LEcTLe 2. PORTLAND CEMENT

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Lecture 2. Portland cement

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2.1 Cement: definitions

**Portland cement**: Hydraulic cementitious material based on clinker, a material composed of calcium silicates and aluminates, and a small amount of added gypsum/anhydrite. The cement is made by burning mixtures of limestone and argilaceous rocks (slates).

**Composite cements (Blended cements)**: Some types of cement are mixtures of Portland cement with other material, such as blastfurnace slag (BFS) from iron production, pulverised fuel ash (FA) from coal-fired electricity power stations or silica fumes. The use of blended cement reduces water demand and therefore water-cement ratio can be reduced, improves workability for the same water content. The blended cements are finer as compared to OPC, therefore the permeability of concrete is less. This results into improved durability.

**Cement clinker**: is a dark grey nodular material made by heating ground limestone and clay at a temperature of about 1400 °C - 1500 °C. The nodules are ground up to a fine powder to produce cement, with a small amount of gypsum added to control the setting properties. Nodules range in size from 1mm to 25mm or more and are composed mainly of calcium silicates, typically 70%-80%. Portland cement clinker contains four principal minerals: (i) Alite (tricalcium silicate), (ii) Belite (dicalcium silicate), (iii) Aluminate(tricalcium aluminate) and (iv) Ferrite (tetracalcium aluminoferrite)

**Setting time**: The transition from fresh cement paste to hardened cement paste. The terms “initial set” and “final set” refer to specific times when the paste becomes no longer workable and completely rigid, respectively. “Setting” is the process by which transition occurs.

**Hydration**: The chemical reactions between cement and water. Hydration is what causes cement paste to first set and then harden.

**Hydration products**: The new solid phases that are formed by hydration.

**Heat of hydration**: Like most spontaneous chemical reactions, the hydration reactions between cement and water are exothermic, meaning that they release heat. Large volumes of concrete can warm up considerably during the first few days after mixing when hydration is rapid.

**Cement paste**: Mixture of Portland cement and water alone (used for filling cracks and sealing small spaces)

**Mortar**: Mixture of Portland cement, fine sand and water (used for example for the construction of brick walls)

**Concrete**: Mixture of Portland cement, coarse and fine aggregates (rock pebbles, sand), water and chemical additives. The mechanical strength can be reinforced by the insertion of steel bars.
2.2 Portland cement production

Cement is the hydraulic binder (hydraulic = hardening when combined with water) which is used to produce concrete. Cement paste (cement mixed with water) sets and hardens by hydration, both in air and under water. The main base materials for Portland cement, are limestone, marl and clay, which are mixed in defined proportions. This raw mix is burned at about 1450 °C to form clinker, which is later ground to the well-known fineness of cement.

![Diagram](image_url)

Figure 2-1. Schematic overview of the Portland cement manufacturing.

### 2.2.1 Raw materials:

Table 2-1. The fundamental chemical compounds to produce cement clinker.

<table>
<thead>
<tr>
<th>Chemical Components</th>
<th>Typical Raw Materials</th>
<th>Formula</th>
<th>Shorthand form</th>
<th>% by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime or Calcium oxide</td>
<td>Limestone (CaCO3), chalk, shells, shale or calcareous rock</td>
<td>CaO</td>
<td>C</td>
<td>60 – 67%</td>
</tr>
<tr>
<td>Silica</td>
<td>sand(SiO2), shale, clay or argillaceous rock</td>
<td>SiO2</td>
<td>S</td>
<td>17 – 25%</td>
</tr>
<tr>
<td>Alumina</td>
<td>bauxite, recycled aluminum, clay</td>
<td>Al2O3</td>
<td>A</td>
<td>3 - 8%</td>
</tr>
<tr>
<td>Iron</td>
<td>clay, iron ore, scrap iron and fly ash</td>
<td>Fe2O3</td>
<td>F</td>
<td>0.5 – 6.0%</td>
</tr>
<tr>
<td>Sulfate</td>
<td>Gypsum, CaSO₄·2H₂O found together with limestone</td>
<td>SO₃</td>
<td>Š</td>
<td>0.5 – 1.3%</td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td>H2O</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.2.2 Manufacturing process:

Manufacturing process of cement include three steps:

1. Mixing and crushing of raw materials
   a. Dry process
   b. Wet process
2. Burning
3. Grinding

4. Figure 2-2. Portland cement manufacturing (dry / wet) process (1).

(1.a) Mixing and crushing of raw materials - Dry process:

- In the dry process calcareous material such as lime stone (calcium carbonate) and argillaceous material such as clay are ground separately to fine powder in the absence of water and then are mixed together in the desired proportions.
- Water is then added to it for getting thick paste and then its cakes are formed, dried and burnt in kilns.
- Dry process is usually used when raw materials are very strong and hard.
- In the dry process, the raw materials are changed to powdered form in the absence of water.
- About 75% of cement is produced using the dry process

(1.b) Mixing and crushing of raw materials - Wet process:

- In the wet process, the raw materials are changed to powdered form in the presence of water.
- Raw materials are pulverized by using a Ball mill, which is a rotary steel cylinder with hardened steel balls. When the mill rotates, steel balls pulverize the raw materials which form slurry (liquid mixture). The slurry is then passed into storage tanks, where correct proportioning is done.

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Proper composition of raw materials can be ensured by using wet process than dry process. Corrected slurry is then fed into rotary kiln for burning.

Wet process is generally used when raw materials are soft because complete mixing is not possible unless water is added.

About 25% of cement is produced using the wet process.

(2) Burning:

Corrected slurry is fed to rotary kiln, which is about 1.5 m in diameter and 15 m in length and temperature arrangement is up to 1500-1650 °C. At this temperature slurry losses moisture and forms into small lumps, after that changes to clinkers. Clinkers are cooled in another inclined tube similar to kiln but of lesser length.

(3) Grinding:

Grinding is the final process where clinker is grinded, it is first cooled down to atmospheric temperature. Grinding of clinker is done in large tube mills. After proper grinding gypsum (Calcium sulphate Ca SO₄) in the ratio of 01-04 % is added for controlling the setting time of cement.

