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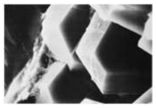


Cement Chemistry, Specifications, and Testing

Anthony F. Bentivegna, PhD, PE

May 8, 2018

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Agenda

Cement Chemistry, Specifications, and Testing

- **Portland Cement Introduction and History**
- Cement Plants and Manufacturing
- Cement Classifications and Chemistry
- Chemical and Physical Cement Testing
- Cement Specifications

Cement History

- 7000 BC – oldest known concrete lime concrete (quicklime)

- 2500 BC – cementing materials between stone blocks Great Pyramid at Giza

- 120 AD– early Roman concrete advances to mix calcined lime-pozzolans from volcanic ash

Cement History

- 1750s – John Smeaton discovered production of stronger cements by burning limestone with clay

- 1824 - Joseph Aspdin credited with the invention of portland cement

- 1845 – I.C. Johnson, England burned raw materials under high heat to produce “today’s” portland cement

Developments Since 1800’s

First cement produced in the US Coplay, Pennsylvannia (1871)

First portland cement produced in Canada (1889)

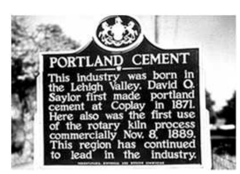
Modern manufacturing – high temperatures, ball mills, & preheaters

Improved energy efficiency

Improved quality control

Wider range of cements

Reduced emissions



Today's Available Cements

Wide range of portland, blended & other cements available:

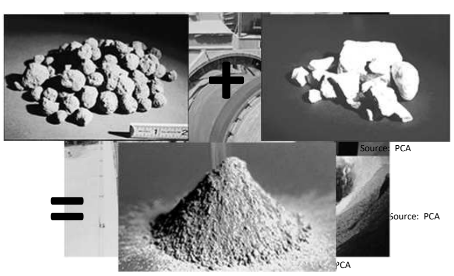
- Sulfate-resisting cements
- Low-heat hydration cements
- Rapid strength gain cements
- ASR resistant cements
- Air entraining cements
- White cements
- Masonry cements
- Mortar cements
- Expansive cements
- Regulated-set cements
- Calcium aluminate cements
- Calcium sulfoaluminate cements

What is portland cement?

Portland cement:

- A hydraulic cement produced by pulverizing clinker formed by heating a mixture, usually of limestone and clay to 1350 to 1450°C (2460 to 2640°F).
- Calcium sulfate is usually ground with clinker to control set.

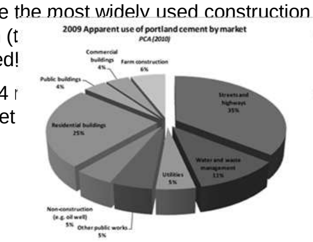
What is portland cement?



Cement and Concrete Production

Concrete the most widely used construction material on earth (t ... rials combined!

1.6 m^3 (4 r ... erson on the planet



* Kosmatka, S.K. and Wilson, M.L., *Design and Control of Concrete Mixtures*, PCA 2011

Cement and CO_2

Responsible for 5-7% of the **worlds** CO_2 production

For 1 m^3 of concrete about 0.2 t of CO_2 are produced, mostly from the production of cement*

U.S. ~1.5% CO_2 production from cement

Source: PCA

*Gartner, E., "Industrially Interesting Approaches to "Low-CO_2" Cements," *Cement and Concrete Research*, 34 [9], September 2004, pp. 1489-1498

Agenda

Cement Chemistry, Specifications, and Testing

- Portland Cement Introduction and History
- **Cement Plants and Manufacturing**
- Cement Classifications and Chemistry
- Chemical and Physical Cement Testing
- Cement Specifications

Cement Plants and Manufacturing

Primary Components of Raw Materials Necessary for Portland Cement Manufacture

- Calcium
  - Introduced as $CaCO_3$
  - CaO composes 60-70% of clinker
  - $CaCO_3$ can be found in limestone, seashell, chalk, etc.
- Silica
  - Composes 18-22%
  - Can be found in clay, quartz, opal, chert, etc.
  - Materials vary based on grindability (clay is the easiest)
- Alumina
  - Composes 4-6%
  - Comes from clay or limestone
- Iron
  - Composes 2-4 %
  - Usually already added, not added separately

Calcium	Iron	Silica	Alumina	Sulfate
Alkali waste	Blast-furnace flue dust	Calcium silicate	Aluminum-ore refuse	Anhydrite
Aragonite	Clay	Cement rock	Bauxite	Calcium sulfate
Calcite	Iron ore	Clay	Cement rock	Gypsum
Cement-kiln dust	Mill scale	Fly ash	Clay	
Cement rock	Ore washings	Fuller's earth	Copper slag	
Chalk	Pyrite cinders	Limestone	Fly ash	
Clay	Shale	Loess	Fuller's earth	
Fuller's earth		Marl	Granodiorite	
Limestone		Ore washings	Limestone	
Marble		Quartzite	Loess	
Marl		Rice-hull ash	Ore washings	
Seashells		Sand	Shale	
Shale		Sandstone	Slag	
Slag		Shale	Staurolite	
		Slag		
		Traprock		

