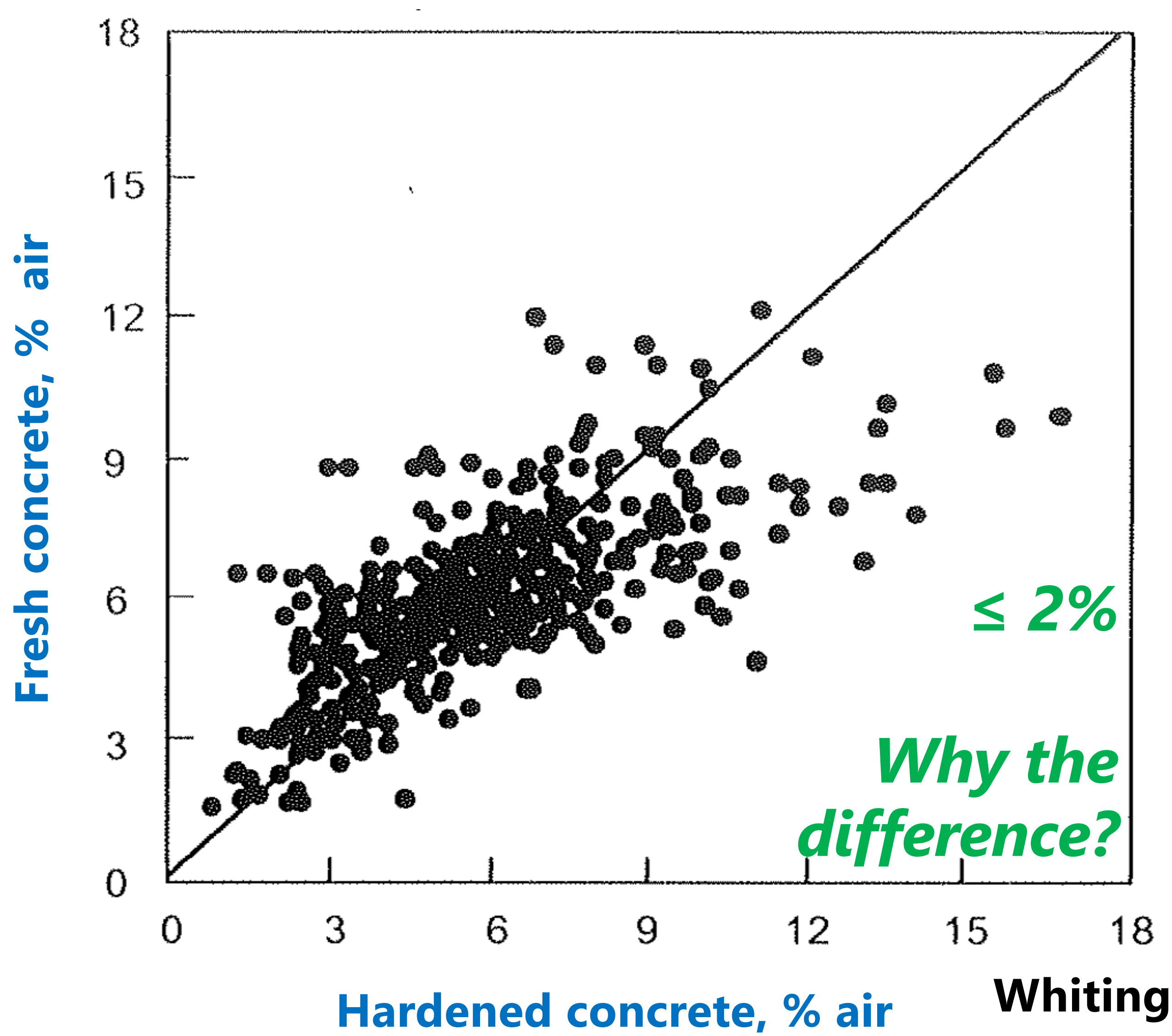
(~0.5% to ~3.0%)   (design mix)

% Total Air Dictated By …

- **Method of placement**
- **Degree of compaction, vibration, etc.**
- **Addition of air-entrainment mixtures, water, etc.**

% Total Air in Concrete

Fresh vs. Hardened Concrete



Whiting and Nagi (1998)

% Total Air in Concrete

% total air = % entrapped air + % entrained air

How Much Air Does Concrete Need?

% Total Air in Concrete

% total air = % entrapped air + % entrained air

How Much Air Does Concrete Need?

Depends on:

- **Climate (exposure to freeze/thaw cycles)**
- **Nominal maximum aggregate size**
- **Use**

Nominal maximum aggregate size, in. (mm)	Air content, percent*		
	Severe exposure**	Moderate exposure†	Mild exposure††
< 3/8 (< 9.5)	9	7	5
3/8 (9.5)	7-1/2	6	4-1/2
1/2 (12.5)	7	5-1/2	4
3/4 (19.0)	6	5	3-1/2
1 (25.0)	6	4-1/2	3
1-1/2 (37.5)	5-1/2	4-1/2	2-1/2
2 (50)‡	5	4	2
3 (75)‡	4-1/2	3-1/2	1-1/2

These recommendations follow guidelines established by the ACI Building Code (ACI 318) and Durability (ACI 201) Committees and Specification for Structural Concrete (ACI 301) (Whiting and Nagi, 1998).

Freeze/Thaw Damage

The ability of air in concrete to mitigate freeze/thaw damage was accidentally discovered in the 1930s … when animal fat was used as a grinding agent during cement production!

Freeze/Thaw Damage

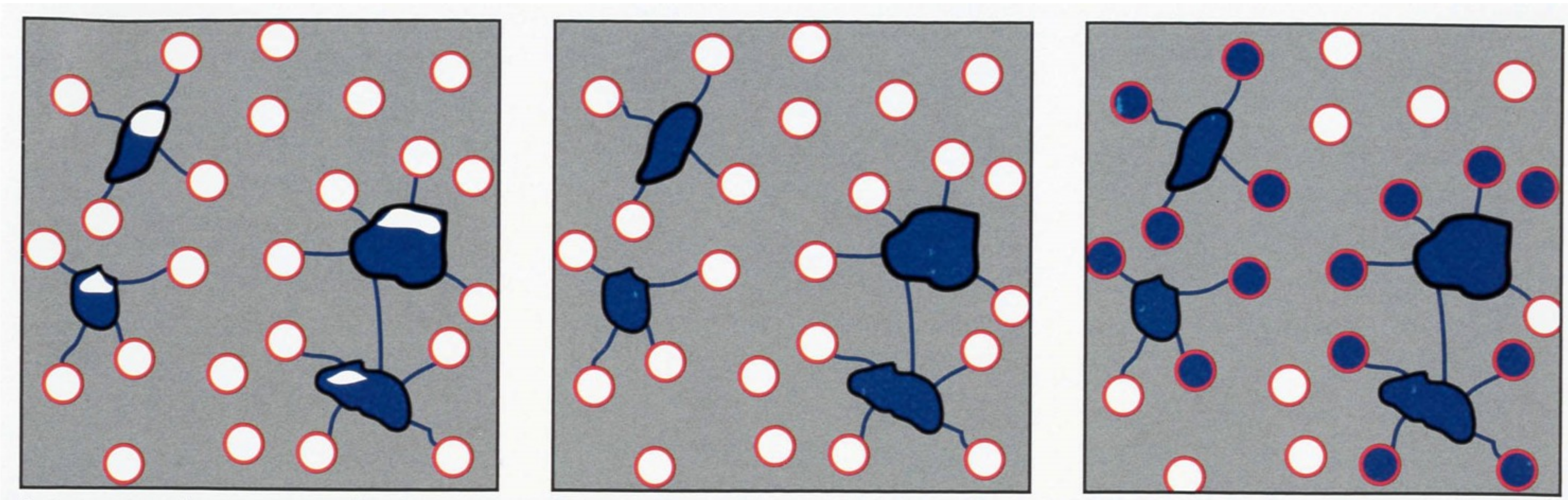
Water expands about 9% in volume when it freezes …

