Cement Production & Concrete Durability

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Cement Production & Concrete Durability

Contents

- Cement Production, Standards, Properties
- Durability of Concrete
  - Principles & Causes
  - Sulfate Attack and How To Prevent

Cement Production, Standards, Properties

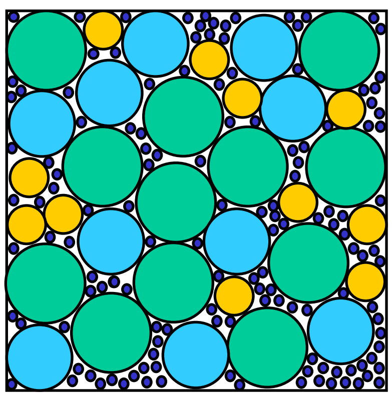
Descriptions

- **Hydraulic Binder :** Cement is a hydraulic binder, having reacted with water it sets and hardens both in air and under water.
- **Hydration :** Chemical reaction between cement and water.
- **Portland Cement :** Hydraulic binder produced by cogrinding clinker and % 3-6 gypsum. Bonding material for stones, sand, bricks, building blocks etc.

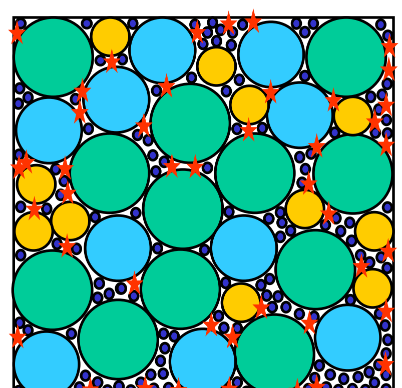
★ Cement is the most important of concrete ingredients, although it is the one with the least amount by volume.

Role of Cement

- When hydrates, bonds aggregate particles together.
- Fills voids, improves compactness (packing) and provides strength.



Without Cement :
A weak heap of aggregate



With Cement:
A very strong artifical stone

Production of Portland Cement

- **Rawmaterial :** Clay, limestone, marl, bauxite, iron ore etc.

- Rawmaterial is proportioned and ground : **Rawmeal**

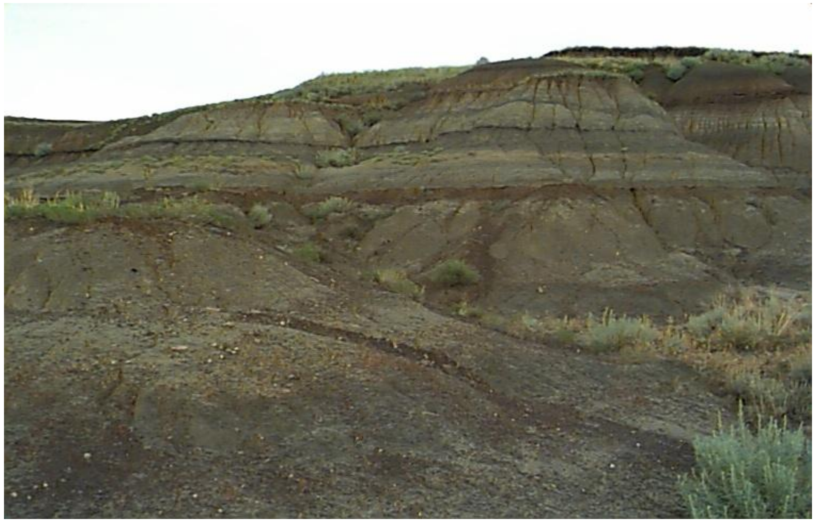
- Rawmeal is pyroprocessed in rotary kiln around 1400-1500 ^oC : **Clinker**

- Clinker and gypsum coground : **Portland cement**

Rawmaterial

Limestone : Calcium ($CaCO_3$)

Clay : Silica (SiO_2),
Aluminium (Al_2O_3)
Ferrum (Fe_2O_3)



Rawmaterial

Gypsum : $CaSO_4.2H_2O$

Cement Production Flow

Rock Excavation & Crushing → **Rawmaterial Premixing + Grinding + Homogenization** → **Rawmeal**

↓

Pyroprocessing (Kiln + Cooler)
Finely ground minerals, react under high temperature and form new chemical structures

→ **Clinker** →

Grinding (Gypsum + Other Minerals)
Clinker is ground to provide high reactivity when mixed with water

↓

Cement → **Storage / Delivery**

Cement Process Film

Portland Cement, Composition

Clinker Composition

- Silicates "alite"		C_3S	% 50 - 70
"belite"		C_2S	% 10 - 20
- Tricalcium Aluminate		C_3A	% 0 - 15
- Tetracalciyum Aluminoferrite		C_4AF	% 1 - 15
- Free Lime		CaO	% 0.5 -1

Setting Control and Workability

- Calcium Sulfate (Gypsum) % 3 - 6

Main Compounds and Their Function

Compound	Heat of Hydration	Reaction	Binding Capacity
C_3A*	Very High	Fast	Low
C_4AF	Moderate	Medium	Low
C_2S	Low	Slow	Low at the beginning, then high
C_3S	Moderate	Medium	High

* W/O gypsum

Gypsum ($CaSO_4.2H_2O$)

- Controls the speed of setting of cement paste (cement + water).
- Cement without gypsum sets immediately (flash setting). In this case mixing, transportation and pouring process of concrete is blocked.
- Addition rate : 3-6 % by cement weight.