Quarry

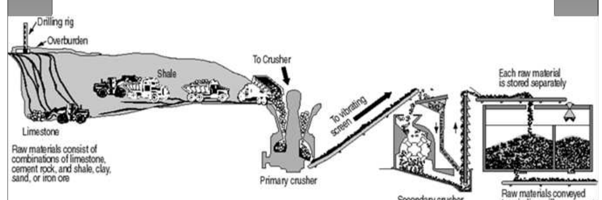
Limestone is the primary raw material

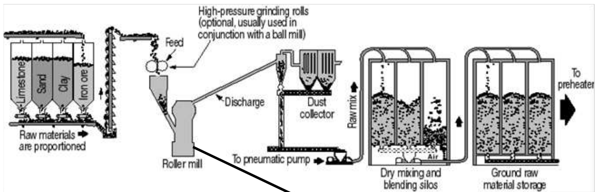
Quarried near cement plant

Quarry

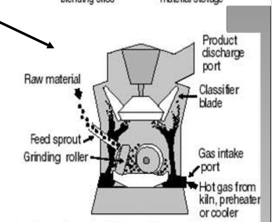
Dry Process Manufacture of Portland Cement

1. Stone is first reduced to 125 mm (5 in.) size, then to 20 mm (3/4 in.), and stored.





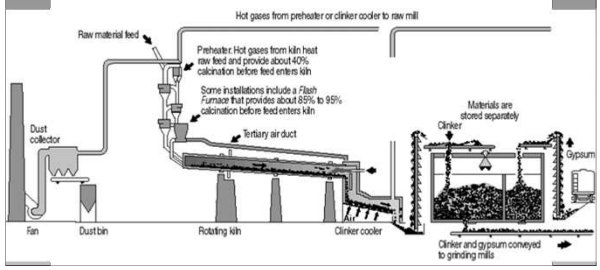
2. Raw materials are ground, to powder and blended.



Detail of roller mill, which combines crushing, grinding, drying, and classifying in one vertical unit

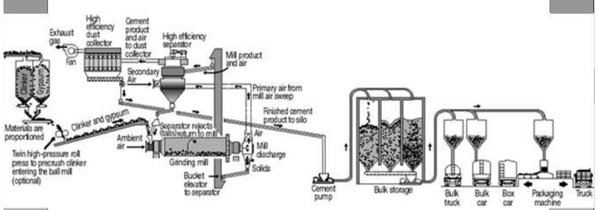
Dry Process Manufacture of Portland Cement

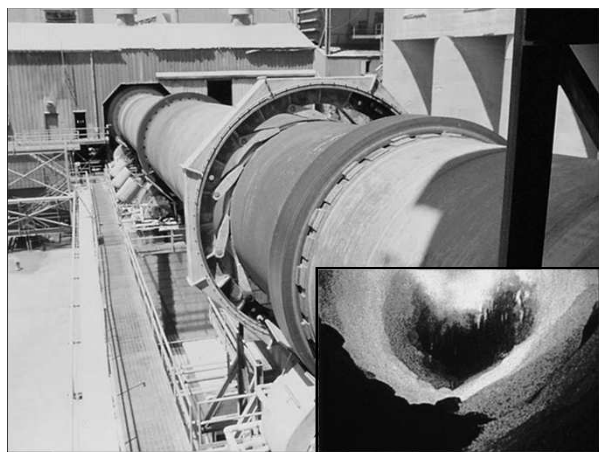
3. Burning changes raw mix chemically into clinker. Note four stage preheater, flash furnaces, and shorter kiln.



Dry Process Manufacture of Portland Cement

4. Clinker with gypsum is ground into portland cement and shipped

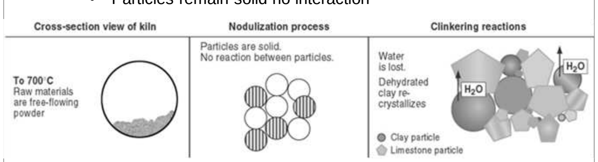




Process of Clinker Production

Temperatures up to 700°C

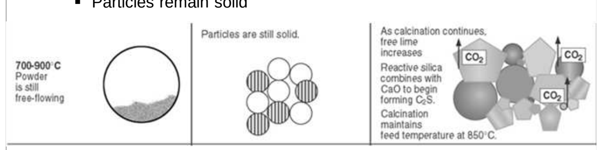
- Water evaporates at 100°C
- Dehydration of clay between 100-250°C
- Lose chemically absorbed water 300-600°C
- Particles remain solid no interaction