Freeze/Thaw Damage

Freeze/Thaw Damage

https://failuremechanisms.files.wordpress.com/2014/01/freeze-thaw.gif

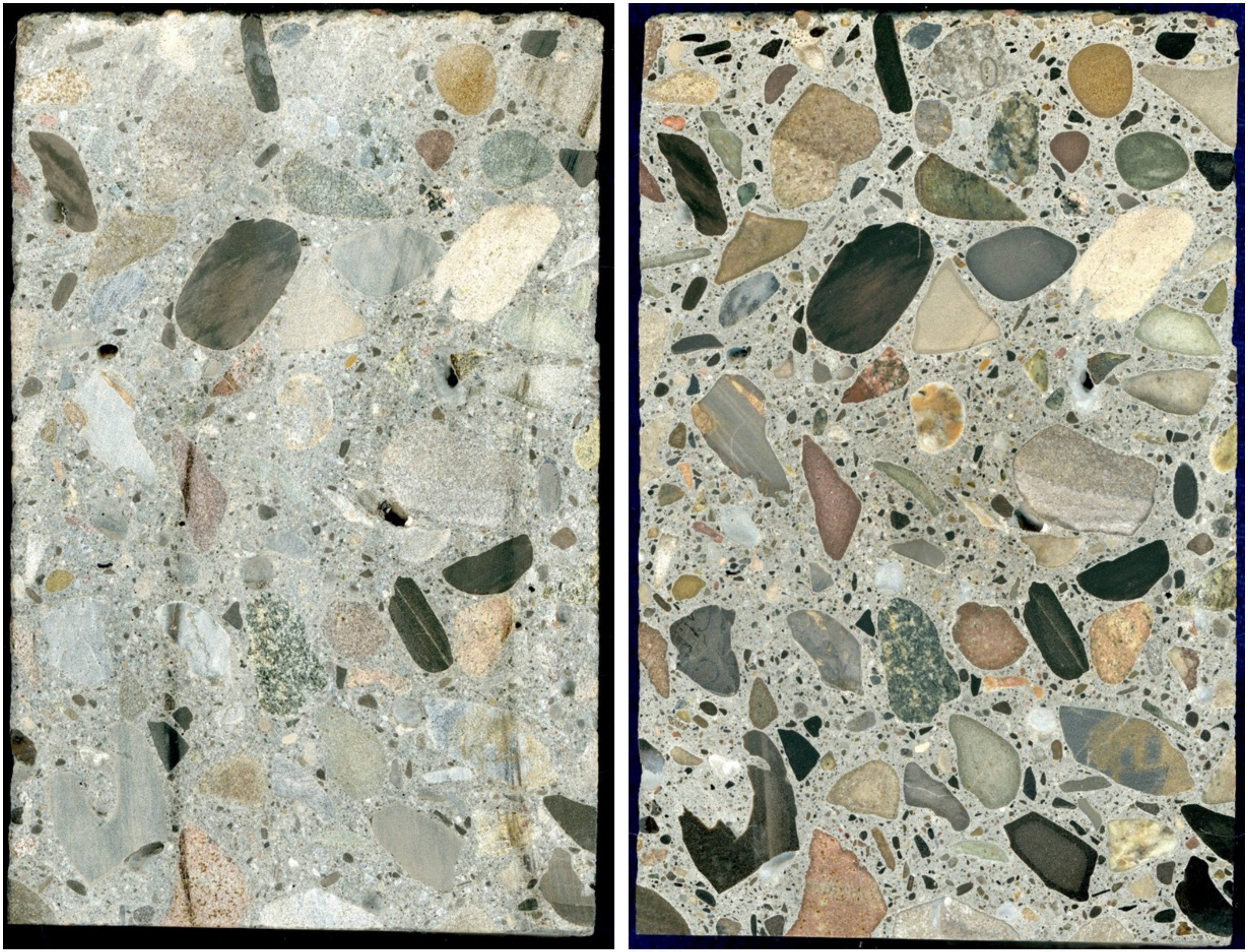
How Do Air Voids Mitigate Freeze/Thaw Damage?

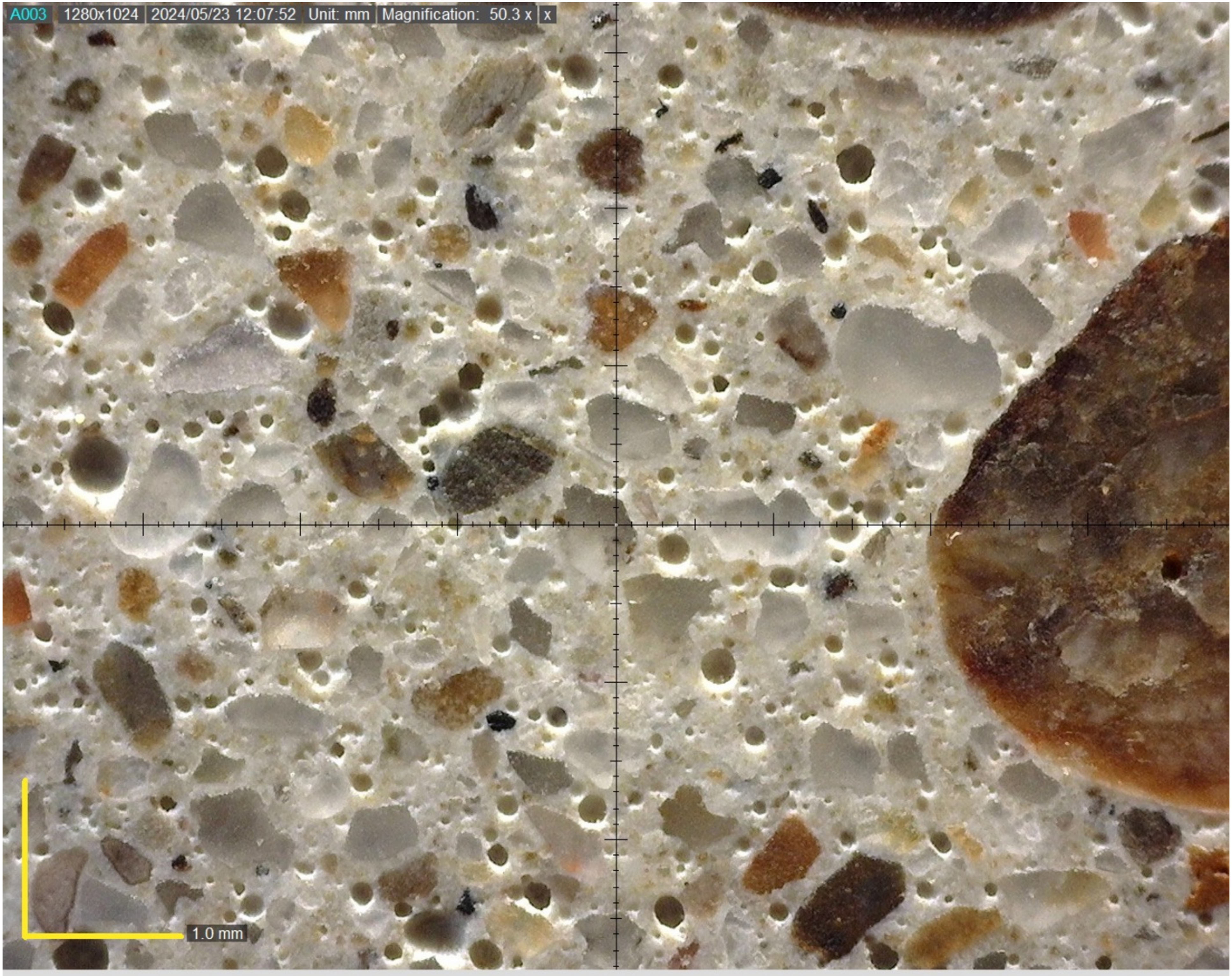


Entrained air voids provide a relief for internal ice pressure by accommodating the volume expansion caused by the freezing water.

