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Durability of blended cements in aggressive environments

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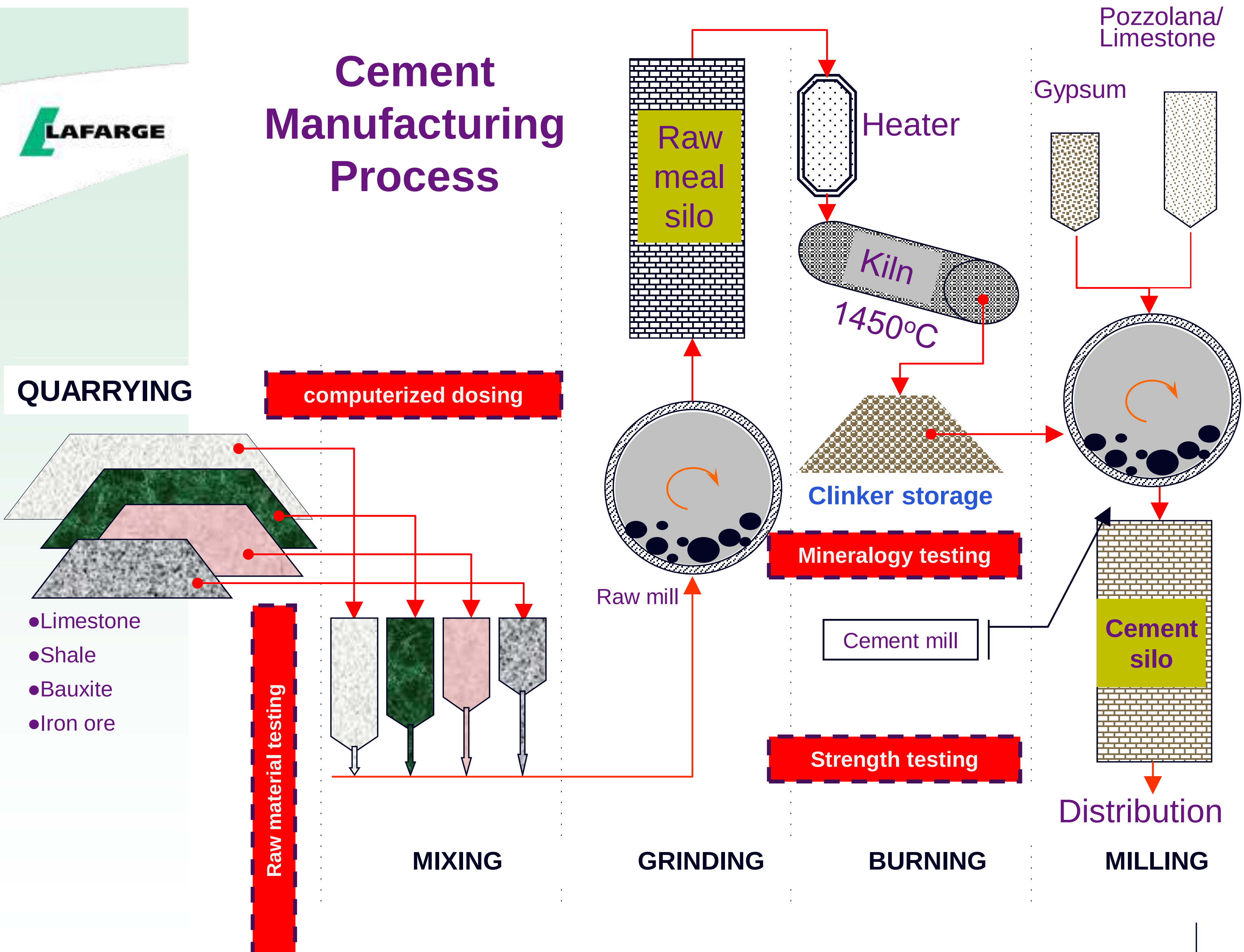
Blended Portland cement

Definition

Finely ground hydraulic binder in which a well-defined fraction of the Portland cement clinker is replaced by other hydraulic, pozzolanic or non-hydraulic materials

Cement Manufacturing Process



Types of blended portland cements

Extract from KS EAS 18-1 Cement standard

- CEM II : Portland-composite cement
  - Portland-slag cement,
  - Portland-silica fume cement
  - Portland-pozzolana cement
  - Portland-fly ash cement
  - Portland-burnt shale cement
  - Portland-composite cement
  - Portland-limestone cement – Inert filler

Components with latent hydraulic properties

Types of blended portland cements

Extract from KS EAS 18-1 Cement standard

- CEM III : Blastfurnace cement
- CEM IV : Pozzolanic cement
- CEM V : Composite cement.