Process of Clinker Production

Temperatures between 700-900°C

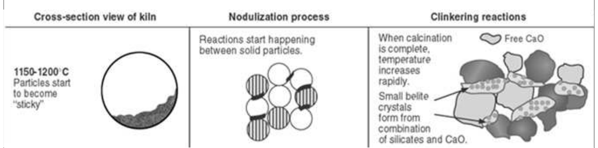
- Calcination continues, free lime (CaO) content increases
- At 700°C, 40% limestone calcined
- At 900 °C, 90-95% limestone calcined
- Impurities in limestone control temperature when limestone calcined
- Particles remain solid



Process of Clinker Production

Temperatures between 1150-1200°C

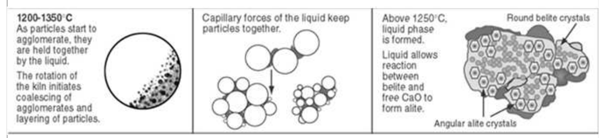
- Particles become sticky
- Calcination is complete and temperature rises quickly
- Belite begins to form first



Process of Clinker Production

Temperatures between 1200-1350°C

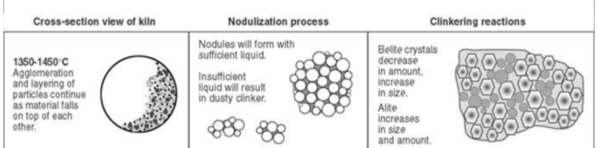
- Start getting to liquid phase and particles agglomerate
- C_3A and C_4AF melt



Process of Clinker Production

Temperatures between 1350-1450°C

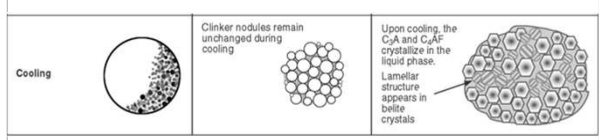
- Nodules form with 25% liquid containing constinuents that from (C_3A and C_4AF)
- C_3S and C_2S remain in the solid phase



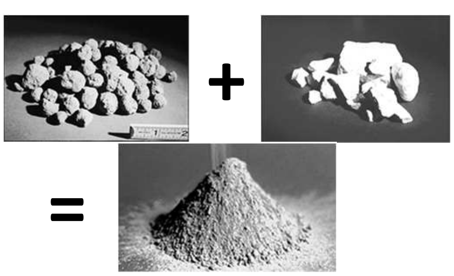
Process of Clinker Production

Cooling

- C_3A and C_4AF crystallize from the liquid phase
- Rate of cooling affects amount of C_3S and C_2S that form



Clinker Produced



Compound Composition

Chemical Name	Chemical Formula	Notation	Mass (%)
Tricalcium silicate	$3CaO \bullet SiO_2$	C_3S	50-70
Dicalcium silicate	$2CaO \bullet SiO_2$	C_2S	15-30
Tricalcium aluminate	$3CaO \bullet Al2O_3$	C_3A	5-10
Tetracalcium aluminoferrite	$4CaO \bullet Al_2O_3 \bullet Fe_2O_3$	C_4AF	5-15
Calcium sulfate dihydrate	$CaSO_4 . 2H_2O$	CSH_2	~ 5

Composition

The relative quantities of each of these phases affects:

- setting time
- rate of strength development
- overall strength
- durability
- color

It is important, then, to know the composition of the cement.

Chemical Analysis: Determine Composition

X-Ray Fluorescence (XRF) Spectroscopy

- Provides bulk elemental composition of materials
- Results are used for Bogue calculations

X-ray Powder Diffraction (XRD)

- Rapid analytical technique used for phase identification of a crystalline material
- Rietveld refinement used to analyze results and provide more precise portland cement phases

Chemical Analysis

ASTM C 114 - Standard Test Methods for Chemical Analysis of Hydraulic Cement

Oxide	Element	
SiO_2	Silicon dioxide	Major Components
Al_2O_3	Aluminum oxide	Major Components
Fe_2O_3	Ferric oxide	Major Components
CaO	Calcium oxide	Major Components
MgO	Magnesium oxide	Major Components
SO_3	Sulfur trioxide	Major Components
LOI	Loss on ignition	Major Components
Na_2O	Sodium oxide	Minor Components
K_2O	Potassium oxide	Minor Components
TiO_2	Titanium dioxide	Minor Components
P_2O_5	Phosphorus pentoxide	Minor Components
ZnO	Zinc oxide	Minor Components
Mn_2O_3	Manganic oxide	Minor Components
Sulfide sulfur		Minor Components