https://precast.org/2012/12/air-entrainment-versus-air-entrapment/

Evaluating the Air Void System in Hardened Concrete

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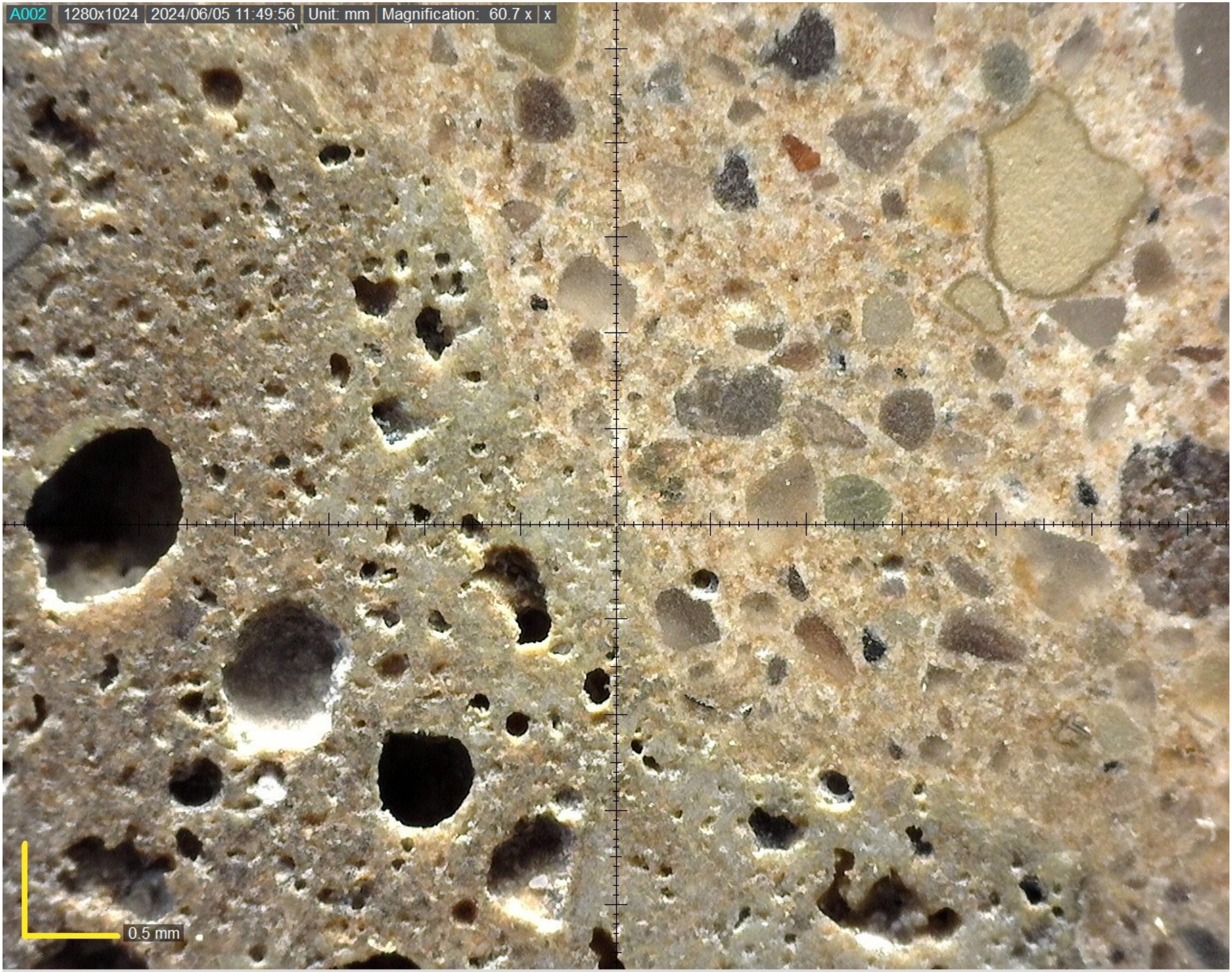
x
1.0 mm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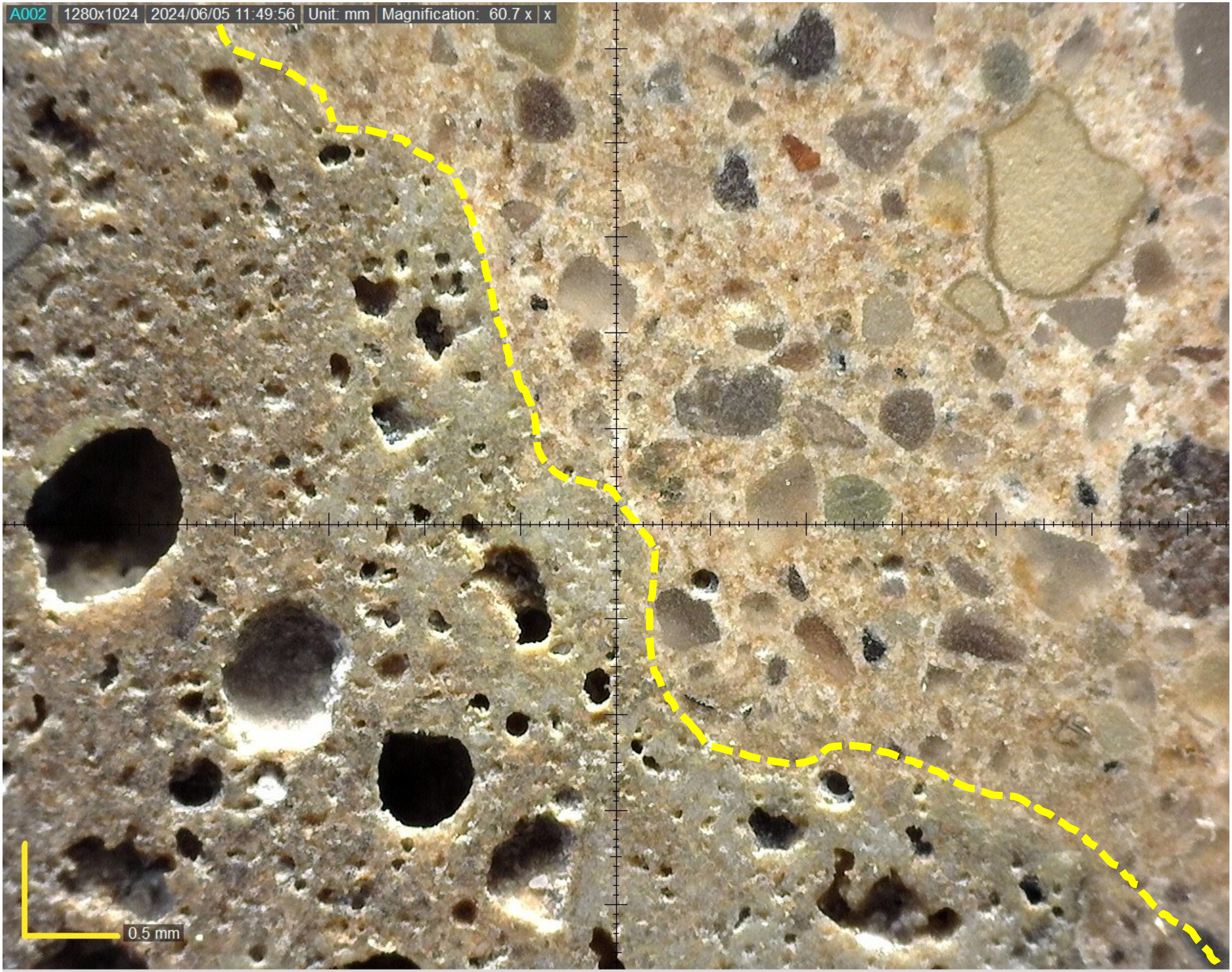
x
0.5 mm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x
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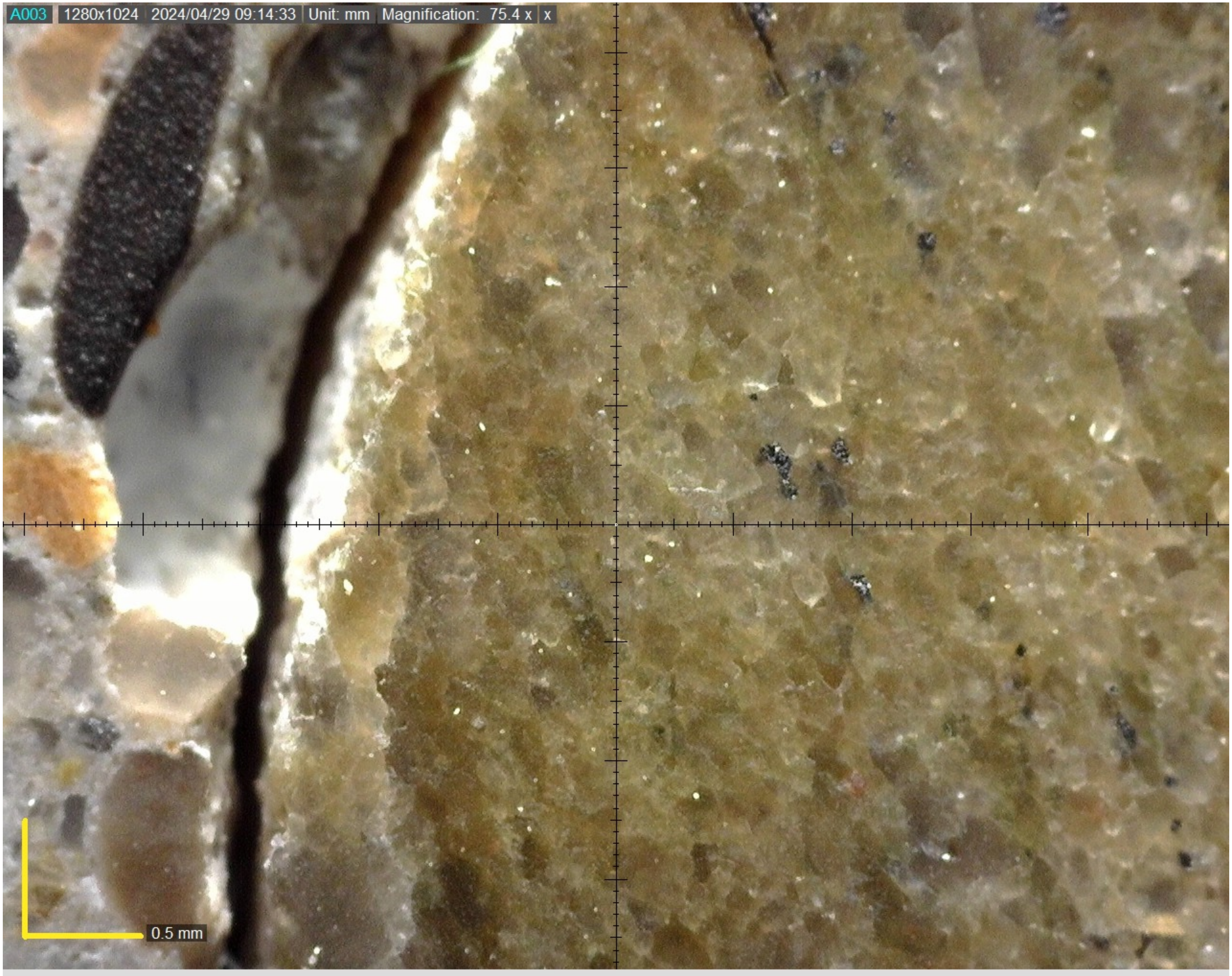