Important Properties of Cement

- Compressive Strength
- Setting Time
- Blaine
- Water Consistency
- C3A
- Color
- Heat of Hydration

Strength

- Cement strength is a vital property for most applications (especially structural concrete).
- **Strength Classes EN 197-1** (28 day, MPa)

  5, 12.5, 22.5, 32.5, 42.5, 52.5
- Cement strength is measured with mortar cubes / bars.
- Strength performance of different types of cements better be tested / compared in concrete formulations (in lab and on site).
- En 197-1 : Prisms 4x4x16 cm
- ASTM & IQ.S 5/1984 : Cube 7x7x7 cm

Cement Fineness

- Hydration starts at the surface of cement particles (total surface of cement is subject to hydration reactions).
- In other words, high rate of hydration (high strength development) is dependant on cement fineness.
- Finely ground cement has higher cost.
- Fine cement is more sensitive against atmospheric conditions (needs to be protected from moisture and humidity).

Cement Fineness

- **Finer cement**
  - – Develops more severe ASR reactions.
  - – Reduces bleeding of concrete.
  - – Increases amount of water for standard consistency.
  - – Slightly improves concrete workability.

Setting

- **Setting :** Hardening of cement paste, transition from liquid phase to solid phase.
- **C_3A and C_3S** are active for setting.
- **Relative humidity** and **ambient temperature** adversely affect setting.

Color

- Cement color comes from the raw material.
- Generally Portland cements are shades of grey.
- Blended cements have different color (depending on type and amount of addition).
- Other than aesthetic (decorative / architectural) applications, cement (and concrete) color is not important.
- Cement color is not a sign of quality.
- Lighter cement has some advantages (easier painting, better insulation).

Heat of Hydration

- Cement hydration is an exothermic reaction (120 cal/g).
- Due to low thermal conductivity of concrete, especially in the core of mass concrete pourings, temperature may very rapidly reach unwanted level.
- This may result in thermal shrinkage cracks.

Heat of Hydration

- During cold weather concreting, heat of hydration (HOH) protects concrete from frost and high HOH cements and / or high cement dosage are advantageous.
- Cement type should be selected according to the application (high HOH / low HOH).
- Rate of HOH is affected by ambient temperature.

Concrete - Important Properties

Important Concrete Properties

- Workability
- Strength
- Durability

Durability

- Maintaining initial characteristics and design function under environmental and service conditions.
- Resistence of concrete to atmospheric conditions, harmful chemical exposures, wearing etc.

Exposures Affecting Concrete

External

- **Chemical**
  - Gases
  - Liquids
  - Soils
  - Salts
- **Physical**
  - Temperature Fluctuation
    - Expansion-shrinkage
    - Freeze-thaw
    - Fire
  - Moisture Fluctuation
    - Shrinkage-swelling
- **Mechanical**
  - Wind
  - Water
  - Impact

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Chemical Exposures

- CaO and MgO Expansion
- Sulfate attack
- Alkali - Silica Reaction
- Alkali – Carbonate Reaction
- Acid attack
- Carbonation

Sulfate Attack

Sulfate Attack on Concrete

- Some salts can react with hydrated cement paste when present in solution in soil or in underground water.
- Most common types of these salts are sulfates of sodium, potassium, magnesium and calcium.
- Sulfates in groundwater are usually of natural origin but can also come from fertilizers or from industrial effluents.

Sulfate Resisting Cement

- **Description**
  - SRC is a kind of pure Portland cement with limited amount of $C3A$: 3.5 % max
  - Complies with Iraqi standard IQ.S 5/1984.
  - It's produced by Lafarge Bazian Plant

- **Areas of Use**

SRC is necessary when concrete application is exposed to

  - Soils or underground water containing sulphate solutions
  - Concrete in contact with waste water

Table 2 — Limiting values for exposure classes for chemical attack from natural soil and ground water

The aggressive chemical environments classified below are based on natural soil and ground water at water/soil temperatures between 5 °C and 25 °C and a water velocity sufficiently slow to approximate to static conditions.

The most onerous value for any single chemical characteristic determines the class.

Where two or more aggressive characteristics lead to the same class, the environment shall be classified into the next higher class, unless a special study for this specific case proves that it is not necessary.