Chemical Analysis

Oxide	%
SiO_2	20.6
Al_2O_3	5.07
Fe_2O_3	2.90
CaO	63.9
MgO	1.53
SO_3	2.53
Na_2O	0.15
K_2O	0.73
LOI	1.58

90-95% (SiO_2 through MgO)

Oxide	Shorthand	Common Name
CaO	C	Lime
SiO_2	S	Silica
Al_2O_3	A	Alumina
Fe_2O_3	F	Ferric Oxide
MgO	M	Magnesia
K_2O	K	Alkalis
Na_2O	Na	Alkalis
SO_3	$\underline{S}$	Sulfate
CO_2	$\underline{C}$	Carbonate
H_2O	$\underline{H}$	Water

Compound Composition

Bogue Composition/Calculations

Alite (Tricalcium Silicate)

$C_3S = 4.07C – 7.60S – 6.72A – 1.43F – 2.85\mathbf{S}$

Belite (Dicalcium Silicate)

$C_2S = 2.87S – 0.75C_3S$

Aluminate Phase (Tricalcium Aluminate)

$C_3A = 2.65A – 1.69F$

Ferrite Compounds(Tetracalcium Aluminoferrite)

$C_4AF = 3.04F$

Compound Composition: Example Bogue

Oxide	%
SiO_2	20.6
Al_2O_3	5.07
Fe_2O_3	2.90
CaO	63.9
MgO	1.53
SO_3	2.53
Na_2O	0.15
K_2O	0.73
LOI	1.58

Calculated Phase Composition

$C_3S = 4.07(63.9) – 7.60(20.6) – 6.72(5.07) – 1.43(2.90) – 2.85(2.53) = \mathbf{58.1}$

$C_2S = 2.87(20.6) – 0.75(58.1) = \mathbf{15.6}$

$C_3A = 2.65(5.07) – 1.69(2.90) = \mathbf{8.5}$

$C_4AF = 3.04(8.8) = \mathbf{8.8}$

Phase	%
C_3S	58
C_2S	16
C_3A	9
C_4AF	9

Bogue Composition Assumptions

- All 4 phases are pure
- All the F present occurs as C_4AF, and the quantities of A = 0.64(% F) and C = 1.40 (% F) are subtracted from the appropriate totals.
- The remaining Al_2O_3 is combined as C_3A and a further quantity of C = 1.65 (% Al_2O_3) is subtracted from the total remaining CaO.
- The SiO_2 combines initially with CaO to form C_2S giving a provisional C_2S figure. The CaO combining with SiO_2 = 2.87%(SiO_2) is subtracted from the total CaO figure, and the remaining CaO is then combined with a part of the C_2S = 4.07(%CaO) to form C_3S.

As a result, Bogue compositions may be "off" by as much as 10% compared to XRD-determined compositions.

Compound Composition: Example Equivalent Alkalis

Oxide	%
SiO_2	20.6
Al_2O_3	5.07
Fe_2O_3	2.90
CaO	63.9
MgO	1.53
SO_3	2.53
Na_2O	0.15
K_2O	0.73
LOI	1.58

Sodium equivalent, Na_2O_e

$Na_2O_e = Na_2O + (0.658 \times K_2O)$

$Na_2O_e = 0.15 + (0.658 \times 0.73)$

Na_2O_e = 0.63%

Portland Cement: Chemical Requirements

Cement Type	I	II	III	IV	V
Chemical Composition and Analysis					
Aluminum oxide (Al_2O_3), max, %	…	6.0	…	…	…
Ferric oxide (Fe_2O_3), max, %	…	6.0	…	6.5	…
Magnesium oxide (MgO), max, %	6.0	6.0	6.0	6.0	6.0
Sulfur trioxide (SO_3),D max, %					
When (C_3A)E is 8 %	3.0	3.0	3.5	2.3	2.3
When (C_3A)E is more than 8 %	3.5	N/A	4.5	N/A	N/A
Loss on ignition, max, %					
When limestone is not an ingredient	3.0	3.0	3.0	2.5	3.0
When limestone is an ingredient	3.5	3.5	3.5	3.5	3.5
Insoluble residue, max, %	1.5	1.5	1.5	1.5	1.5
Bogue Calculations					
Tricalcium silicate (C_3S), max, %	…	…	…	35	…
Ferric oxide (Fe_2O_3), max, %	…	…	…	40	…
Tricalcium aluminate (C_3A), max, %	…	8	15	7	5
Sum of $C_3S + 4.75C_3A$, max, %	…	…	…	…	…
Tetracalcium aluminoferrite plus twice the tricalcium aluminate ($C_4AF + 2(C_3A)$), or solid solution ($C_4AF + C_2F$), as applicable, max, %	…	…	…	…	25

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Cement Chemistry, Specifications, and Testing

- Portland Cement Introduction and History
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- Cement Specifications

Portland Cement

By definition:

- a hydraulic cement produced by pulverizing clinker consisting essentially of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulfate as an interground addition.