Ordinary Portland cement

- CEM I : Portland cement (Commonly known as OPC)

Types of blended portland cements

Extract from ASTM C595/C595M : blended cements

- Type IS : Portland blastfurnace slag cement,
- Type IP : Portland pozzolan cement
- Type IT : Ternary blends

Extract from ASTM C150 : C150M - OPC

- Type I, IA, II and IIA

Components of cement clinker

Description	Notation	Short notation
Tri-Calcium Silicate	$3CaO.SiO_2$	C_3S
Di-calcium Silicate	$2CaO.SiO_2$	C_2S
Tri-Calcium Aluminate	$3CaO.Al_2.O_3$	C_3A
Tetra-Calcium-Aluminoferrite	$4CaO.Al_2O3.2Fe_2O_3$	C_4AF

Pozzolanic aterials – natural and calcined

Pozolanic material properties

- Natural pozzolana contain siliceous and or silico aluminous composition, iron oxide and other oxides
- Reactive SiO_2 > 25% (KS EAS 18-1 cement standard)

Natural pozzolanas

- Primarily volcanic with cementitious properties

Natural calcined pozzolanas

- Materials of volcanic origin, sedimentary rocks, clays, shales activated by thermal treatment.

Pozzolanic reactions

Portland cement hydration

Calcium silicate hydrate hardened phases

- C_3S + aq. → C-S-H + CH

$Ca(OH)_2$ – free lime - portlandite

- •Fast reaction
- •Fast strength development
- •High liberation of heat of hydration