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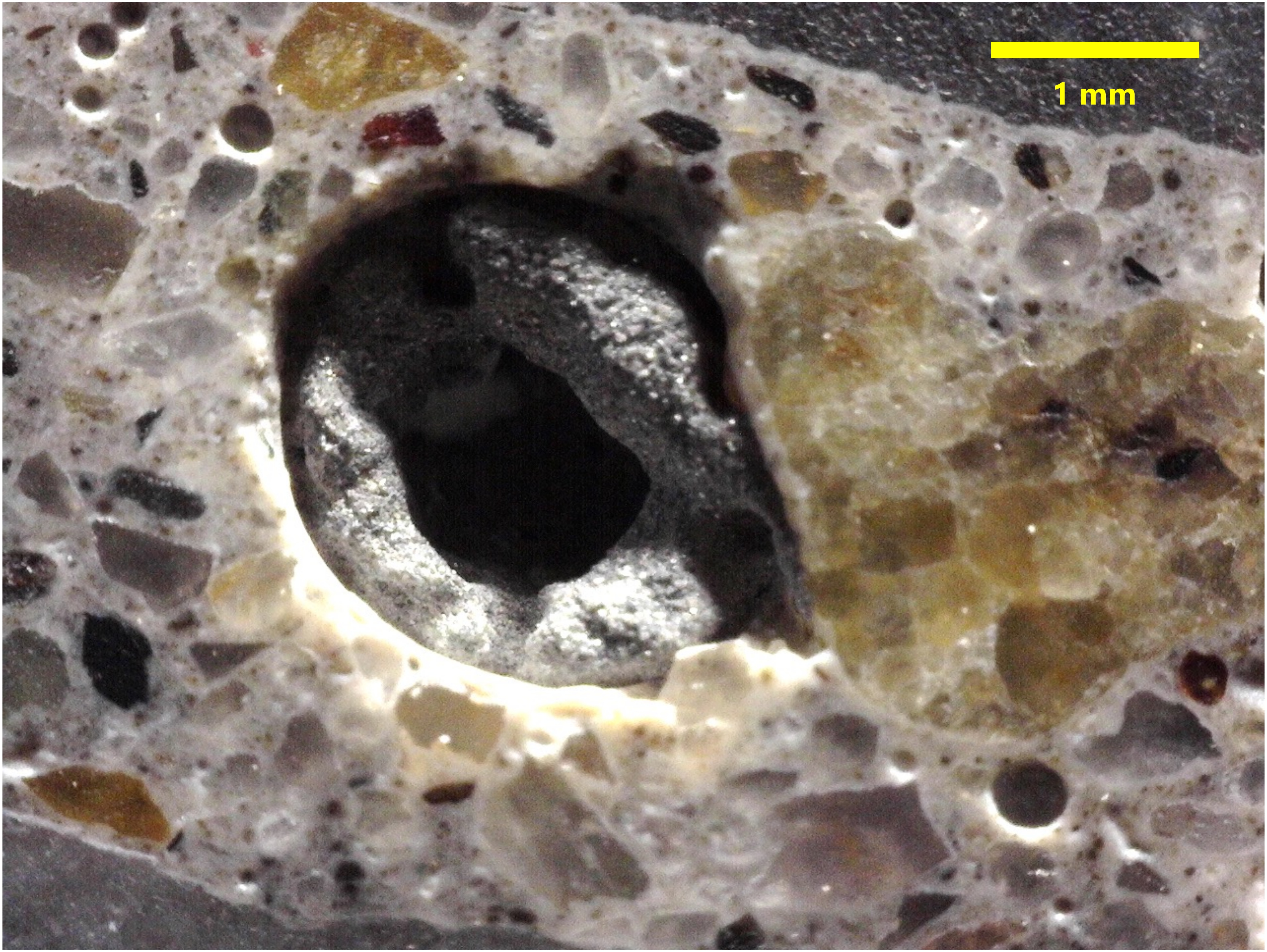
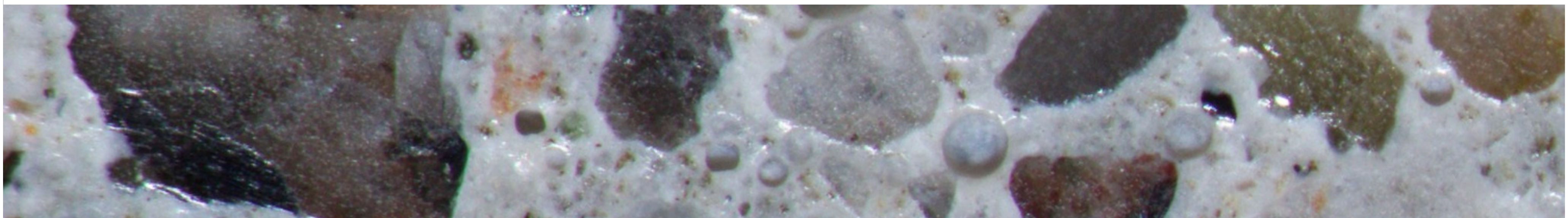
x
0.5 mm


1 mm

Evaluating the Air Void System in Hardened Concrete



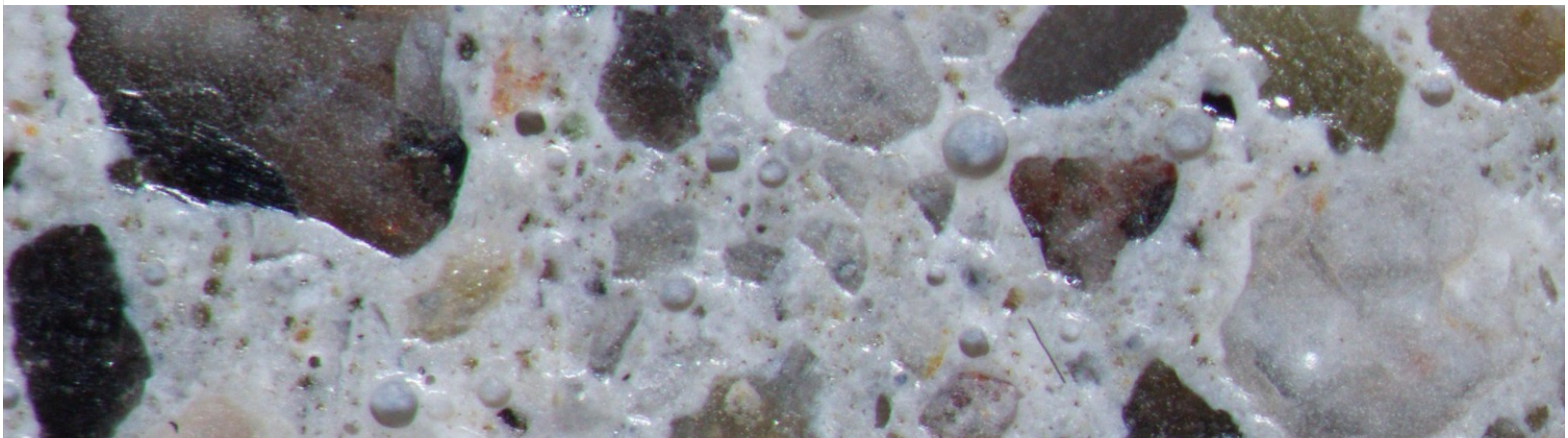
ASTM C457
Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

Procedure A—Linear-traverse method

Procedure B—Modified point-count method

Procedure C—Contrast enhanced method

Evaluating the Air Void System in Hardened Concrete



Air Content	A
Paste Content	p
Paste-Air Ratio	p/A
Void Frequency	n
Specific Surface	α
Spacing Factor	$\bar{L}$

ASTM C 457
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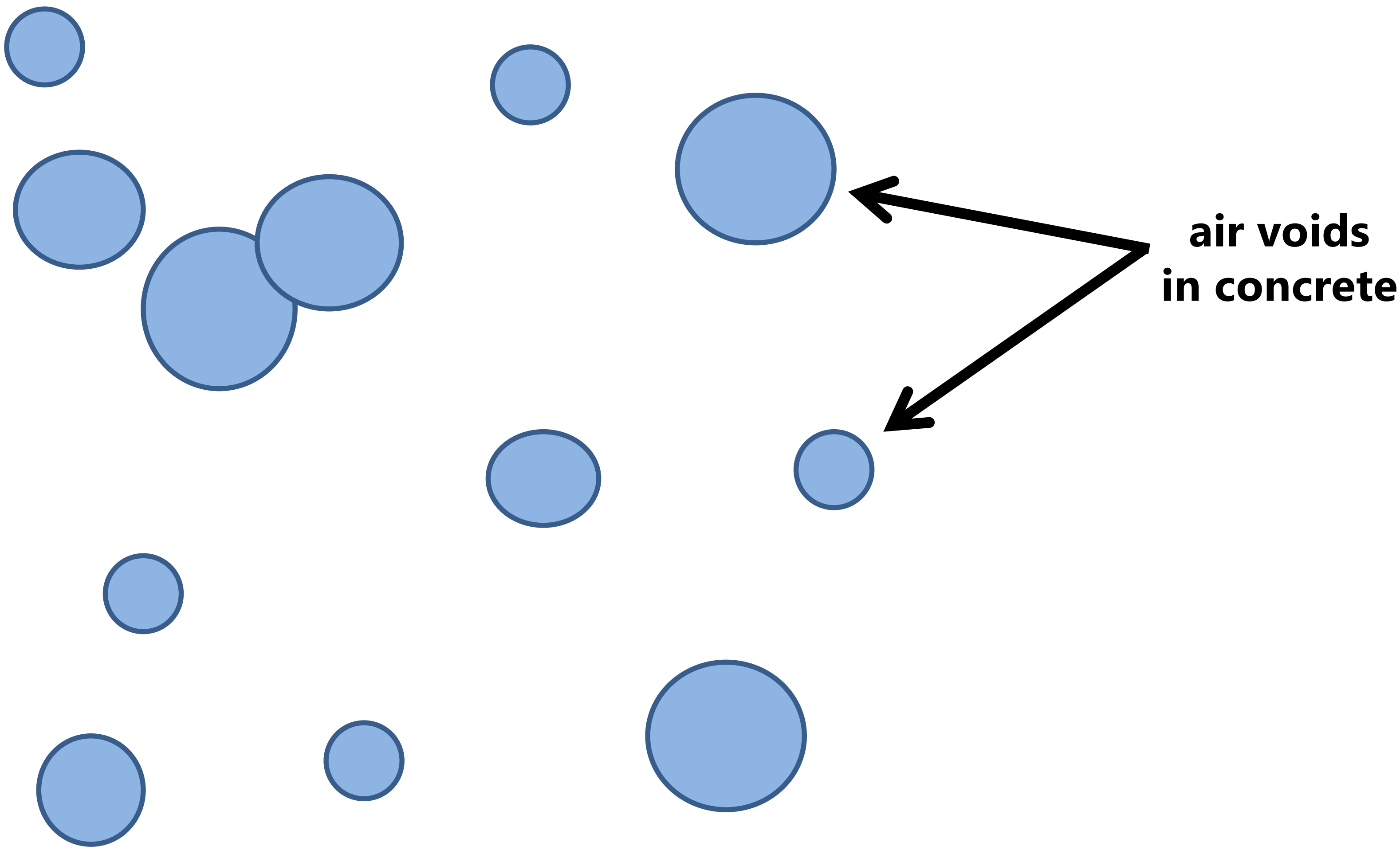
Procedure B – Modified Point-Count Method