Chemical characteristic	Reference test method	XA1	XA2	XA3
Ground water				
SO_4^{2-} mg/l	EN 196-2	≥ 200 and ≤ 600	> 600 and ≤ 3 000	> 3 000 and ≤ 6 000
pH	ISO 4316	≤ 6,5 and ≥ 5,5	< 5,5 and ≥ 4,5	< 4,5 and ≥ 4,0
CO_2 mg/l aggressive	prEN 13577:1999	≥ 15 and ≤ 40	> 40 and ≤ 100	> 100 up to saturation
NH_4^+ mg/l	ISO 7150-1 or ISO 7150-2	≥ 15 and ≤ 30	> 30 and ≤ 60	> 60 and ≤ 100
Mg^{2+} mg/l	ISO 7980	≥ 300 and ≤ 1 000	> 1 000 and ≤ 3 000	> 3 000 up to saturation
Soil				
SO_4^{2-} mg/kg[a] total	EN 196-2[b]	≥ 2 000 and ≤ 3 000[c]	> 3 000[c] and ≤ 12 000	> 12 000 and ≤ 24 000
Acidity ml/kg	DIN 4030-2	> 200 Baumann Gully	Not encountered in practice	

[a] Clay soils with a permeability below 10^{-5} m/s may be moved into a lower class.

[b] The test method prescribes the extraction of SO_4^{2-} by hydrochloric acid; alternatively, water extraction may be used, if experience is available in the place of use of the concrete.

[c] The 3 000 mg/kg limit shall be reduced to 2 000 mg/kg, where there is a risk of accumulation of sulfate ions in the concrete due to drying and wetting cycles or capillary suction.

Table F.1 — Recommended limiting values for composition and properties of concrete

	Exposure classes																	
	No risk of corrosion or attack	Carbonation-induced corrosion				Chloride-induced corrosion						Freeze/thaw attack				Aggressive chemical environments		
						Sea water			Chloride other than from sea water									
	X0	XC 1	XC 2	XC 3	XC 4	XS 1	XS 2	XS 3	XD 1	XD 2	XD 3	XF 1	XF 2	XF 3	XF 4	XA 1	XA 2	XA 3
Maximum w/c	—	0,65	0,60	0,55	0,50	0,50	0,45	0,45	0,55	0,55	0,45	0,55	0,55	0,50	0,45	0,55	0,50	0,45
Minimum strength class	C12/15	C20/25	C25/30	C30/37	C30/37	C30/37	C35/45	C35/45	C30/37	C30/37	C35/45	C30/37	C25/30	C30/37	C30/37	C30/37	C30/37	C35/45
Minimum cement content (kg/m^3)	—	260	280	280	300	300	320	340	300	300	320	300	300	320	340	300	320	360
Minimum air content (%)	—	—	—	—	—	—	—	—	—	—	—	—	4,0[a]	4,0[a]	4,0[a]	—	—	—
Other requirements												Aggregate in accordance with prEN 12620:2000 with sufficient freeze/thaw resistance					Sulfate-resisting cement[b]	

[a] Where the concrete is not air entrained, the performance of concrete should be tested according to an appropriate test method in comparison with a concrete for which freeze/thaw resistance for the relevant exposure class is proven.

[b] When SO_4^{2-} leads to exposure Classes XA2 and XA3, it is essential to use sulfate-resisting cement. Where cement is classified with respect to sulfate resistance, moderate or high sulfate-resisting cement should be used in exposure Class XA2 (and in exposure Class XA1 when applicable) and high sulfate-resisting cement should be used in exposure Class XA3.

Basics Rules For Durable Concrete

Porous Concrete and Durability

Caution !! Concrete has to be compact enough to block penetration of harmful substances.

How ?

- Aggregate skeleton with high compactness
- Sufficient cement paste
- Low permeability (low W/C)
- Proper compaction
- Special cement if necessary (slag cement, FA cement)

→ **Highly Compact Concrete**

Principles For Durable Concrete

- Porosity and concrete performance

  High Porosity = Low Strength

  High Porosity = Low Durability

- Due to high permeability,
  - weaker hardened concrete against aggressive exposures
  - insufficiently protected reinforcement

Principles For Durable Concrete

- Exposures should be evaluated during design of structure and building process (suitable concrete formulation),
- Cement type and quantity, aggregate type, W/C and admixtures should be selected according to exposure conditions (refer standard restrictions),
- Concrete porosity / permeability should be minimized : low W/C and proper compaction.

Principles For Durable Concrete

- Choose concrete ingredients after preliminary testing,
- Use right type and amount of cement,
- Use right type and amount of mineral additive (FA, slag , microsilica)
- Prefer low W/C **: Ready mix is a must!**
- Provide proper compaction : **Vibration is a must!**
- Apply sufficient concrete cover.

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Thank you...