Finally, fine ground cement is stored in storage tanks from where it is drawn for packing.

Fineness of Portland cement

- Most of the cement particles have a size of between 2 and 80 μm.
- The surface area per unit weight values of most cements in common use range from about 300 to 400 m²/kg.
- The fineness of cement affects the rate of hydration and thus the rate of strength gain.
- Greater fineness increases the surface available for hydration, causing greater early strength and more rapid generation of heat.
- The coarser cement will result in higher ultimate strength and lower early strength gain of mortar.

Figure 2-3. Schematic diagram of cement compounds
## 2.3 Chemical compounds of Portland cement

The proportions of the chemical compounds of cement vary in the various Portland cements. Table 2-2 presents the composition and percentage of found compounds for Portland cement.

### Table 2-2. Chemical compounds of cement clinker.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Formula</th>
<th>Shorthand form</th>
<th>% by weight</th>
<th>Properties of cement compounds</th>
</tr>
</thead>
</table>
| Alite or tricalcium silicate | Ca$_3$SiO$_4$ | C$_3$S         | 50 - 70%    | ▪ It is responsible for early strength  
▪ First 7 days strength is due to C$_3$S  
▪ It produces more heat of hydration  
▪ Cement with more C$_3$S is better for cold weather concreting. |
| Belite or dicalcium silicate | Ca$_2$SiO$_5$ | C$_2$S         | 15 - 30%    | ▪ C$_2$S hydrates after 7 days. Hence, it gives strength after 7 days.  
▪ C$_2$S hydrates and harden slowly and provides much of the ultimate strength  
▪ It produces less heat of hydration.  
▪ Responsible for long term strength |
| Tricalcium aluminate       | Ca$_3$Al$_2$O$_6$ | C$_3$A       | 5 - 10%     | ▪ The reaction of C$_3$A with water is very fast and may lead to an immediate stiffening of paste, and this process is termed as flash set.  
▪ To prevent this flash set, 2 to 3% gypsum is added at the time of grinding the cement clinkers.  
▪ C$_3$A liberates a lot of heat during the early stages of hydration, but has little (almost none) strength contribution.  
▪ Cement low in C$_3$A is sulfate resistant. |
| Tetracalcium aluminoferrite | Ca$_4$Al$_2$Fe$_2$O$_{10}$ | C4AF   | 5-15%       | ▪ It hydrates very rapidly.  
▪ Contributes very little strength of concrete even though  
▪ Also responsible for grey colour of Ordinary Portland Cement  
▪ The hydrates of C4AF show a comparatively higher resistance to sulphate attaches than the hydrates of C3A |
| Sodium oxide              | Na$_2$O       | N             | 0.5 - 1.3%  |                                                                                                 |
| Potassium oxide           | K$_2$O        | K             |             |                                                                                                 |
| Gypsum                    | CaSO$_4$.2H$_2$O | CSH$_2$     |             |                                                                                                 |

### The Bogue calculation of cement mineral composition:

A simple estimate of the phase composition of a portland cement can be obtained from the oxide composition, shown in Table 2-1, if it is assumed that the four main cement clinker minerals occur in their pure form. With this assumption, all of the Fe$_2$O$_3$ is assigned to C4AF and the remaining Al$_2$O$_3$ is assigned to C3A. This leaves a set of two linear equations to be solved for the amounts of C2S and
C3S. This method is named after the cement chemist R.H. Bogue. There are two sets of equations, based on the ratio of $\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3$ (A/F) in the cement (both inputs and outputs are in weight percent):

a) If $\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3$ (A/F) > 0.64

\[
\begin{align*}
\text{C}_3\text{S} &= 4.071\text{C} - 7.600\text{S} - 6.718\text{A} - 1.430\text{F} - 2.852\hat{S} \\
\text{C}_2\text{S} &= 2.867\text{S} - 0.7544\text{C}_3\text{S} \\
\text{C}_3\text{A} &= 2.650\text{A} - 1.692\text{F} \\
\text{C}_4\text{AF} &= 3.043\hat{F} \\
\end{align*}
\]

b) If A/F < 0.64

\[
\begin{align*}
\text{C}_3\text{S} &= 4.071\text{C} - 7.600\text{S} - 4.479\text{A} - 2.859\text{F} - 2.852\hat{S} \\
\text{C}_2\text{S} &= 2.867\text{S} - 0.7544\text{C}_3\text{S} \\
\text{C}_3\text{A} &= 0 \\
\text{C}_4\text{AF} &= 2.100\text{A} + 1.702\text{F} \\
\end{align*}
\]

2.4 Hydration of Portland cement

- Hydration is a series of irreversible exothermic chemical reactions between cement and water
- Cement-water paste sets and hardenes, gluing the aggregates together in a solid mass
- Complete hydration of Portland cement generates $300-500$ J/g
- Temperature in large structures can rise up to 80 – 100 °C, which can cause surface cracking
- Formation of hydration products over time leads to:
  - Stiffening (loss of workability)
  - Setting (Solidification)
  - Hardening (Strength gain)

2.4.1 Hydration mechanisms

There are two primary mechanisms for the cement hydration, topochemical and through-solution reaction as shown in Figure 2-4 [²], [³].

---

Topochemical or solid-state hydration

- Reactions take place directly at the surface of the un-hydrated cement compounds without going into solution.

![Diagram of topochemical reaction and through-solution mechanism](image)

Figure 2-4. Schematic representation of proposed hydration mechanisms

Through-Solution Concept

- Involves dissolution of un-hydrated cement compounds to their ionic constituents (Ca$^{+2}$, Al$^{+3}$, SiO$^-_4$) formation of hydrates in solution, and eventual precipitation due to their low solubility.

When water is added to cement, what happens?