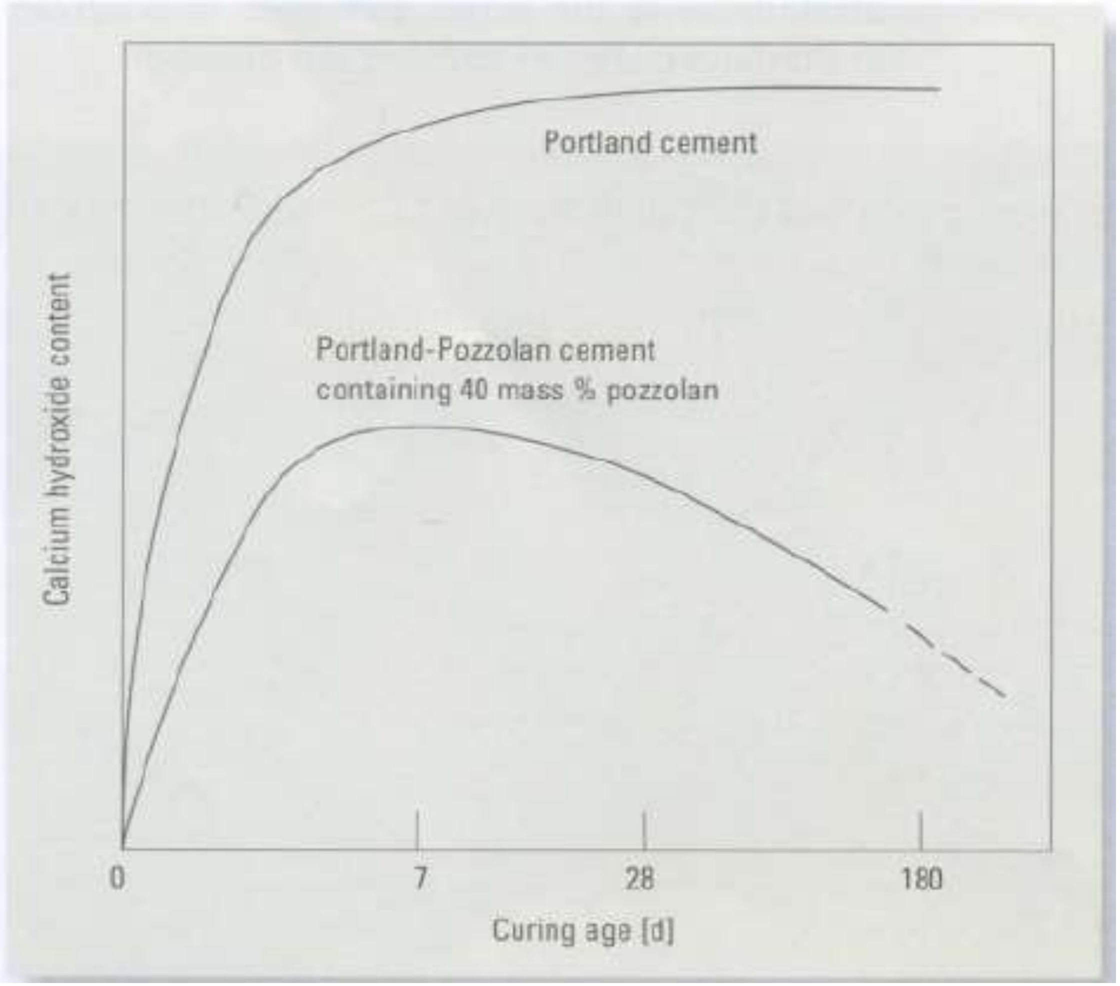
Pozzolanic reaction

- Pozzolanic material reacts with liberated CH to give C-S-H (strength compounds)
- CH + S +aq. → C-S-H
- Calcium Aluminate compounds also formed

- •Slower pozzolanic reaction
- •Lower rate of strength development
- •Lower heat of hydration

Portlandite consumption in pozzolana blend

Changes in the free lime content of a hydrating Portland pozzolanic cement



Source : Cement International, 4/2008 Vol 6.

Conventional form of sulphate attack

Mechanism

- Portland cement susceptible to attack by aq. solutions of sulphate salts (commonly magnesium, calcium and sodium) depending on
  - Concentrations of the sulphates
  - Presence of water
  - Characteristics of the concrete such as permeability
  - Calcium hydroxide and Calcium Aluminate Hydrate
- Sulphate attack on freelime
  - $SO_4^{2-} + Ca(OH)_2 \rightarrow CaSO_4.2H_2O$

CH (Portlandite)

Gypsum (Calcium Sulphate dihydrate)

Sulphate and magnesium attack

- Sulphate attack on C-A-H (Calcium Aluminate Hydrate)

  SO_4^{2-} + C-A-H → $3CaO.Al_2O_3.3CaSO_4.31H_2O$

  calcium sulfo-aluminate hydrate (ettringite)

- Magnesium attack on CH
  - Mg^{2+} + CH → $Mg(OH)_2$

    Magnesium hydroxide (brucite) – low solubility

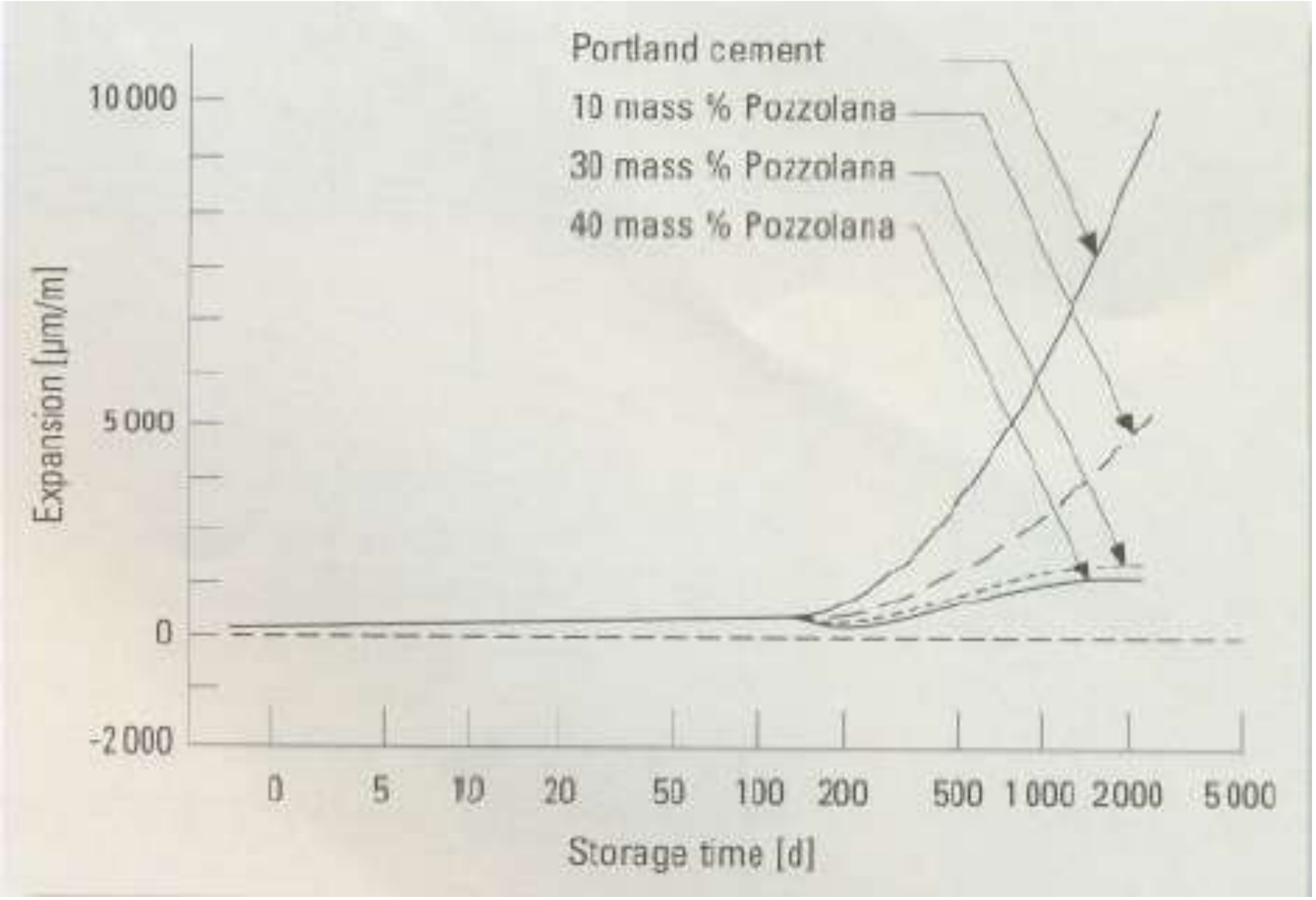
- Gypsum, brucite and ettringite occupy greater volume
  - Cause expansion
  - Cause extensive cracking
  - Loss of bond between the cement paste and aggregate
  - Reaction leads to loss of strength in Hardened Cement paste resulting in spalling and crumbling.