Types of Portland Cement

ASTM C150 (AASHTO M 85)

I Normal

II Moderate sulfate resistance

III High early strength

IV Low heat of hydration

V High sulfate resistance

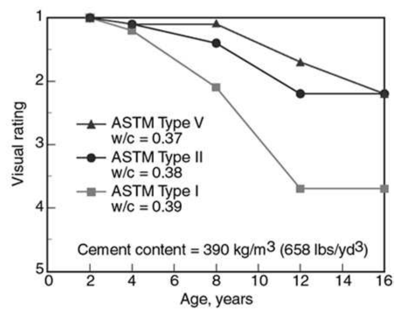
Type II & Type V Sulfate Resistant Cements

Outdoor Sulfate Test

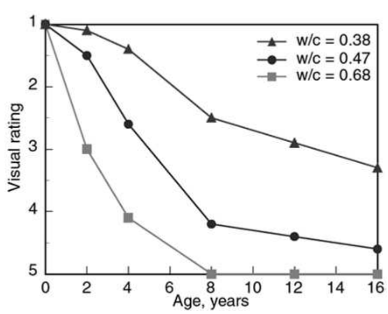
Type V Cement
W/C-ratio = 0.65

Type V Cement
W/C-ratio = 0.39

Performance of Concretes Made with Different Cements in Sulfate Soil



Performance of Concretes Made with Different W/C-Ratios in Sulfate Soil



Type IV - Moderate and Low Heat Cements

Type III - High Early Strength Cements

Blended Hydraulic Cement (ASTM C 595)

General:

- a hydraulic cement consisting of two or more inorganic constituents, which contribute to the strength gaining properties of cement.

Blended Cements

Clinker
Gypsum
Portland cement
Fly ash
Slag
Silica Fume
Calcined Clay

Blended Hydraulic Cements

ASTM C 595

Type IS	Portland blast-furnace slag cement
Type IP	Portland-pozzolan cement
Type IL	Portland-limestone cement
Type IT	Ternary blended cement

ASTM C1157 - Hydraulic Cements

General:

- First performance specification for hydraulic cements
- Cements meet physical performance test requirements rather than prescriptive restrictions on ingredients or cement chemistry as in other cement specifications.
- Provides for six types

Hydraulic Cement

ASTM C 1157

Type GU	General use
Type HE	High early strength
Type MS	Moderate sulfate resistance
Type HS	High sulfate resistance
Type MH	Moderate heat of hydration
Type LH	Low heat of hydration

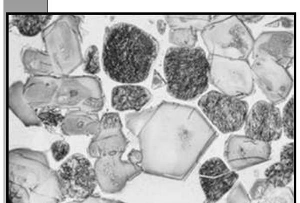
Cement specification	Cement Applications: General purpose	Moderate heat of hydration	High early strength	Low heat of hydration	Moderate sulfate resistance	High sulfate resistance	Resistance to alkali-silica reactivity (ASR)
ASTM C 150 (AASHTO M 85) portland cements	I	II (moderate heat option)	III	IV	II	V	Low alkali option
ASTM C 595 (AASHTO M 240) blended hydraulic cements	IS IP I(PM) I(SM) S, P	IS(MH) IP(MH) I(PM)(MH) I(SM)(MH)		P(LH)	IS(MS) IP(MS) P(MS) I(PM)(MS) I(SM)(MS)		Low reactivity option
ASTM C 1157 hydraulic cements	GU	MH	HE	LH	MS	HS	Option R

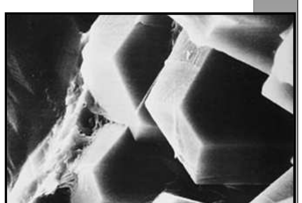
Type of portland cement	Potential compound composition,%: C_3S	C_2S	C_3A	C_4AF	Blaine fineness m^2/kg
I (mean)	54	18	10	8	369
II (mean)	55	19	6	11	377
III (mean)	55	17	9	8	548
IV (mean)	42	32	4	15	340
V (mean)	54	22	4	13	373
White (mean)	63	18	10	1	482

Chemical Compounds of Portland Cement

Polished thin-section examination of portland cement clinker shows

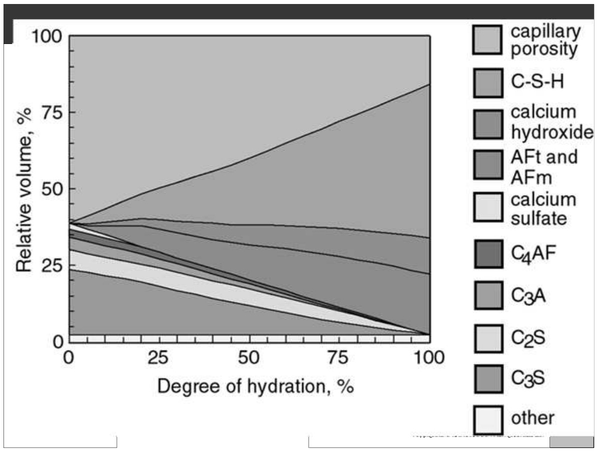
- Alite (C_3S), Light angular crystals
- Belite (C_2S), Darker rounded crystals