- Dissolution of cement grains
- Growing ionic concentration in “water” (now a solution)
- Formation of cement compounds in solution
- After reaching a saturation concentration, compounds precipitate out as solids (“hydration products”)
- In later stages, products form on or very near the surface of the anhydrous cement

![Diagram of cement hydration process](image)

Figure 2-5. Cement hydration process
2.4.2 Stages of cement hydration

To simplify the hydration process, 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 (shown in Figure 2-6) [4].

Stage (1): Initial reactions

- several dissolution and hydration reactions
- reactions of C3A with gypsum
- duration 10 – 20 minutes after addition of water

Stage (2): Induction phase

- low reaction rates
- ettringite hinders C3A reaction
- member-osmosis theory
- duration 2 – 4 hours at 20 °C → transporting, casting and finishing of concrete
- setting begins at the end of this phase

Stage (3): Accelerating phase

- increasing reaction rate

---

beginning of C3S hydration
compressive strength growth begins
duration from 5 – 10 hours after addition of water

**Stage (4): Decelerating phase**
- products generated during hydration of C3A are attached onto cement particles
- hydration products are larger than clinker mineral particles
- water space around particles is filled up
- reaction rate decreases
- C3A reaction peak noticed after gypsum is consumed
- Ettringite begins to decompose to monosulfate

**Stage (5): Steady state (can continue for years)**
- Belite (C2S) dissolves and reacts more slowly than alite (C3S).
- Belite reactions also produce C-S-H and CH, forming a solid
- The longer the cement in concrete hydrates (that is, belites and any remaining alites react with water), the greater the concrete’s strength and the lower the permeability.
2.4.3 Cement hydration reactions

- The C3A and C3S phase are the most reactive phases, despite the presence of gypsum which is added mainly to control the reaction of the aluminate.
- In the absence of gypsum or other sulfate, the C3A would react extremely quickly and setting of the cement would occur in minutes – a process known as flash set.
- The rate of reaction of the ferrite phase in the presence of gypsum is somewhat slower than that of the C3S.
- C2S – or belite – reacts more slowly than the other compounds.

Figure 2-7. Rate of hydration of cement compounds in portland cement paste

<table>
<thead>
<tr>
<th>Atomic Mass</th>
<th>Chemical compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Element</strong></td>
<td><strong>Formula</strong></td>
</tr>
<tr>
<td>Ca</td>
<td>CaO</td>
</tr>
<tr>
<td>Si</td>
<td>SiO2</td>
</tr>
<tr>
<td>O</td>
<td>Al2O3</td>
</tr>
<tr>
<td>H</td>
<td>Fe2O3</td>
</tr>
<tr>
<td>S</td>
<td>SO3</td>
</tr>
<tr>
<td>Al</td>
<td>H2O</td>
</tr>
<tr>
<td>Fe</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2-8. The atomic mass of the cement elements and the chemical compounds of cement clinker used in the cement hydration reactions.
2.4.3.1 Tricalcium aluminate (C3A) reactions

In reactions without gypsum.

C3A react with water generating tricalcium aluminate hydrate

\[
\begin{align*}
\text{C}_3\text{A} &\quad + \quad \text{6H} &\rightarrow \text{C}_3\text{AH}_6 \\
\text{Tricalcium aluminate} &\quad +\text{Water} &\rightarrow \text{tricalcium aluminate hydrate} \\
\text{Total atomic mass:} &\quad + \quad 108.09 &\rightarrow \quad 336.405 \\
\text{Clinker} = 1 \text{ g} &\quad \text{Water} /1\text{g clinker} &\rightarrow \quad 1.40 \text{ g} \\
&\quad (\text{H} + 0.40 \text{ g}) &\rightarrow \quad 1.40 \text{ g} \\
\end{align*}
\]

C3A react with water generating dicalcium aluminate hydrate and tetracalcium aluminate hydrate

\[
\begin{align*}
\text{C}_3\text{A} &\quad + \quad \text{27H} &\rightarrow \text{C}_2\text{AH}_8 \\
\text{Tricalcium aluminate} &\quad +\text{Water} &\rightarrow \text{di}\text{calcium aluminate hydrate} \\
&\quad + \quad \text{C}_4\text{AH}_{19} &\rightarrow \text{tetra}\text{calcium aluminate hydrate} \\
1 \text{ g} &\quad + \quad 0.90 \text{ g} &\rightarrow \quad 0.66 \text{ g} \\
&\quad + \quad 1.25 \text{ g} &\rightarrow \quad 0.66 \text{ g} \\
\end{align*}
\]

In reactions with gypsum.

The tricalcium aluminate reacts with the gypsum in the presence of water to produce ettringite (trisulfate- Aft) and heat.

Ettringite consists of long crystals that are only stable in a solution with gypsum. The compound does not contribute to the strength of the cement glue.

\[
\begin{align*}
\text{C}_3\text{A} &\quad + \quad 3\text{C}\text{SH}_2 &\rightarrow \text{C}_6\text{A}\$$_3\text{H}_{32} \\
\text{Tricalcium aluminate} &\quad +\text{gypsum} &\rightarrow \text{ettringite (trisulfate)} \\
1 \text{ g} &\quad + \quad 2.08 \text{ g} &\rightarrow \quad 4.82 \text{ g} \\
&\quad + \quad 1.73 \text{ g} &\rightarrow \quad 4.82 \text{ g} \\
\end{align*}
\]

Once all the gypsum is consumed as per reaction above, the ettringite becomes unstable and reacts with the remaining tricalcium aluminate to form monosulfate crystals.

\[
\begin{align*}
2\text{C}_3\text{A} &\quad + \quad \text{C}_6\text{A}\$$_3\text{H}_{32} &\rightarrow 3(\text{C}_4\text{A}\$$_4\text{H}_{12}) \\
\text{Tricalcium aluminate} &\quad +\text{ettringite} &\rightarrow \text{monosulfate} \\
1 \text{ g} &\quad + \quad 2.41 \text{ g} &\rightarrow \quad 4.14 \text{ g} \\
&\quad + \quad 0.13 \text{ g} &\rightarrow \quad 4.14 \text{ g} \\
\end{align*}
\]