Sulphate and magnesium attack

Beneficial effects of pozzolana in sulphate resistance

- Dilution effect of available C_3A in cement (hydrates to C-A-H)
- Dilution of clinker to lower evolved $Ca(OH)_2$ component
- Reacts with $Ca(OH)_2$ rendering it largely unavailable for attack by sulphates
- Enhances durability of concrete exposed to sea water/water bodies containing sulphates
- Pozzolanic reactions reduce permeability by sealing effect
  - Less permeable, better resistance to attacks by other external agents i.e. chlorides, CO_2 etc.

Sulphate resistance



Source : Cement International, 4/2008 Vol 6.

Effect on the sulphate expansion of a 1:3 mortar in a solution containing 1 mass % of $MgSO_4$ replacing Portland cement by an Italian natural pozzolan.

Sulphate resistance

Cement Type	Compressive strength before immersion [MPa]	Compressive strength after immersion [MPa]	Strength Loss
Portland cement (OPC)	18.0	6.1	65%
Santorin Earth (10% mass)	18.5	9.5	49%
Santorin Earth (20% mass)	16.1	12.9	20%
Santorin Earth (30% mass)	15.2	12.8	16%

Source : Cement International, 4/2008 Vol 6.

Compressive strength loss of cement paste cylinders in sulfate solution held at constant pH

Sulphate resistance

Approach of KS EAS 18-1 (EN 197-1)

K - clinker

SR 0 : C_3A of K = 0%
SR 3 : C_3A of K = 3%
SR 5 : C_3A of K = 5%
(CEM I)

No C_3A requirement (CEM III)

C_3A of K < 9% (CEM IV)

Main types	Notation of the seven products (types of sulfate resisting common cement)		Composition (percentage by mass[a])				
			Main constituents				Minor additional constituents
			Clinker K	Blast furnace slag S	Pozzolana natural P	Siliceous fly ash V	
CEM I	Sulfate resisting Portland cement	CEM I-SR 0 CEM I-SR 3 CEM I-SR 5	95 – 100				0 – 5
CEM III	Sulfate resisting blast furnace cement	CEM III/B-SR	20 – 34	66 – 80	-	-	0 – 5
		CEM III/C-SR	5 – 19	81 – 95	-	-	0 – 5
CEM IV	Sulfate[b] resisting pozzolanic cement	CEM IV/A-SR	65 – 79		⇦ --- 21 – 35 --- ⇨		0 – 5
		CEM IV/B-SR	45 – 64		⇦ --- 36 – 55 --- ⇨		0 – 5

Conclusion

The use of blended cements has significant advantages in the durability of concrete structures that can be exploited at design stage. Concrete designs should endeavor to incorporate durability performance concepts.

Thank you

Bamburi cement
Part of you. From the start

A member of LafargeHolcim