Research on cements
The Williamson Morphology

- Originally described by Prof. Brady Williamson (U.C. Berkeley).
- He referred to the morphology as “sheaf-of-wheat”.

![Image of Prof. Brady Williamson](image)
The C-S-H growth mechanism that results in the Williamson morphology:

- An initial product nucleates on the silica surface. This initial product is essentially crystalline.
- Outward growth of this product continues in all directions, but is favored along either the a-axis or the b-axis.
- As growth continues further from the silica source, the products formed have a higher Ca/Si ratio due to the lower silica and higher calcium concentrations.
The C-S-H growth mechanism that results in the Williamson morphology:

- The lower silica content at the growing extremities produces silicate defects between the lamellae, resulting in “unfurling” of the sheaf at the ends, leading to the appearance of ribbons “bundled” at the center.
- The growth rates become limited by the rate at which silica can diffuse to the growing extremities.
- Increased silica concentrations around the central plane of the sheaf tend to cause the ribbons to grow towards that area, resulting in a spherulitic morphology.
The Williamson morphology observed in the SEM
The Williamson morphology observed in the soft x-ray microscope

X-ray image of ASR gel in saturated Ca(OH)$_2$ solution after 30 minutes
The Williamson morphology observed in the soft x-ray microscope

Two X-ray microscopy images of the evolution of the sheaf-of-wheat morphology during the reaction of chemical grade silica gel in a solution of 0.7 M NaOH+0.1 M CaCl$_2$ after 10 min (a) and 19 min (b). Exposure times for the X-ray images measured 3 and 36 s with beam currents of 347.3 and 335.7 mA, respectively. Original magnification was 2400×. Scalebar=0.5 µm.
To learn more:

TEM Nanotomography of C-S-H

Taylor et al, JACers, 2015
TEM Nanotomography – Closer look

Taylor et al, JACers, 2015
Soft X-Ray Microscopes

**Full-Field Microscope**
- Best spatial resolution
- Modest spectral resolution
- Shortest exposure time
- Bending magnet radiation
- Higher radiation dose
- Flexible sample environment (wet, cryo, labeled magnetic fields, electric fields, cement, ...)

**Scanning Microscope**
- Least radiation dose
- Good spatial resolution
- Best spectral resolution
- Requires spatially coherent radiation
- Long exposure time
- Flexible sample environment
- Photoemission (restricted magnetic fields), fluorescence imaging
Nucleation

nanosilica

1μm


The molecular model of C–S–H (I) obtained by reverse Monte Carlo refinement. The initial structure is based on Hamid 1.1 nm tobermorite crystal structure.

X-ray structure factor $S_x(Q)$ of synthetic C–S–H (I)

The final structure is refined to be consistent with the measured data. Green polyhedral: CaO, blue tetrahedral: SiO, red spheres: inter layer O from water, green spheres: interlayer Ca.

X-ray pair distribution function of synthetic C–S–H (I) has no correlated structure beyond 3.5 nm