- 2–5 % gypsum retards C3A hydration reaction
- Ettringite is formed on the C3A patch of the cement grain and hinders its reaction. Ettringite needles are stable as long as there is unreacted gypsum in mix water
- Thereafter ettringite reacts with C3A and generates monosulfate
- When ettringite patch disintegrates hydration of C3A begins
2.4.3.2 **Tricalcium silicate (C3S) reaction**

The tricalcium silicate (alite) is hydrated to produce calcium silicate hydrates, calcium hydroxide (CH) and heat. The CSH has a short-networked fiber structure, which contributes greatly to the initial strength of the cement glue.

\[
2\text{C}_3\text{S} + 6\text{H} \rightarrow \text{C}_3\text{S}_2\text{H}_3 + 3\text{CH}
\]

**Tricalcium silicate**

\[1 \text{ g} + 0.37 \text{ g} \rightarrow 0.78 \text{ g} + 0.90 \text{ g}\]

2.4.3.3 **Tetracalcium alumino ferrite (C4AF) reactions**

The Tetracalcium alumino ferrite reactions are similar reaction as with C3A, but slower.

The ferrite undergoes two progressive reactions with the gypsum:

- in the first of the reactions, the tetracalcium alumino ferrite (C4AF) reacts with the gypsum and water to form ettringite, calcium hydroxide and alumina hydroxides.

\[
\text{C}_4\text{AF} + 3\text{C}_3\text{S}_2\text{H}_3 + 3\text{O} \rightarrow \text{C}_6\text{A}_3\text{H}_{32} + \text{CH} + \text{FH}_3
\]

**Tetracalcium aluminate ferrite**

\[1 \text{ g} + 1.16 \text{ g} + 1.11 \text{ g} \rightarrow 2.68 \text{ g} + 0.15 \text{ g} + 0.44 \text{ g}\]

- the ferrite further reacts with the ettringite formed above to produce monosulfate.

- The monosulfate only take up space and do not - in any way- contribute to the strength of the cement paste.

\[
2\text{C}_4\text{AF} + \text{C}_6\text{A}_3\text{H}_{32} + 12\text{H} \rightarrow 3(\text{C}_4\text{A}_3\text{H}_{12}) + 2\text{CH} + 2\text{FH}_3
\]

**Tetracalcium aluminate ferrite**

\[1 \text{ g} + 1.34 \text{ g} + 0.22 \text{ g} \rightarrow 1.97 \text{ g} + 0.15 \text{ g} + 0.44 \text{ g}\]
2.4.3.4  Dicalcium silicate (C2S) reaction

The belite (dicalcium silicate) also hydrates to form calcium silicate hydrates and heat

\[
2\text{C}_3\text{S} + 4\text{H} \rightarrow \text{C}_3\text{S}_2\text{H}_3 + \text{CH}
\]

Tricalcium silicate + water \rightarrow tobermorite + calcium hydroxide

1 g +0.21 g \rightarrow 0.99 g +0.22 g

Reduction of the volume of pore space and the formation of reaction products with time are shown in Figure 2-9.

Figure 2-9. Schematic illustration of formation of reaction products and reduction of the volume of pore space with time in a portland cement paste.

2.4.4  Temperature and strength development during hydration

Concrete temperature is primarily determined by the cement hydration process and by heat exchange with the surrounding environment. The hydration process reflects the characteristics of concrete materials and mix proportions as well as the change in construction practices and environmental conditions. Cement hydration also consequently influences concrete workability, setting behavior, strength gain rates, and pore structures.

2.4.4.1  Heat of hydration

When Portland cement is mixed with water, heat is liberated. This heat is called the heat of hydration, the result of the exothermic chemical reaction between cement and water. The heat generated by the cement’s hydration raises the temperature of concrete.

During normal concrete construction, the heat is dissipated into the air and resulting temperature changes within the structure are not significant. However, in some situations, particularly in massive structures, such as dams, mat foundations, or any element more than about a meter thick, the heat can not be readily released. The mass concrete may then attain high internal temperatures, especially
during hot weather construction, or if high cement contents are used. Figure 2-10 demonstrates the effect of element size on concrete temperature with time due to the heat of hydration.

![Figure 2-10. Effect of member thickness on temperature of concrete](image)

As a rule of thumb, the maximum temperature differential between the interior and exterior concrete should not exceed 20°C to avoid crack development.

For the normal Portland cement:

- 50% of the total heat is liberated in 1-3 days
- 75% of the total heat is liberated at 7 days
- 83-91% at 180 days

**Factors affecting heat of hydration**

Materials can be selected to minimize or maximize the heat of hydration, depending on the need.

- Cements with higher contents of tricalcium silicate and tricalcium aluminate, as well as a higher fineness have higher rates of heat generation than other cements.
- Sulfate content, in its relation to controlling the hydration of calcium aluminate, participates in the rate of heat liberation.
- Higher fineness provides a greater surface area to be wetted, resulting in an acceleration of the reaction between cement and water. This causes an increase in the rate of heat liberation at early ages, but may not influence the total amount of heat developed over several weeks.
- Other factors influencing heat development in concrete include the cement content, water-cement ratio, placing and curing temperature, the presence of mineral and chemical admixtures, and the dimensions of the structural element.
### Table 2-3. Characteristics of hydration of the cement compounds

<table>
<thead>
<tr>
<th>Compounds</th>
<th>Reaction rate (setting)</th>
<th>Amount of Heat Liberated</th>
<th>Strength Development</th>
<th>Resistance to Chemical attack</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_3S$</td>
<td>rapid (hours)</td>
<td>medium (120 cal/g)</td>
<td>rapid (days)</td>
<td>low</td>
</tr>
<tr>
<td>$C_2S$</td>
<td>slow (days)</td>
<td>low (60 cal/g)</td>
<td>slow (weeks)</td>
<td>moderate</td>
</tr>
<tr>
<td>$C_3A + C_5H_2$</td>
<td>instantaneous</td>
<td>very high (200 cal/g)</td>
<td>very Rapid (1day)</td>
<td>very low</td>
</tr>
<tr>
<td>$C_4AF + C_5H_2$</td>
<td>very rapid (min)</td>
<td>medium (100 cal/g)</td>
<td>very Rapid (1day)</td>
<td>high</td>
</tr>
</tbody>
</table>

NOTICE: Modelling of the temperature development will be presented in lecture 5 – properties of fresh concrete.