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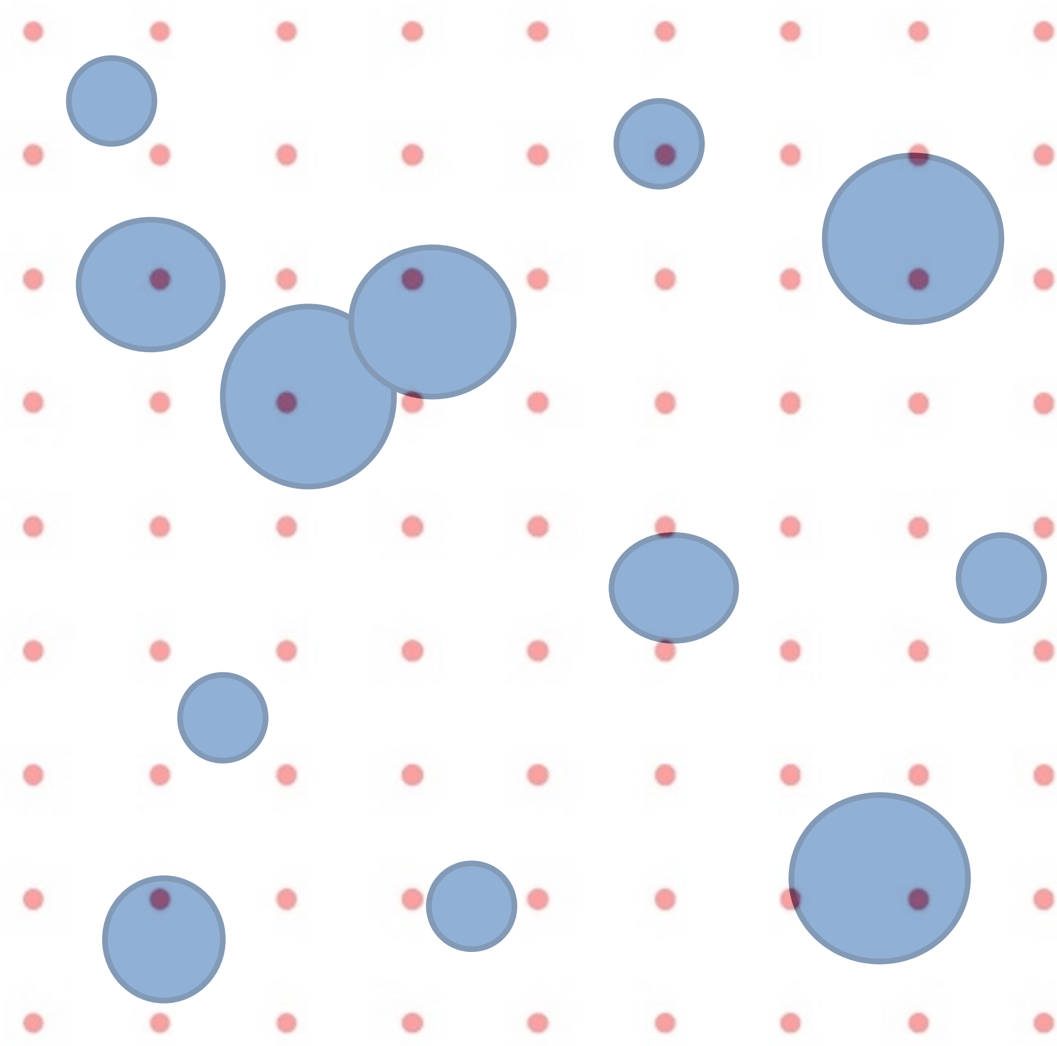
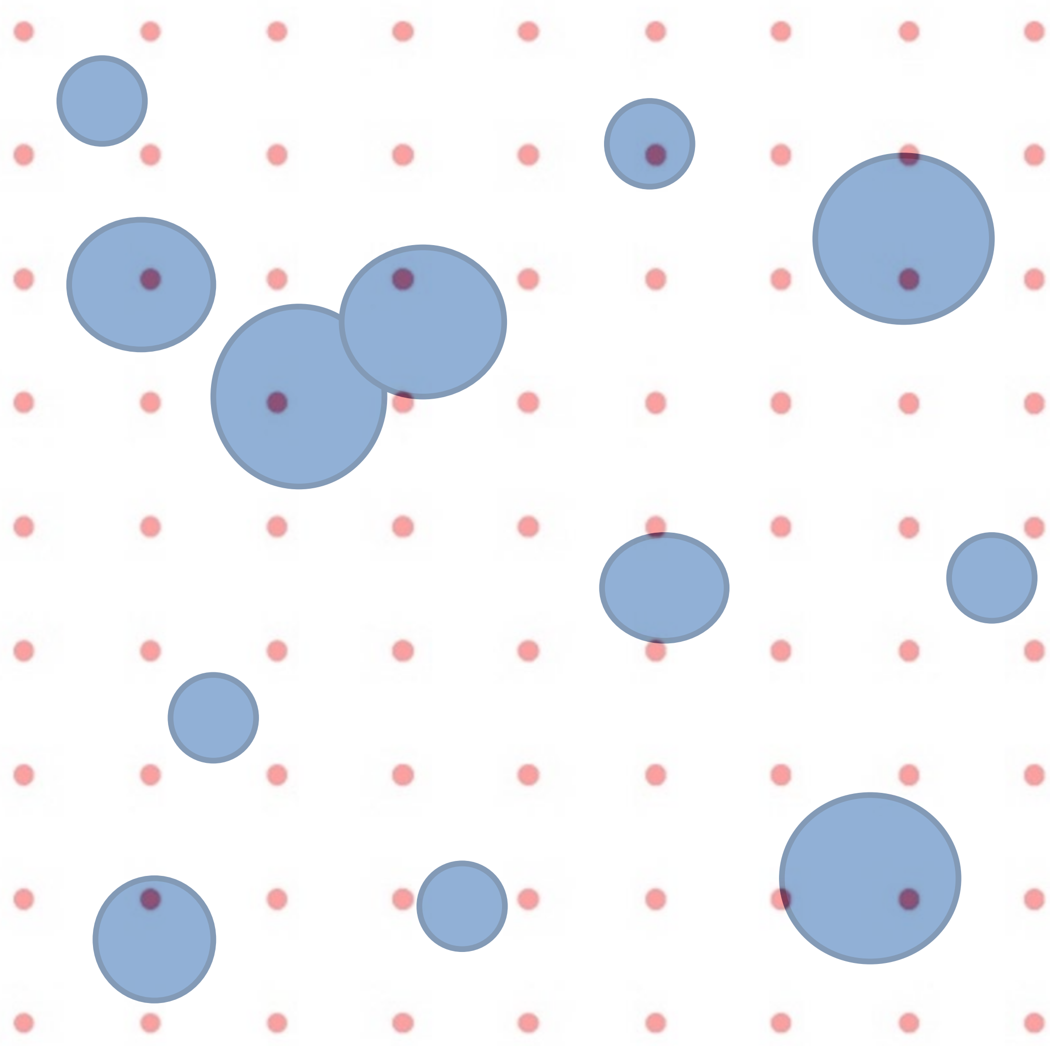


Consists of equally-spaced analysis points along several parallel paths across the sample surface.

Procedure B – Modified Point-Count Method



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Nominal maximum size of aggregate in sample dictates the required surface area to be analyzed = number of required points = total traverse length

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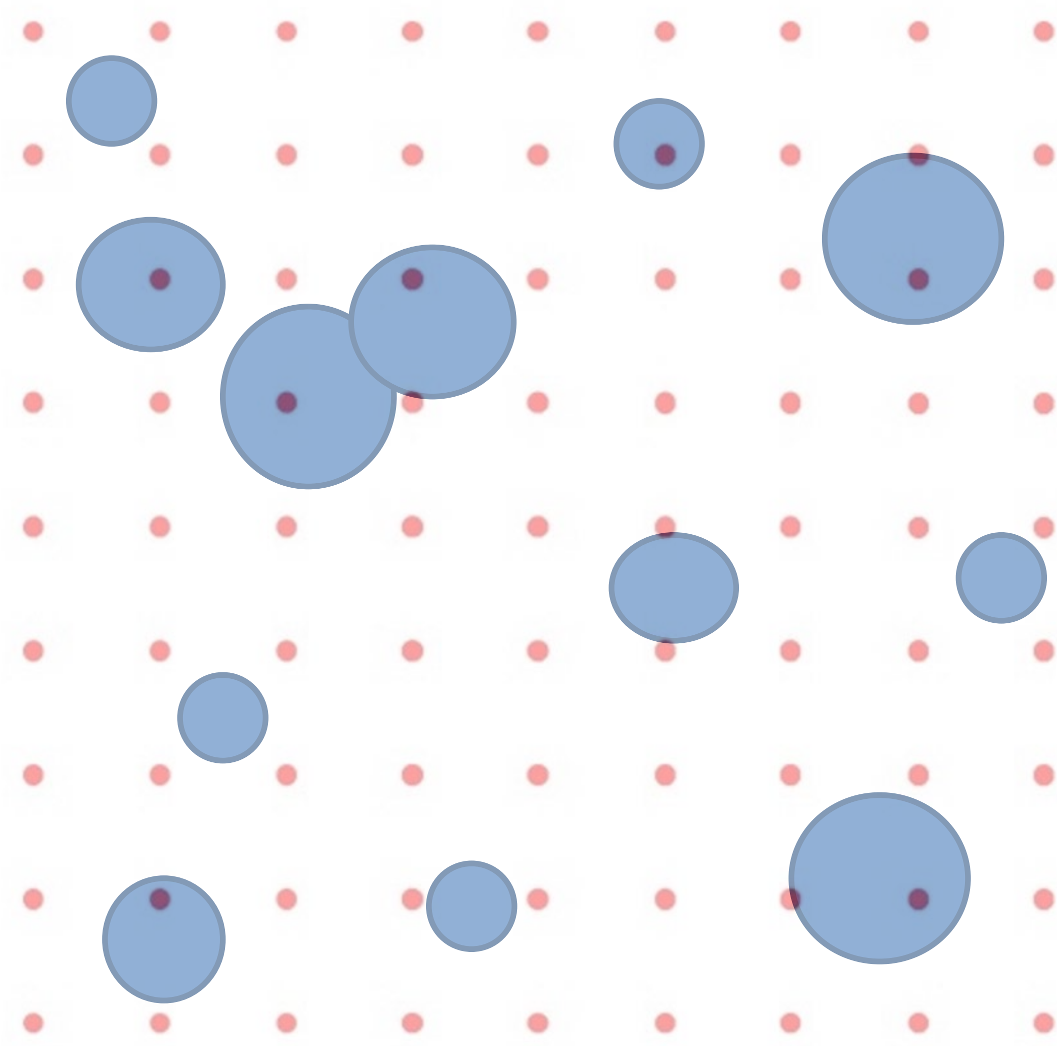