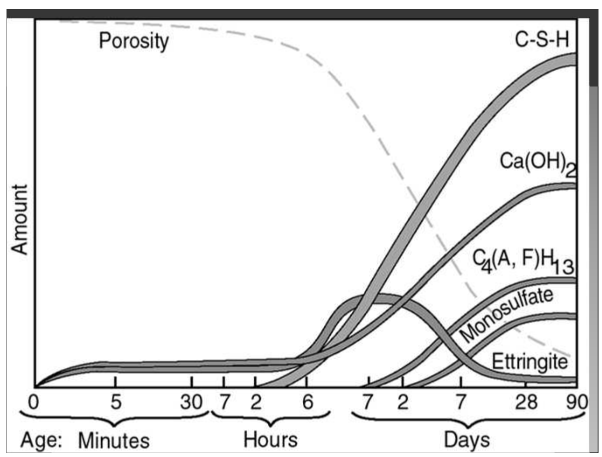




Portland Cement Compound Hydration Reactions (Oxide Notation)

$2 (3CaO \cdot SiO_2)$ Tricalcium silicate	$+ 11 H_2O$ Water	$= 3CaO \cdot 2SiO_2 \cdot 8H_2O$ Calcium silicate hydrate (C-S-H)	$+ 3 (CaO \cdot H_2O)$ Calcium hydroxide
$2 (2CaO \cdot SiO_2)$ Dicalcium silicate	$+ 9 H_2O$ Water	$= 3CaO \cdot 2SiO_2 \cdot 8H_2O$ Calcium silicate hydrate (C-S-H)	$+ CaO \cdot H_2O$ Calcium hydroxide
$3CaO \cdot Al_2O_3$ Tricalcium aluminate	$+ 3 (CaO \cdot SO_3 \cdot 2H_2O)$ Gypsum	$+ 26 H_2O$ Water	$= 6CaO \cdot Al_2O_3 \cdot 3SO_3 \cdot 32H_2O$ Ettringite
$2 (3CaO \cdot Al_2O_3)$ Tricalcium aluminate	$+ 6CaO \cdot Al_2O_3 \cdot 3SO_3 \cdot 32H_2O$ Ettringite	$+ 4 H_2O$ Water	$= 3 (4CaO \cdot Al_2O_3 \cdot SO_3 \cdot 12H_2O)$ Calcium monosulfoaluminate
$3CaO \cdot Al_2O_3$ Tricalcium aluminate	$+ CaO \cdot H_2O$ Calcium hydroxide	$+ 12 H_2O$ Water	$= 4CaO \cdot Al_2O_3 \cdot 13H_2O$ Tetracalcium aluminate hydrate
$4CaO \cdot Al_2O_3 \cdot Fe_2O_3$ Tetracalcium aluminoferrite	$+ 10 H_2O$ Water	$+ 2 (CaO \cdot H_2O)$ Calcium hydroxide	$= 6CaO \cdot Al_2O_3 \cdot Fe_2O_3 \cdot 12H_2O$ Calcium aluminoferrite hydrate





Type of portland cement	Potential compound composition,%				Blaine fineness m²/kg
	C_3S	C_2S	C_3A	C_4AF	
I (mean)	54	18	10	8	369
II (mean)	55	19	6	11	377
III (mean)	55	17	9	8	548
IV (mean)	42	32	4	15	340
V (mean)	54	22	4	13	373
White (mean)	63	18	10	1	482

Comparison: British Standards Institution

BS EN 197-1:2011

Part 1: Composition, specifications and conformity criteria for common cements

Separates into:

- 5 main cement types
- 27 Common Cements
- 7 Sulfate Resisting Cements
  - 3 Low Early Strength blast furnace cements
  - 2 sulfate resisting low early strength blast furnace cements
- Definition of each cement includes:
  - Proportions
  - 9 Strength Classes
  - Mechanical, Physical, and Chemical Requirements

Common Cements (5 Main Types)

Composition:

- CEM I – Portland Cement
  - Minor Constituents (0-5%)
- CEM II – Portland-composite cement
  - Slag cement, Silica Fume, Fly Ash, Pozzolans
- CEM III – Blast furnace cement
  - Slag cement
- CEM IV – Pozzolanic cement
  - Pozzolans
- CEM V – Composite cement
  - Slag cement and pozzolans (ternary blends)