#### 2.4.4.2 Strength development for pure clinker minerals

The compressive strength development of pastes made of pure $C_3S$, $C_2S$, ($C_3A +$ gypsum) and ($C_4AF +$ gypsum) is presented Figure 2-11.

![Figure 2-11. Compressive Strength development in pastes of pure cement compounds.](Image)

The research results may be summarized as follows:

- C3S exhibits fairly rapid short-time strength development and subsequent gradual strength increase for at least 1 year.
- The initial strength development of C2S is sluggish, yet the strength increases gradually for at least 1 year and reaches reasonably high final values.
The strength of hydrated C3A is very low even after 1 year of hydration
C4AF exhibits a rapid short-term strength development but only a very moderate strength increase, or even a moderate strength decline later on.

NOTICE: Modelling of the strength development based on the heat of hydration will be presented in lecture 5 – properties of fresh concrete.

2.5 Volume of hydration products

Hardened paste consists of the following:

- Calcium Sulfoaluminate (Ettringite) 15 to 20%
- Calcium silicate hydrates, CSH 50 to 60%
- Calcium hydroxide (lime) 20 to 25%
- Voids (form of capillary voids and entrapped and entrained air) 5 to 6%

2.5.1.1 Microstructure of hydrated cement pastes

The development of cement microstructure relates to the five chemical stages described earlier in this lecture.

![Figure 2-12. Structure of hardened cement paste.](image)

Calcium silicate hydrate (C-S-H) -- the largest component of the cement paste (50-60%) and is the most important component in the hydration process. The amount of C-S-H coating on a C3S grain is very small during stage (2) of hydration and increases rapidly in stage (3). The spines of the forming C-S-H radiate outward from each grain with the bulk of the material below the spines. As the C-S-H hydrates further, the coating thickness grows forcing the outward spines of adjacent particles to interlock to form solid bonds. As hydration continues the intermeshed spines contribute to an increase in the undercoating of C-S-H growth. The effect is to bond the cement grains together with the C-S-H coating.

Calcium hydroxide (CH) -- constitutes 20-25% of the cement volume. In the acceleration stage, CH grows in the capillary pore space. CH will only grow in free space; on encountering another CH crystal it will grow in another direction; also it will grow completely around a hydrating cement grain. The latter effect gives the CH a larger apparent volume in cement pastes than it would have as a pure crystal.

Calcium Sulfoaluminate -- a small component of cement pastes (15-20%) having little effect on microstructure. Young spiny ettringite crystals grow into capillary space and later convert to flat monosulfoaluminate crystals. There will be unhydrated residues in the cement paste, mainly caused by calcium hydroxide, even in very matured hydrated pastes.

Porosity -- a major component of microstructure which will influence paste properties. Pore size distribution is difficult to measure. Many tests require drying, which affects the pore structure. The classifications of pore sizes are:

1) Capillary pore -- space formed between hydrating gains.
- Depend on initial separation of cement particles, which is controlled by the ratio of water to cement (w/c)
- On the order of 10 to 50 nm, although larger for higher w/c
  - Larger pores effect strength and permeability, whereas smaller pores impact shrinkage.

2) **Gel pores** -- very small spaces in the C-S-H coating. Constitutes the bulk of porosity in a cement paste.
   - Space between layers in C-S-H with thickness between 0.5 and 2.5 nm
   - Can contribute 28% of paste porosity
   - Little impact on strength, permeability, or shrinkage

3) **Trapped air (Air voids)**
   - In addition to the interlayer space and capillary voids, air can be trapped in the cement paste during mixing.
   - The trapped air reduces strength and increases permeability.
   - However, well-distributed, minute air bubbles can greatly increase the durability of the cement paste.
   - Admixtures are widely used to entrain air into the cement paste.

---

![Dimensional range of pores in a hydrated cement paste.](image)

---

2.5.1.2 The volumes of hydration products using Powers and Brownyard’s model

Water requirement in hydration is denoted by \( w_k \)

\[
w_k = \frac{\text{Weight of cemically bound water}}{\text{Weight of reacted clinker mineral}} = \frac{W_n}{C_{hyd}}
\]

On complete hydration of Portland cement the water amount bound chemically is \( w_k = 0.25 \)

\[
C_{hyd} = \alpha \times C
\]

Where: \( \alpha \) is the degree of hydration

\( C \) is the total amount of cement (kg/m³)

\[
\frac{W_n}{C_{hyd}} = \frac{W_n}{\alpha \times C} = 0.25
\]

The degree of hydration is estimated as:

\[
\alpha = \frac{W_n}{0.25 \times C}
\]

\( W_n \) = the amount of water that has been chemically combined into the hydration products (non-evaporable water)

The maximum degree of hydration is calculated based on the type of curing as follow:

1) without wet curing (no outside water)

\[
\alpha_{max} = \frac{\theta}{1.4 \times (1 - \theta)} \leq 1
\]

where \( \theta = \frac{w}{w + \rho_w} \)

\( w/c \) is the water cement ratio

\( \rho_w \) is the density of water

\( \rho_c \) is the density of cement

2) with wet curing

\[
\alpha_{max} = \frac{\theta}{1.2 \times (1 - \theta)} \leq 1
\]

---

Figure 2-15. Schematic representation of the volumetric proportions of the main components in hardened concrete at time of initial set (a) and at time t after setting (b).

