Potential problems with SCMs
- Possibly significant delay in early strength gain, especially in cold-weather concreting, that can affect sawing operations.
- Increased risk of flash set with class C fly ash because it is high in calcium aluminates.
- Interference with development of air-void system (especially very fine fly ashes with high loss-on-ignition).
- Perhaps increased potential for frost damage (with fly ash or GGBF slag).

Water Reducers
How they work
Disperse cement clasters, freezing trapped water which can then react (hydrate) with cement.

How they affect hydration
More of the mix cement is hydrated, resulting in a greater volume of hydration products.

Potential benefits
- Possibly increased initial workability.
- Possibly increased air entrainment (polycarboxylate water reducers only).
- Reduced concrete permeability, increased durability.

Cement Hydration: The Basics
Cement hydration is a series of irreversible chemical reactions between cement and water. During hydration, the cement-water paste sets and hardens, “gluing” the aggregate together in a solid mass. Cement hydration is central to the formation of concrete. It influences how the plastic concrete behaves when it is being placed and finished and governs how strong and durable the hardened concrete becomes. During the first 72 hours after mixing, concrete can often gain 50 percent of its strength or more. During that time, it is especially susceptible to stresses that may cause cracking because it has not gained its full strength.

Why is it Important?
Cement hydration is central to the formation of concrete. It influences how the plastic concrete behaves when it is being placed and finished and governs how strong and durable the hardened concrete becomes. During the first 72 hours after mixing, concrete can often gain 50 percent of its strength or more. During that time, it is especially susceptible to stresses that may cause cracking because it has not gained its full strength.

Understanding the basics of hydration will help readers recognize and mitigate the stresses to control and/or prevent cracking and to appreciate the importance of good curing and construction practices.

Potential benefits of SCMs
- Set Retarders
  How they work
  Coat cement particles so they dissolve more slowly.
  How they affect hydration
  - Slow hydration.
  - Reduce heat peak and extend hydration and heat generation (similar to water reducers).

Potential problems with SCMs
- Generally result in a finer, less permeable microstructure, increased strength, and durability.
- Lower heat of hydration can be useful in hot-weather paving projects.
- Extended haul times or other accommodations to production cycles.

Potential problems
- Possibly reduced rate of alite hydration and thus strength gain.
- Possibly short sawing window, increasing the risk of cracking.

Primary Compounds in Cement
Clinker consists primarily of calcium aluminates and calcium silicates (in this summary, aluminates and silicates):
- Calcium (as in teeth) aluminates (in aluminum):
  - Tricalcium aluminate (C$_3$A), ferrite (C$_4$AF).
- Aluminates reduce the amount of heat required for the manufacture of clinker.
- Aluminates (as in glass: alite (C$_3$S), belite (C$_2$S)).
  The calcium sulfate (CS) as in sulfur, the smell of rotten eggs) is primarily gypsum, but it is also present as plaster and anhydrate.

During cement hydration, products of aluminate reactions contribute to early stiffening of concrete; and products of silicate reactions contribute to concrete's strength.
Five Stages of Hydration

To simplify this discussion, chemical reactions between the various compounds in portland cement and water are described in five stages. The stages are illustrated by a curve that represents changes in heat during the first hours and days of hydration (figure 2).

Stage 1: Mixing (< 15 minutes)

What is happening
- Aluminates dissolve and react quickly, with high heat.
- Sulfate dissolves quickly, too. It reacts with aluminate and water, forming a gel (C-A-S-H, a precursor to ettringite).
- The gel limits water's access to aluminate (figure 3).
- Reactions slow. Heat drops.
- Sulfate is included in cement primarily to control aluminate reactions as just described. However,
  - Too little sulfate in solution can result in immediate hardening of the mix, or flash set—rare but permanent.
  - Too much sulfate in solution can precipitate out, causing temporary stiffening of the mix, or false set. False set can generally be corrected by additional mixing.
  - Different forms of sulfate result in different amounts of sulfate ions in solution.

Implications
The correct balance of sulfate (amount and form of CS) to aluminate is necessary to prevent flash set and false set.

Stage 2: Dormancy (2–4 hours)

What is happening
- While the C-A-S-H gel controls aluminate reactions, the concrete is cool, plastic, and workable.
- During this dormant period, the silicates (alite and belite) slowly dissolve, releasing calcium ions in solution (figure 4).

Implications
- During dormancy—the period when the mix can be transported, placed, finished, and textured.

Stage 3: Hardening (2–4 hours)

What is happening
- The solution eventually becomes supersaturated with calcium ions, triggering the formation of new compounds:
  - Calcium silicate hydrate (C-S-H, fiber-like particles), which adheres to aggregate and gives concrete its strength.
  - Calcium hydroxide (CH, crystals).
- Formation of C-S-H and CH generates heat, causing thermal expansion.
- "Initial set" occurs when enough C-S-H and CH form to mesh together, causing the mix to stiffen (figure 3).
- As these products continue to mesh, the concrete begins developing some strength.
- "Final set" occurs when the concrete achieves a defined stiffness, about when the concrete is hard enough to walk on.
- The gel-like C-A-S-H transforms into a needle-like solid (ettringite) that contributes somewhat to early strength.

Implications
- It is critical to apply curing compound thoroughly (or conduct other curing practices) as soon as possible after finishing, before the concrete begins hardening.

Stage 4: Cooling (several hours)

What is happening
- Soon after final set, the buildup of C-S-H and CH begins to limit access of water to undissolved cement (figure 6).
- Silicate reactions slow. Heat peaks and begins to drop.
- As it cools, concrete contracts. Movement of the contracting slab is restrained by the subgrade, causing tensile stress to develop in the slab.
- At some point the stress will become greater than the concrete's strength. The concrete will crack.

Implications
- Before the concrete cracks randomly, joints must be sawed to control the crack locations.
- For early-age saws, the "sawing window" may begin slightly before final set. For conventional saws, the window generally begins after final set.

Stage 5: Densification (can continue for years)

What is happening
- Belite dissolves and reacts more slowly than alite.
- During stage 5, belite reactions start to have an impact on the slab. They can continue for years.
- Belite reactions also produce C-S-H and CH, forming a solid mass (figure 7).
- The longer the cement in concrete hydrates (that is, belites and any remaining alites react with water), the greater the concrete's strength.
- The lower its permeability.
- The greater its potential durability.

Implications
- To promote continued hydration, moisture must be retained in the slab as long as possible.
- Therefore, after finishing, curing compound should be applied uniformly and at recommended coverage rates, then protected from weather and construction traffic as long as possible.

Effects of Other Materials on Hydration

Most mixes today include supplementary cementsitious materials (SCMs), economical materials that can enhance certain concrete properties. These may include class C fly ash, class F fly ash, and/or ground, granulated blast-furnace (GGBF) slag. Other common admixtures are water reducers, set retarders, and set accelerators.

Certain combinations of perfectly acceptable SCMs and chemical admixtures may react in undesirable ways. Such materials incompatibilities are described in Technical Summary 4b.

SCMs
How they work
In general, SCMs convert CH (a somewhat less desirable product of hydration) into C-S-H (which gives concrete its strength).