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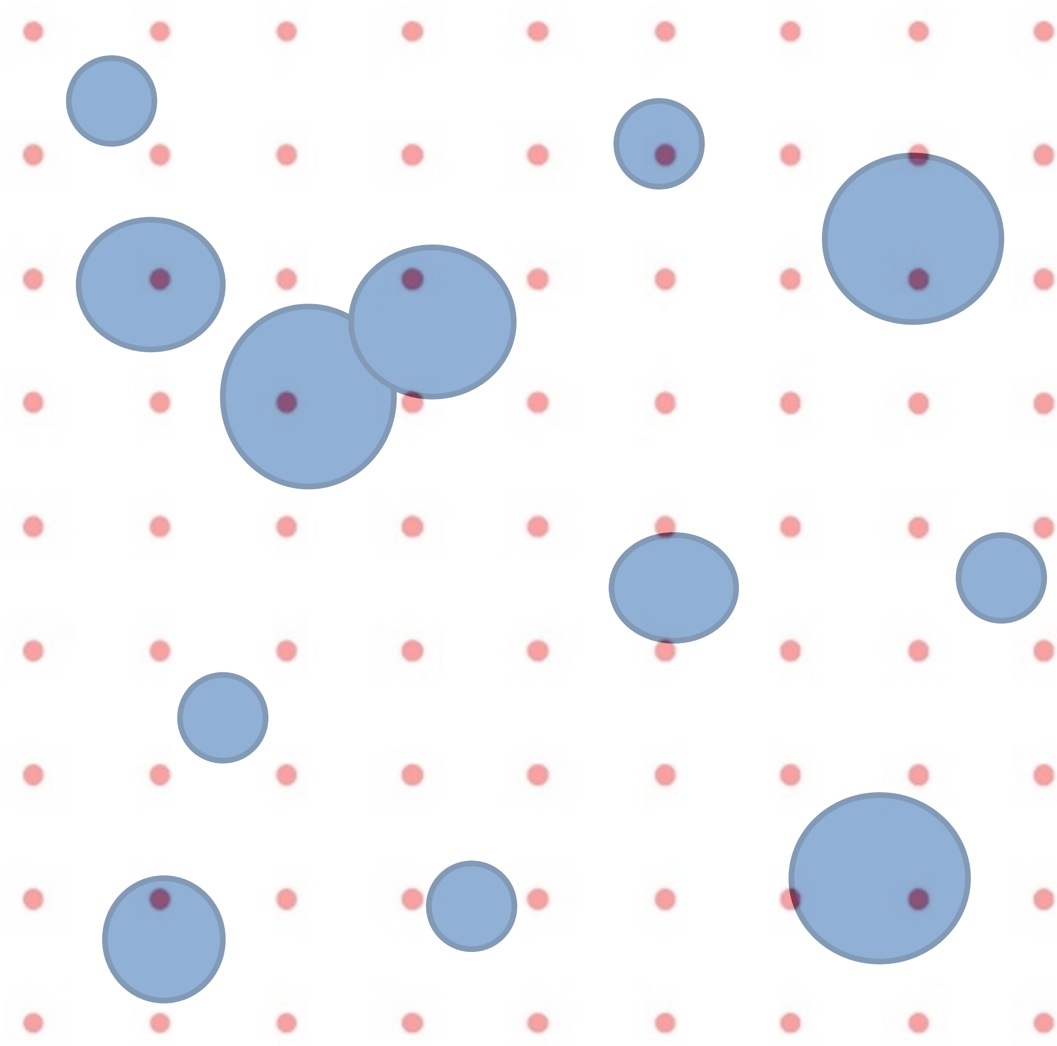

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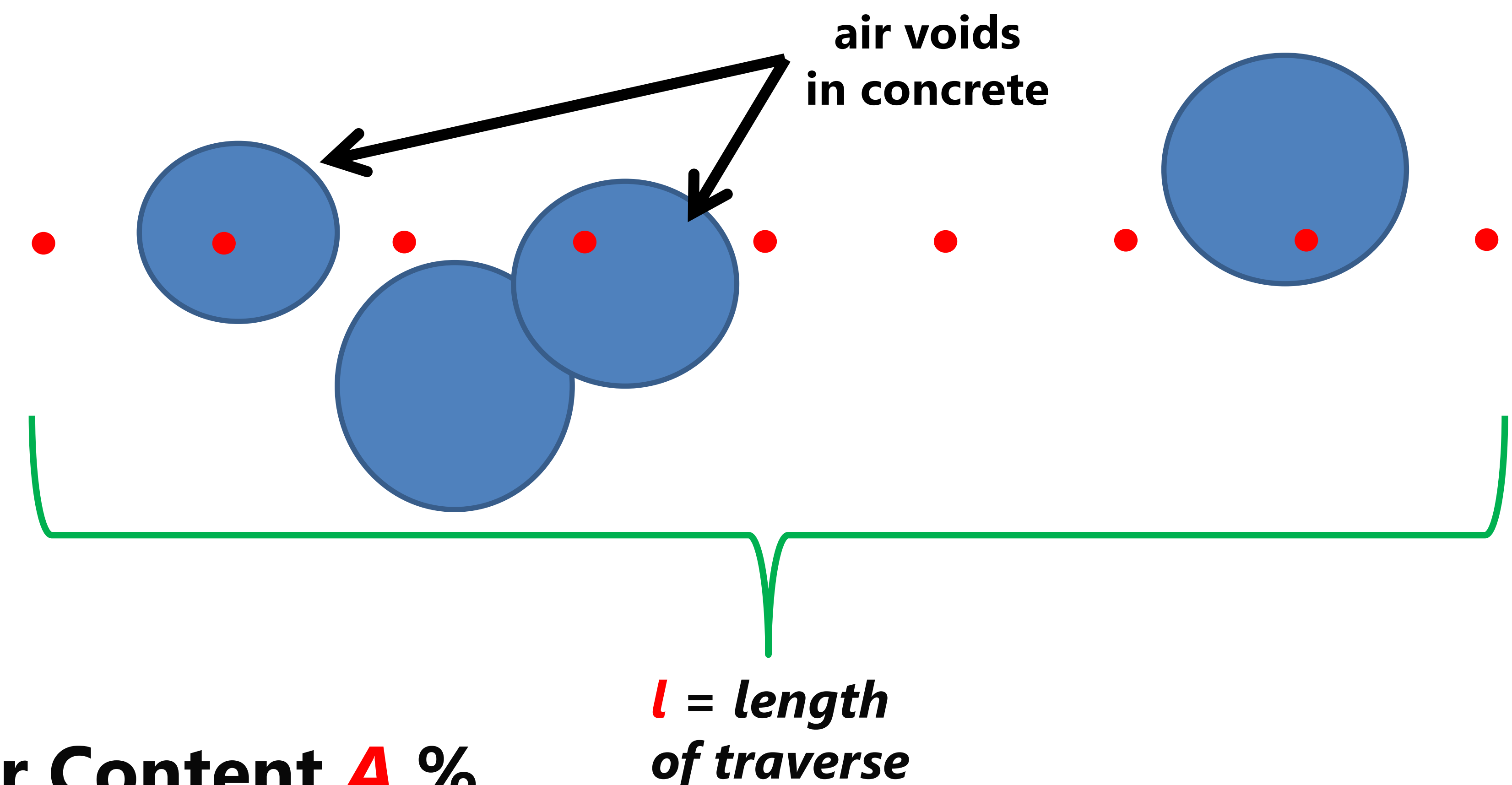
Data entered at each point: Aggregate, paste, or void; data also entered when a void is intercepted between points.