1) Total volume of the cement paste

Total volume of the cement paste \( V_{\text{paste}} = V_c + V_w + A \)

- \( V_c \): The volume of cement
- \( V_w \): The volume of water
- \( A \): The air content of the past

2) Amount of unhydrated cement

The amount of unhydrated cement is:

\[ V_{\text{AH}} = \frac{C - C_{\text{hydr}}}{{\rho}_c} = \frac{C - \alpha C}{{\rho}_c} = \frac{C(1 - \alpha)}{{\rho}_c} \]

- \( C_{\text{hydr}} \): The amount of hydrated cement

Considering \( {\rho}_{\text{cem}} = 3.1 \text{ g/cm}^3 \)

\[ V_{\text{AH}} = \frac{C(1 - \alpha)}{3.1} = 0.32C(1 - \alpha) \]

3) Volume of contraction pores

Contraction pores appear during hydration, because the volume of the hydration products is less than that of the constituents cement plus water. Contraction pores are 25% of the original volume of chemically bound water.
\[ V_s = 0.25 \times \frac{W_n}{\rho_w} \]

\( W_n = \) the amount of water that has been chemically combined into the hydration products (non-evaporable water) = \( w_k \times C_{hyd} = 0.26 \times C_{hyd} \)

\[ V_s = 0.25 \times \frac{0.25 \times C_{hyd}}{\rho_w} = 0.0625 \left( \alpha \times \frac{C}{\rho_w} \right) \]

considering \( \rho_w = 1 \text{ g/cm}^3 \)

\[ V_s = 0.0625 \times \alpha \times C \]

4) Solid products of hydration – cement gel

\[ V_{gs} = \text{Hydrated cement (} V_{hp} \text{)} + \text{Chemically bound water (} V_n \text{)} - \text{Contraction pores (} V_s \text{)} \]

\[ V_s = 0.25 \times V_n \]

\[ V_{gs} = V_{hyd} + V_n - 0.25 \times V_n \]

\( V_{hyd} = \) the volume of hydrated cement

\[ V_{gs} = V_{hyd} + 0.75 \times V_n \]

\[ V_{gs} = \frac{C_{hyd}}{\sigma_c} + 0.75 \times \left( \frac{0.25 \times C_{hyd}}{\rho_w} \right) \]

Consider \( C_{hyd} = \alpha \times C \), then \( V_{gs} = \frac{\alpha \times C}{\sigma_c} + 0.75 \times \left( \frac{0.25 \times \alpha \times C}{\rho_w} \right) \)

Considering \( \rho_c = 3.1 \text{ g/cm}^3 \) and \( \rho_w = 1.0 \text{ g/cm}^3 \)

\[ V_{gs} = \alpha \times C \times \left( \frac{1}{3.1} + \frac{0.1875}{1.0} \right) = 0.51 \times \alpha \times C \ [dm^3] \]
2.5.1.3 Water in the cement past

The types of water in the cement past are:

1) Chemically bound water (Non-evaporable water).
2) Gel water (Evaporable water).
3) Capillary water (Evaporable water).

\[
\frac{w}{c} = \left(\frac{\rho_w}{\rho_{w'}}\right) \times \frac{\theta}{1-\theta} \approx \left(\frac{1.0 \text{ kg/dm}^3}{3.1 \text{ kg/dm}^3}\right) \times \frac{\theta}{1-\theta} \approx 0.32 \times \left(\frac{\theta}{1-\theta}\right)
\]

The air content (A) has to be taken into account to calculate the consumed water amount during cement hydration.

\[
\frac{w}{c} = \left(\frac{\rho_w}{\rho_{w'}}\right) \times \frac{\theta - A}{1-\theta} \quad \text{and} \quad (1-\theta) = (1-A) \times \left(\frac{1}{1 + \left(\frac{\rho_c}{\rho_w}\right) \times \frac{w}{c}}\right)
\]

1) Chemically bound water

Chemically bound (constitutive) water is the water bound in C-S-H layers. The chemically bound water separation may occur only by calcining the material at high temperatures (range 600-750°C).

The water requirement in hydration \(w_k\) = \(\frac{\text{weight of the chemically bound water}}{\text{weight of the reacted clinker minerals}}\)

For complete hydration of the Portland cement (\(\alpha=1\)), the water amount bound chemically (\(w_k = 0.25\))

In the chemical reactions during the hydration process, the volume of the hydration products is smaller than the original volume of the reacting components.

The volume decrease = 25% of the original water volume reacting
2) Gel water

The volume of gel pores in the hydrated cement paste \( V_{gp} \) is a 28 % of the total volume of the cement paste gel. \( \frac{V_{gp}}{V_{gp} + V_{gs}} = 0.28 \)

where \( V_{gs} \) is the solid part of the cement past gel.

\[
V_{gp} = 0.28 \left( V_{gp} + V_{gs} \right) = 0.28 \times V_{gp} + 0.28 \times V_{gs} = \frac{0.28}{0.72} \times V_{gs}
\]

\[
V_{gp} = \frac{0.28}{0.72} \times \alpha \times C \left( \frac{\rho_c}{\rho_w} + \frac{0.19}{\rho_w} \right)
\]

Considering \( \rho_{cem} = 3.1 \text{ g/cm}^3 \) and \( \rho_w = 1 \text{ g/cm}^3 \), then

\[
V_{gp} = 0.2 \times \alpha \times C \ [dm^3]
\]

A more precise for calculating the volume of gel pores is:

\[
W_{gp} = 3 \times k \times W_n
\]

where \( k = 0.23(C3S \ \text{wt%}) + 0.32(C2S \ \text{wt%}) + 0.317(C3A \ \text{wt%}) + 0.368(C4AF \ \text{wt%}) \), in which the weight percent of the cement compounds is used.

\[
V_{gp} = \frac{W_{gp}}{\rho_w} = 3 \times \left( 0.23(C3S) + 0.32(C2S) + 0.317(C3A) + 0.368(C4AF) \right) \times W_n
\]

considering \( \rho_w = 1 \text{ g/cm}^3 \)