Main types	Notation of the 27 products (types of common cement)		Composition (percentage by mass[a]) Main constituents: Clinker K	Blast-furnace slag S	Silica fume D[b]	Pozzolana natural P	Pozzolana natural calcined Q	Fly ash siliceous V	Fly ash calcareous W	Burnt shale T	Limestone L	Limestone LL	Minor additional constituents	
CEM I	Portland cement	CEM I	95-100	–	–	–	–	–	–	–	–	–	0-5	Portland Cement Clinker
CEM II	Portland-slag cement	CEM II/A-S	80-94	6-20	–	–	–	–	–	–	–	–	0-5	Portland Cement Clinker + Slag Cement, Silica Fume, Pozzolans, Fly Ash, Shale, **OR** Limestone
		CEM II/B-S	65-79	21-35	–	–	–	–	–	–	–	–	0-5	
	Portland-silica fume cement	CEM II/A-D	90-94	–	6-10	–	–	–	–	–	–	–	0-5	
	Portland-pozzolana cement	CEM II/A-P	80-94	–	–	6-20	–	–	–	–	–	–	0-5	
		CEM II/B-P	65-79	–	–	21-35	–	–	–	–	–	–	0-5	
		CEM II/A-Q	80-94	–	–	–	6-20	–	–	–	–	–	0-5	
		CEM II/B-Q	65-79	–	–	–	21-35	–	–	–	–	–	0-5	
	Portland-fly ash cement	CEM II/A-V	80-94	–	–	–	–	6-20	–	–	–	–	0-5	
		CEM II/B-V	65-79	–	–	–	–	21-35	–	–	–	–	0-5	
		CEM II/A-W	80-94	–	–	–	–	–	6-20	–	–	–	0-5	
		CEM II/B-W	65-79	–	–	–	–	–	21-35	–	–	–	0-5	
	Portland-burnt shale cement	CEM II/A-T	80-94	–	–	–	–	–	–	6-20	–	–	0-5	
		CEM II/B-T	65-79	–	–	–	–	–	–	21-35	–	–	0-5	
	Portland-limestone cement	CEM II/A-L	80-94	–	–	–	–	–	–	–	6-20	–	0-5	
		CEM II/B-L	65-79	–	–	–	–	–	–	–	21-35	–	0-5	
		CEM II/A-LL	80-94	–	–	–	–	–	–	–	–	6-20	0-5	
		CEM II/B-LL	65-79	–	–	–	–	–	–	–	–	21-35	0-5	
	Portland-composite cement[c]	CEM II/A-M	80-88	← 12-20 →									0-5	
		CEM II/B-M	65-79	← 21-35 →									0-5	
CEM III	Blast furnace cement	CEM III/A	35-64	36-65	–	–	–	–	–	–	–	–	0-5	PC + Slag Cement
		CEM III/B	20-34	66-80	–	–	–	–	–	–	–	–	0-5	
		CEM III/C	5-19	81-95	–	–	–	–	–	–	–	–	0-5	
CEM IV	Pozzolanic cement[c]	CEM IV/A	65-89	–	← 11-35 →					–	–	–	0-5	PC + Pozzolans
		CEM IV/B	45-64	–	← 36-55 →					–	–	–	0-5	
CEM V	Composite cement[c]	CEM V/A	40-64	18-30	–	← 18-30 →			–	–	–	–	0-5	PC + Slag Cement + Pozzolans or Fly Ash
		CEM V/B	20-38	31-49	–	← 31-49 →			–	–	–	–	0-5	

[a] The values in the table refer to the sum of the main and minor additional constituents.

[b] The proportion of silica fume is limited to 10 %.

[c] In Portland-composite cements CEM II/A-M and CEM II/B-M, in pozzolanic cements CEM IV/A and CEM IV/B and in composite cements CEM V/A and CEM V/B the main constituents other than clinker shall be declared by designation of the cement (for examples, see Clause 8).

Sulfate Resisting Common Cements

Main types	Notation of the seven products (types of sulfate resisting common cement)		Composition (percentage by mass[a]) Main constituents: Clinker K	Blast furnace slag S	Pozzolana natural P	Siliceous fly ash V	Minor additional constituents	
CEM I	Sulfate resisting Portland cement	CEM I-SR 0 CEM I-SR 3 CEM I-SR 5	95 – 100				0 – 5	Portland Cement Clinker with Limited C_3A
CEM III	Sulfate resisting blast furnace cement	CEM III/B-SR	20 – 34	66 – 80	-	-	0 – 5	Portland Cement Clinker + Slag Cement
		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	Portland Cement Clinker + Nat. Pozz. Or Class F Fly Ash
		CEM IV/B-SR	45 – 64		⟸ — 36 – 55 — ⟹		0 – 5	

[a] The values in the table refer to the sum of the main and minor additional constituents.