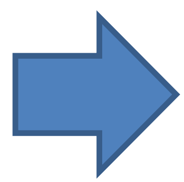
Ex: ½" aggregate = 10 in^2 surface area to analyze = 80" total traverse length = 1200 points

Evaluating the Air Void System in Hardened Concrete

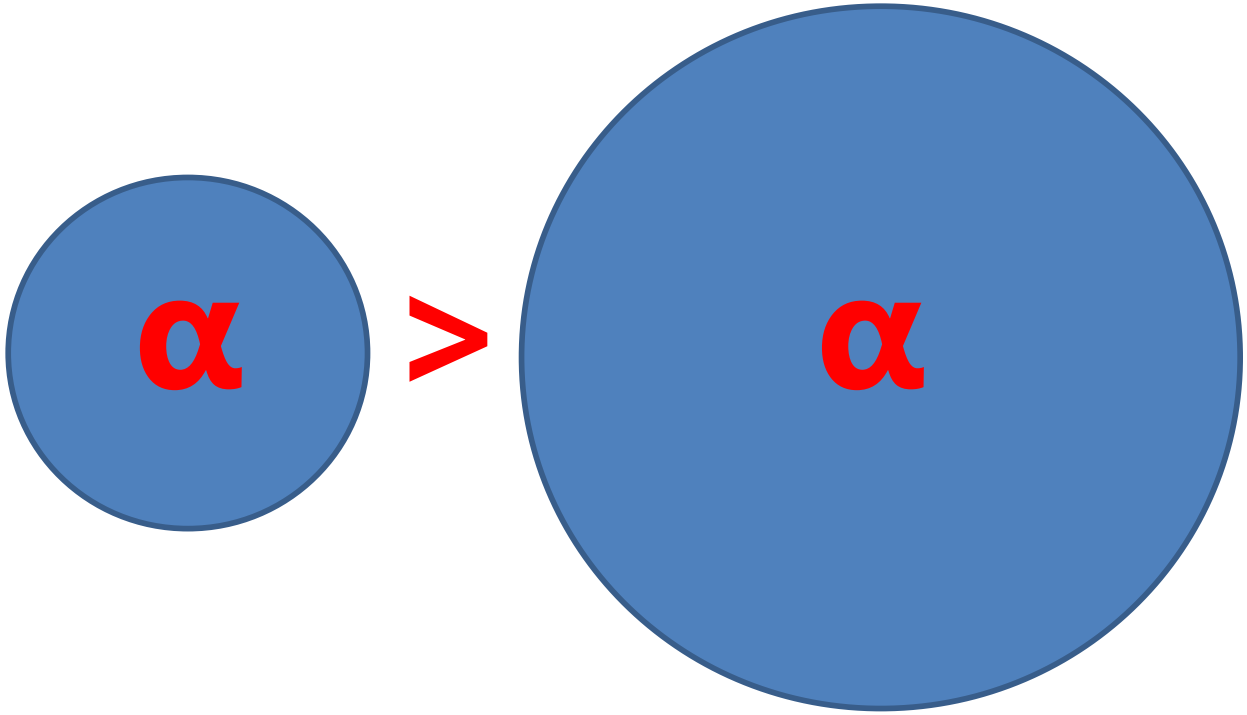
Air Content *A* %
Paste Content *p* %
Paste-Air Ratio *p/A*



Air Content *A* %
Paste Content *p* %
Paste-Air Ratio *p/A*
Void Frequency *n* (voids/in)



Number of voids per length of traverse ***n* = 3**

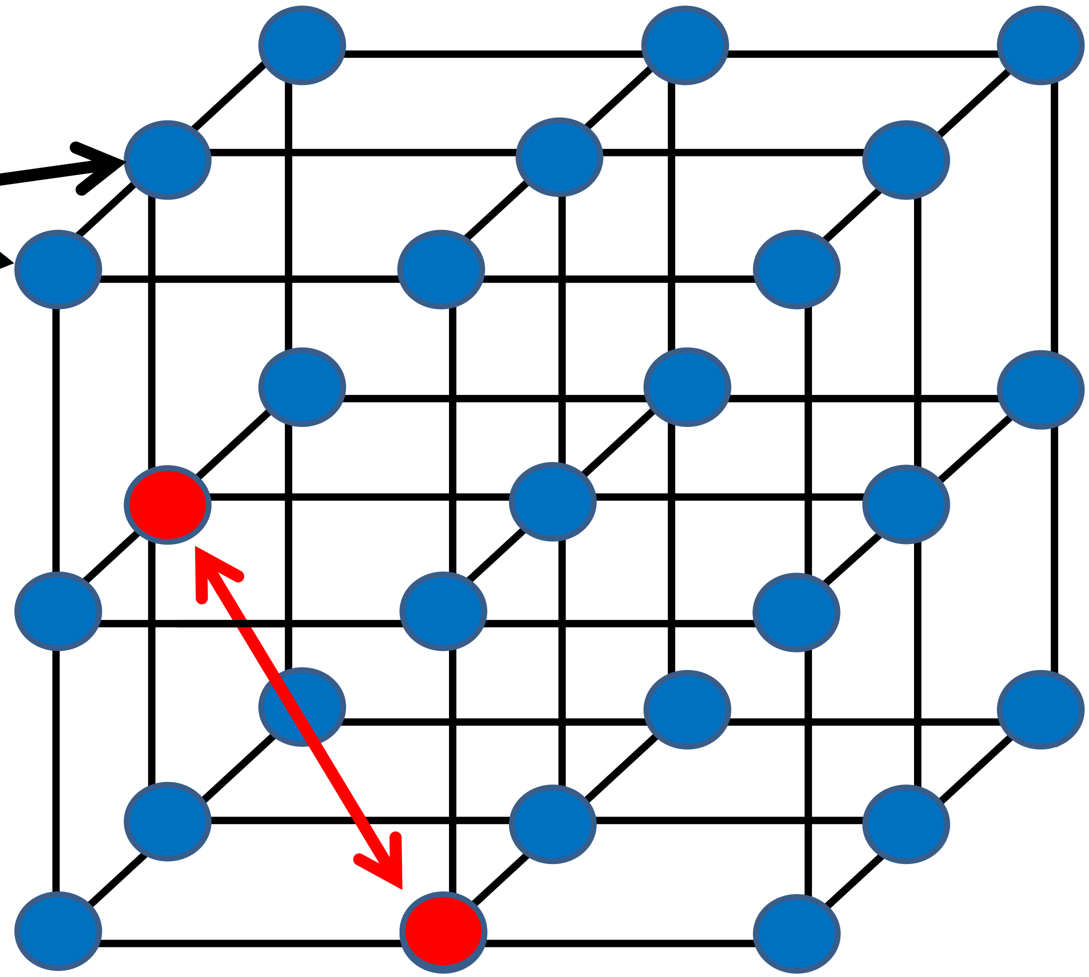


cumulative void surface area
÷
cumulative void volume

Air Content *A* %
Paste Content *p* %
Paste-Air Ratio *p/A*
Void Frequency *n* (voids/in)
Specific Surface α (in^2/in^3) → **≈fineness of air void system**

= average surface area of the voids in hardened concrete per unit volume of air.

air voids
in concrete



<u>Calculation requires:</u>
air content
paste content
specific surface

Air Content *A* %
Paste Content *p* %
Paste-Air Ratio *p/A*
Void Frequency *n* (voids/in)
Specific Surface α (in^2/in^3)
Spacing Factor *L* (in)

Theoretical maximum distance from any point in the paste to the nearest air void

Optimal Air Void System Parameters of Hardened Concrete to Resist Freeze/Thaw

Parameter	Imperial	Metric
Air Content *A*	4.5% (mild) - 9% (severe) exposure	4.5% (mild) - 9% (severe) exposure
Paste Content *p*	%	%
Paste-Air Ratio *p/A*	4-10	4-10
Void Frequency *n*	> 8 voids/in	> 300 voids/m
Specific Surface α	600-1100 in^2/in^3	25-45 mm^2/mm^3
Spacing Factor $\bar{L}$ **requires A,p,α*	0.004-0.008 in	0.1-0.2 mm

ASTM C457

Factors that influence the % air of concrete

Factor	Result
Increase in alkali content of cement	Increase air %
Increase in cement fineness	Increase air %
Increase in C content of fly ash Increase in GGBFS in cement Increase in silica fume content	Increase in air-entraining agent needed
Water reducers	Increase air % in the presence of air-entraining agent
Retarders	Increase air %

… more factors that influence the % air of concrete

Factor	Result
Accelerators	Negligible
Increase in maximum size of aggregate	Decrease air %
Increase in sand-total aggregate ratio	Increase air %
Increase in middle size fraction of sand (No. 30 to 100)	Increase air %
Increase in w/c	Increase air % with use of air-entraining agent

… yet even more factors that influence the % air of concrete

- **Pigments (specifically black)**
- **Mixer capacity**
- **Mixing time**
- **Mixing speed**
- **Sequence of materials addition**
- **Agitation**
- **Placement method (belt, pump, etc.)**
- **Vibration**
- **Finishing**
- **Temperature**
- **Dust on aggregate particles**
- **Hard mixing water**

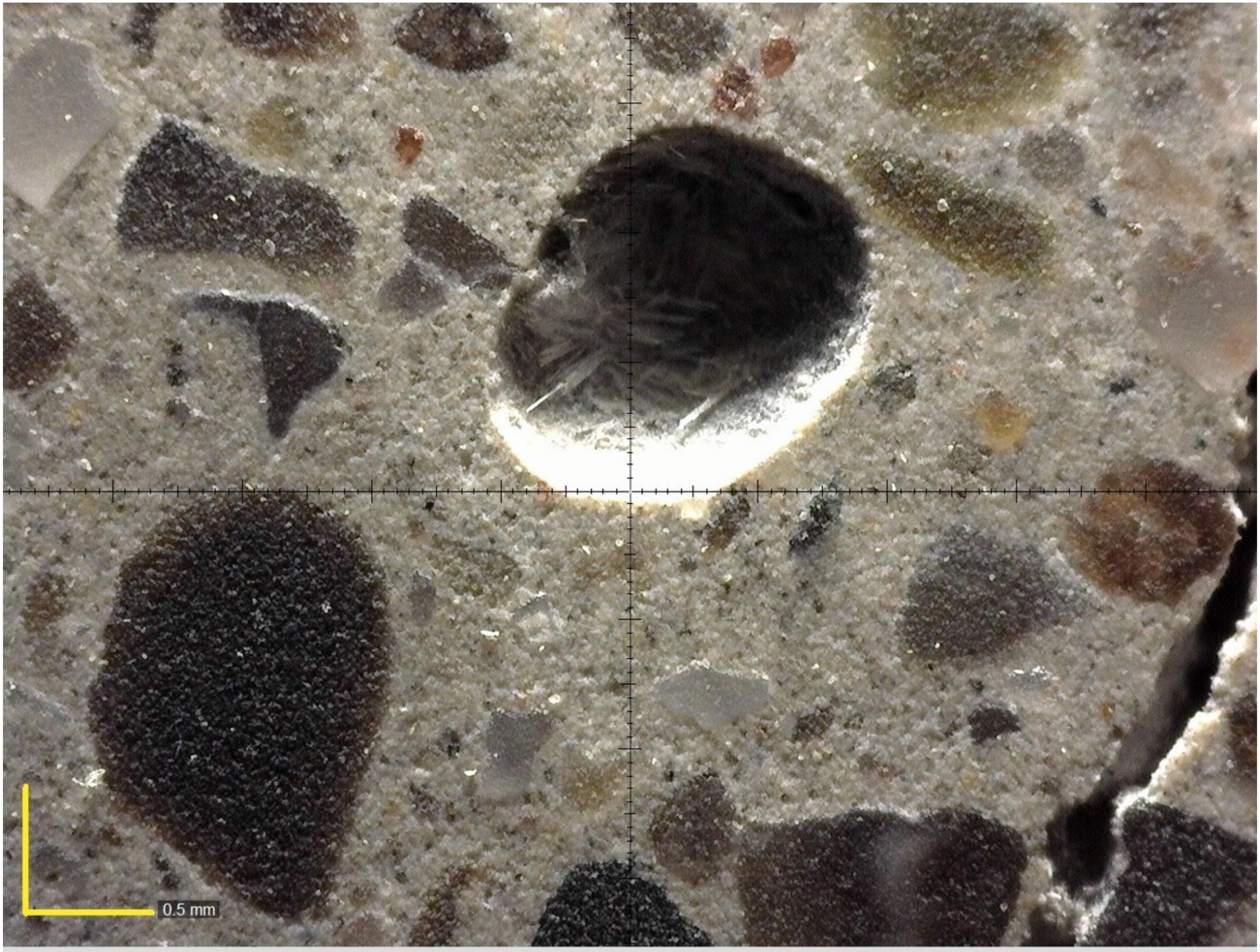
Can the total % air in hardened concrete INCREASE over time?