3) Capillary water

The volume of the capillary pores \( V_{cap} = V_w - V_n - V_{gp} \)

where \( V_w \) is the total water amount

\( V_n \) is the chemically bound water

\( V_{gp} \) is the gel water

\[
V_{cap} = V_w - V_n - V_{gp} = \frac{1}{\rho_w} \left( W \times C - 0.25 \times \alpha \times C - 0.2 \times \alpha \times C \right) = C \left( \frac{W}{C} - 0.45 \times \alpha \right)
\]
2.6 Interfacial Transition Zone

Concrete is made up of two distinctly different constituents, (i) the cement paste and (ii) the aggregate, and there is a tendency to assume that the properties of each of these is unaffected by the presence of the other. The cement particles in fresh concrete, which are suspended in the mix water, cannot pack together as efficiently when they are in the close vicinity of a much larger solid object, such as an aggregate particle. This is actually a general phenomenon associated with particle packing, known as the "wall effect." In the case of concrete, this effect is magnified by the shearing stresses exerted on the cement paste by the aggregate particles during mixing, which tend to cause the water to separate from the cement particles. The result is a narrow region around the aggregate particles with fewer cement particles, and thus more water. This is called the interfacial transition zone, abbreviated ITZ.

The ITZ is a region with a higher w/c, and thus a higher porosity, than the bulk paste. It is not uniform, but varies from point to point along each aggregate particle, with an average thickness of 20-50 µm. Because of the larger pores, the ITZ is characterized by the presence of larger crystals, particularly of calcium hydroxide, than are found in the bulk paste (see Figure 2-17). The ITZ tends to be larger around larger aggregate particles.

The ITZ has important effects on the properties of concrete, because it tends to act as the "weak link in the chain" when compared to the bulk cement paste and the aggregate particles. Thus the lower strength and stiffness of the ITZ translate directly into lower strength and stiffness values for concrete as compared to cement paste. The total volume of ITZ in a concrete increases with the total amount of large aggregate and with the average size of the aggregate, which explains why the strength is observed to decrease with both of these parameters. The ITZ is also more permeable than the bulk paste, due to its higher porosity. In most concretes the ITZs are linked (percolated), creating a continuous high-permeability phase across the structure. As a result, the permeability of concrete can be 1000 times greater than that of the pure cement paste it contains. The durability of concrete is inversely related to the permeability, as most damage mechanisms involve the diffusion of reactive ions into the concrete to attack either the cement paste or the steel reinforcement.

As summary of ITZ:

- ITZ is a zone between the aggregate and bulk paste and 30 to 50 µm in thickness
- ITZ has a major impact on the strength and permeability of concrete
- Generally weaker than either the paste or aggregate due to locally high w/c and the “wall effect” (packing problems) – in some cases predominately large crystals of calcium hydroxide and ettringite are oriented perpendicular to aggregate surface
- Greater porosity and few unhydrated cement grains
- Microcracking commonly exists in transition zone
- Results in shear-bond failure and interconnected macro-porosity, which influences permeability
Modification of transition zone is key to improving concrete

Figure 2-17. Interfacial Transition Zone (ITZ)

2.7 References


Kimberly Kurtis. Structure of the Hydrated Cement Paste – Lecture notes. School of Civil Engineering, Georgia Institute of Technology Atlanta, Georgia. Online at: http://people.ce.gatech.edu/~kk92/hcp.pdf


SFS-EN 197-1 Sementti. Osa 1: Tavallisten sementtien koostumus, laatuvaatimuksen ja vaatimustenmukaisuus
Appendix 1 - Cement types and Finnish cements

In Europe, cements are covered by the standard EN 197-1 (composition, specifications and conformity criteria)\(^8\). The standard divides the common cements into 5 main types\(^9\), as follows:

Table 2-4. Designation, notation, and composition of main types of common cement (EN 197-1).

<table>
<thead>
<tr>
<th>Notation</th>
<th>Type</th>
<th>Clinker (%)</th>
<th>Other main constituent rather than clinker</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM I</td>
<td>Portland cement</td>
<td>95 - 100</td>
<td>-</td>
</tr>
<tr>
<td>CEM II</td>
<td>Portland Composite cements</td>
<td>65-94</td>
<td>Up to 35% of an addition (different sub-classification, see Table 2-6)</td>
</tr>
<tr>
<td>CEM III</td>
<td>Blast furnace cement</td>
<td>5-64</td>
<td>36 – 95% blast furnace slag</td>
</tr>
<tr>
<td>CEM IV</td>
<td>Pozzolan cement</td>
<td>45-89</td>
<td>11 – 65% of pozzolanic materials (of one type or mixture of several types)</td>
</tr>
<tr>
<td>CEM V</td>
<td>Composite cement</td>
<td>20-64</td>
<td>Mixture of: 18 - 50% of blast furnace slag and 18 – 50% of natural pozzolan and/or fly ash.</td>
</tr>
</tbody>
</table>

In accordance with EN 197-1, cement is also categorized by strength class as well as cement type, and these categories are shown in Table 2-5, where there are minimum limits to early-age strength and limits for 28-day strength.

Table 2-5. Requirements for standard strength and early strength

<table>
<thead>
<tr>
<th>Strength class</th>
<th>Compressive strength [MPa]</th>
<th>Initial setting time [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Early strength</td>
<td>Standard strength</td>
</tr>
<tr>
<td>32,5 N</td>
<td>-</td>
<td>≤ 16,0</td>
</tr>
<tr>
<td>32,5 R</td>
<td>≥ 10,0</td>
<td>-</td>
</tr>
<tr>
<td>42,5 N</td>
<td>≥ 10,0</td>
<td>-</td>
</tr>
<tr>
<td>42,5 R</td>
<td>≥ 20,0</td>
<td>-</td>
</tr>
<tr>
<td>52,5 N</td>
<td>≥ 20,0</td>
<td>-</td>
</tr>
<tr>
<td>52,5 R</td>
<td>≥ 30,0</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^8\) EN 197-1: Cement. Composition, specifications and conformity criteria for common cements
**Table 2-6. Common cement products according to EN 197-1:2000**