Can the total % air in hardened concrete INCREASE over time?

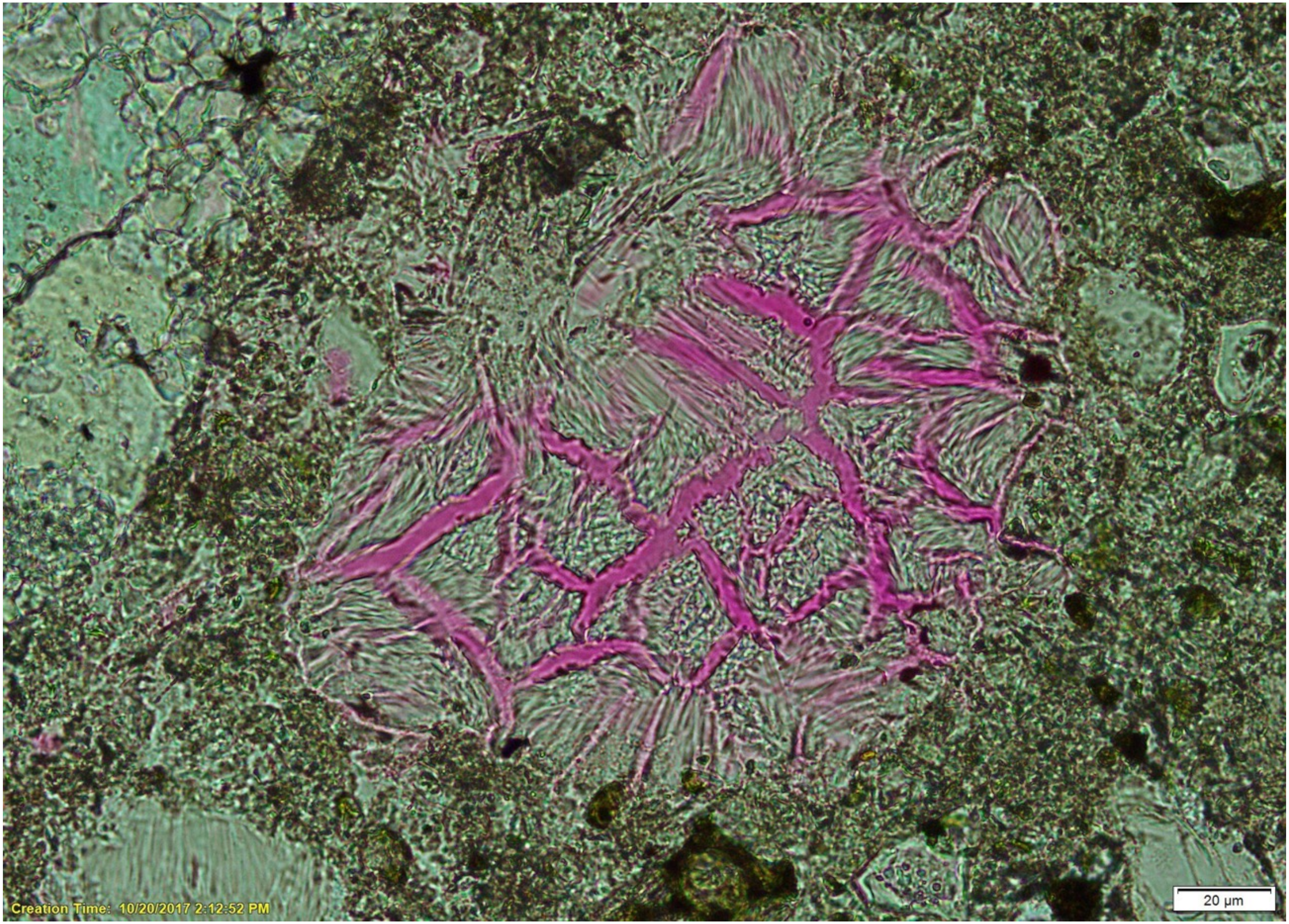
no

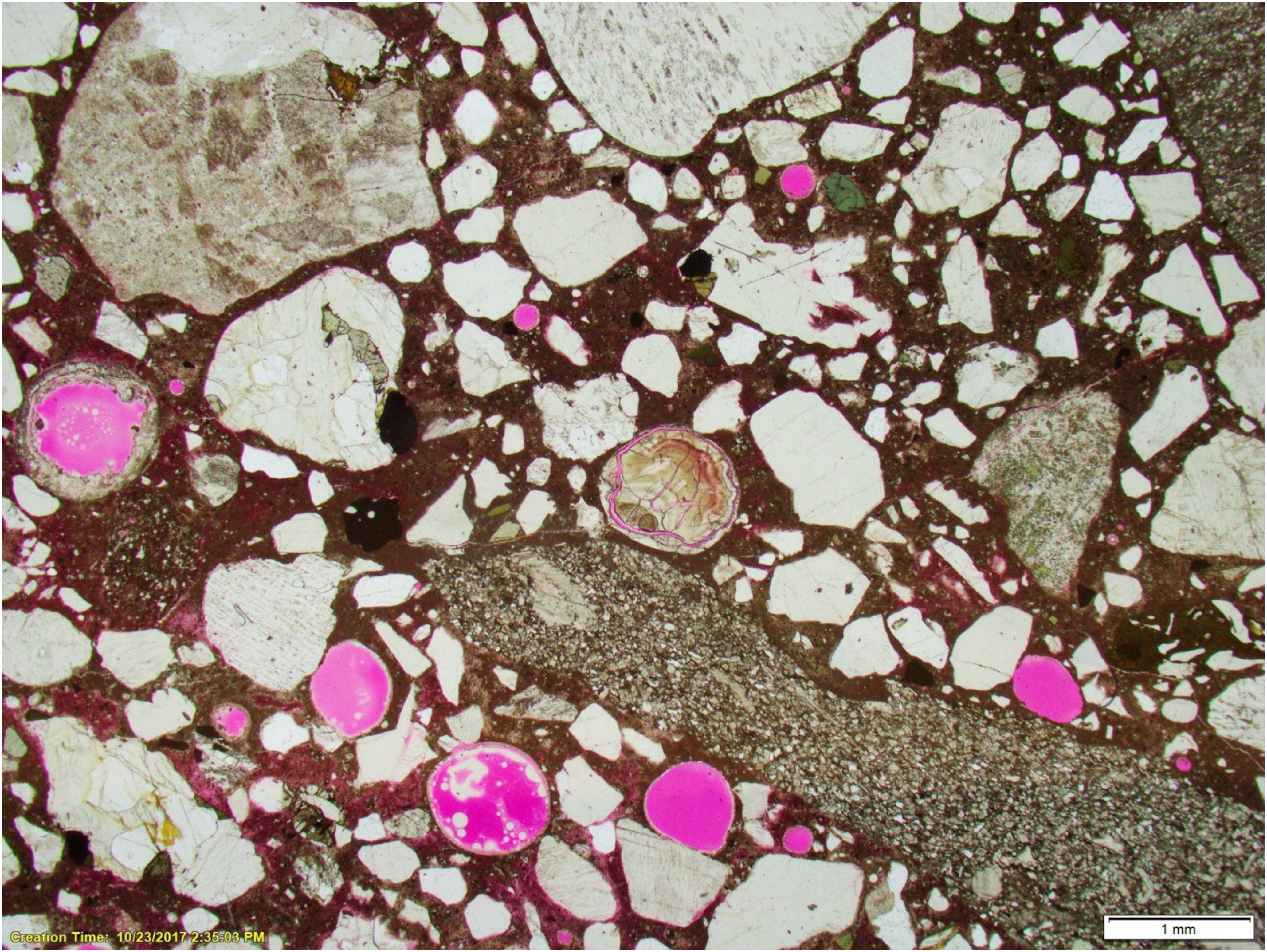
Can the total % air in hardened concrete DECREASE over time?

Can the total % air in hardened concrete DECREASE over time?



Can the total % air in hardened concrete DECREASE over time?

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Can the total % air in hardened concrete DECREASE over time?

Can the total % air in hardened concrete DECREASE over time?

yes

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