<table>
<thead>
<tr>
<th>Main cement type</th>
<th>Designation</th>
<th>Cement type</th>
<th>Portland cement clinker</th>
<th>Silica dust</th>
<th>Pozzolanes</th>
<th>Fly ashes</th>
<th>Burnt shale</th>
<th>Limestone</th>
<th>Minor components</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CEM I</td>
<td>Portland cement</td>
<td>CEM I</td>
<td>95-100</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Portland slag cement</td>
<td>CEM III/A-S</td>
<td>80-94</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM III/B-S</td>
<td>65-79</td>
<td>21-35</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Portland silica dust cement</td>
<td>CEM III/A-D</td>
<td>90-94</td>
<td>-</td>
<td>6-10</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td>CEM II</td>
<td>Portland pozzolan cement</td>
<td>CEM III/A-P</td>
<td>80-94</td>
<td>-</td>
<td>-</td>
<td>6-20</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM III/B-P</td>
<td>65-79</td>
<td>-</td>
<td>21-35</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM III/A-Q</td>
<td>80-94</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6-20</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM III/B-Q</td>
<td>65-79</td>
<td>-</td>
<td>-</td>
<td>21-35</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td>Portland fly ash cement</td>
<td>CEM III/A-V</td>
<td>80-94</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6-20</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM III/B-V</td>
<td>65-79</td>
<td>-</td>
<td>-</td>
<td>21-35</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM III/A-W</td>
<td>80-94</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6-20</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM III/B-W</td>
<td>65-79</td>
<td>-</td>
<td>-</td>
<td>21-35</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td>Portland shale cement</td>
<td>CEM III/A-T</td>
<td>80-94</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6-20</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM III/B-T</td>
<td>65-79</td>
<td>-</td>
<td>-</td>
<td>6-20</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td>Portland limestone cement</td>
<td>CEM III/A-L</td>
<td>80-94</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6-20</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM III/B-L</td>
<td>65-79</td>
<td>-</td>
<td>-</td>
<td>6-20</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td>Portland composite cement</td>
<td>CEM III/A-M</td>
<td>80-94</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6-20</td>
<td>0-5</td>
</tr>
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<td></td>
<td></td>
<td>CEM III/B-M</td>
<td>65-79</td>
<td>-</td>
<td>-</td>
<td>6-20</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td>CEM III</td>
<td>Blast furnace cement</td>
<td>CEM III/A</td>
<td>35-64</td>
<td>36-65</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM III/B</td>
<td>20-34</td>
<td>66-80</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
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<td></td>
<td>CEM III/C</td>
<td>5-19</td>
<td>81-95</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td>CEM IV</td>
<td>Pozzolan cement</td>
<td>CEM IV/A</td>
<td>65-89</td>
<td>-</td>
<td>-</td>
<td>11-35</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM IV/B</td>
<td>45-64</td>
<td>-</td>
<td>36-55</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td>CEM V</td>
<td>Composite cement</td>
<td>CEM V/A</td>
<td>40-64</td>
<td>18-30</td>
<td>-</td>
<td>18-30</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM V/B</td>
<td>20-39</td>
<td>31-50</td>
<td>-</td>
<td>31-50</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
</tbody>
</table>

1. The silica dust content is limited to 10 %.
2. Total organic carbon (TOC) must not exceed 0.2 % by weight.
3. Total organic carbon (TOC) must not exceed 0.5 % by weight.
Table 2-7. Example of the cement naming according to the cement standard SFS-EN 197-1\(^{(10)}\).

<table>
<thead>
<tr>
<th>CEM II/A-LL 42,5 R</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CEM II</strong></td>
</tr>
<tr>
<td>Cement notation “Type: Portland Composite Cement”, see Table 2-4</td>
</tr>
</tbody>
</table>

Finnsementti Oy\(^{(11)}\) is a Finnish cement manufacturer since year 1914. Most of the cement needed in Finland is manufactured in Finnsementti’s works in Parainen and Lappeenranta. Finnsementti’s cement assortment includes Plus cement, Yleis-(general) cement, Rapid cement, Pika-(quick) cement, Mega cement, SR cement, and Valko-(white) cement.

**Plus cement:** Normally hardening Portland composite cement, **CEM II/B-M (SLL) 42,5N**. Plus cement is used in general construction purposes (most buildings, bridges, pavements, precast units, etc). Plus cement includes 15 - 25 % blast furnace slag.

**Yleis (General) cement:** Normally hardening Portland composite cement, **CEM II A-M (SLL) 42,5N**. Yleis (General) cement is also used for all general construction purposes. Yleis (General) cement includes 3 – 14 % blast furnace slag.

**Rapid cement:** Rapidly hardening Portland composite cement **CEM II/A-LL 42,5R**. The hardening rate depends of the cement fineness. The rapid cement is used in rapid construction, cold weather concreting and precast concreting. The Rapid cement includes 0 - 5 % blast furnace slag.

**Pika (Quick) cement:** Very fast hardening Portland cement **CEM I 52,5R**. Pika-cement is used in rapid construction when the form work is removed quickly. Pika-cement is also used for high and ultra-high strength concretes.

**Mega-cement:** Fast hardening Portland cement **CEM I 42,5R**. Mega cement is used in ready mixed concrete productions and the industrial pre-cast concrete productions.

**SR-cement:** Sulfate resistance Portland cement **CEM I 42,5N SR3**. SR-cement is used in structures exposed to high levels of sulfate ions as: harbors constructions, waste water systems, dams, underground water pipes, foundations, sewers, irrigation canals and treatment plants. it is appropriate cement for using at the structures that require resistance against chemical effects such as sea water and sulfate environments

**Valko (white) cement:** White cement is normally hardening Portland cement **CEM I 52,5R**. White cement is used in architectural works requiring great brightness and artistic finishes, to create mosaics and artificial granite, and for sculptural casts and other applications where white prevails.

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\(^{(10)}\) SFS-EN 197-1 Sementti. Osa 1: Tavallisten sementtien koostumus, laatuvaatimukset ja vaatimustenmukaisuus  
\(^{(11)}\) Finnsementti Oy In Englis - http://www.finnsementti.fi/en