[b] In sulfate resisting pozzolanic cements, types CEM IV/A-SR and CEM IV/B-SR, the main constituents other than clinker shall be declared by designation of the cement (for examples, see Clause 8).

- CEM I – C_3A limited between 0-5% for three cements
- CEM III – No requirement for C_3A content on clinker
- CEM IV - C_3A limited below 9%

Mechanical and Physical Requirements

Strength class	Compressive strength MPa: Early strength 2 days	Early strength 7 days	Standard strength 28 days		Initial setting time min	Soundness (expansion) mm
32,5 L[a]	-	≥ 12,0	≥ 32,5	≤ 52,5	≥ 75	≤ 10
32,5 N	-	≥ 16,0				
32,5 R	≥ 10,0	-				
42,5 L[a]	-	≥16,0	≥ 42,5	≤ 62,5	≥ 60	
42,5 N	≥ 10,0	-				
42,5 R	≥ 20,0	-				
52,5 L[a]	≥ 10,0	-	≥ 52,5	-	≥ 45	
52,5 N	≥ 20,0	-				
52,5 R	≥ 30,0	-				

[a] Strength class only defined for CEM III cements.

- Three classes of standard strength (@ 28days): 32.5, 42.5, 52.5
- Three classes of early strength: N – Normal, L – Low, R – High
  - Class L is only applicable to CEM III cements

Chemical Requirements

1	2	3	4	5
Property	Test reference	Cement type	Strength class	Requirements[a]
Loss on ignition	EN 196-2	CEM I CEM III	All	≤ 5,0 %
Insoluble residue	EN 196-2 [b]	CEM I CEM III	All	≤ 5,0 %
Sulfate content (as SO_3)	EN 196-2	CEM I CEM II[c] CEM IV CEM V	32,5 N 32,5 R 42,5 N	≤ 3,5 %
			42,5 R 52,5 N 52,5 R	≤ 4,0 %
		CEM III[d]	All	
Chloride content	EN 196-2	all [e]	All	≤ 0,10 %[f]
Pozzolanicity	EN 196-5	CEM IV	All	Satisfies the test

[a] Requirements are given as percentage by mass of the final cement.

[b] Determination of residue insoluble in hydrochloric acid and sodium carbonate.

[c] Cement types CEM II/B-T and CEM II/B-M with a T content > 20 % may contain up to 4,5 % sulfate (as SO_3) for all strength classes.

[d] Cement type CEM III/C may contain up to 4,5 % sulfate.

[e] Cement type CEM III may contain more than 0,10 % chloride but in that case the maximum chloride content shall be stated on the packaging and/or the delivery note.

[f] For pre-stressing applications cements may be produced according to a lower requirement. If so, the value of 0,10 % shall be replaced by this lower value which shall be stated in the delivery note.

Agenda

Cement Chemistry, Specifications, and Testing

- Portland Cement Introduction and History
- Cement Plants and Manufacturing
- Cement Classifications and Chemistry
- **Chemical and Physical Cement Testing**
- Cement Specifications

Cement Testing – Standard Requirements

Cement Fineness and Particle Size

- ASTM C204 – Blaine Surface Area
- ASTM C115 – Turbidimeter
- ASTM C430 – No. 325 Sieve (45 µm Sieve)
- Particle Size Distribution (PSD)

Heat of Hydration

- ASTM C186 – Heat of Hydration
- ASTM C1702 – Isothermal Calorimetry

Loss on Ignition

Density of Cement

Thermal Analysis of Cement

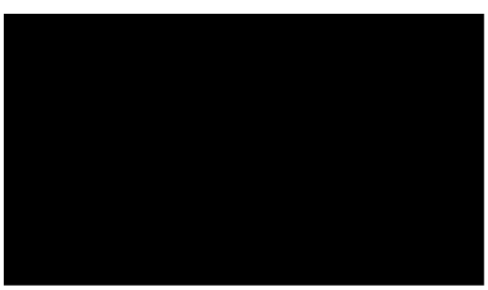
Fineness Standards

ASTM C204 – Blaine Surface Area

ASTM C115 – Turbidimeter

ASTM C430 – No. 325 Sieve

Procedure: ASTM C204 – Blaine Surface Area



Fineness

Requirements for Type I, II, IV & V

- (No requirements for Type III)

	Air Permeability
Minimum, m^2/kg	260
Maximum, m^2/kg	430 (Type IV Only)
Typical Values, m^2/kg	350-380 Type I 450-600 Type III

No limits for blended cement (ASTM C 595), hydraulic cements (ASTM C 1157), or slag cement (ASTM C989) but values must be reported

Heat of Hydration

ASTM C186 - Standard Test Method for Heat of Hydration of Hydraulic Cement

ASTM C1702 - Standard Test Method for Measurement of Heat of Hydration of Hydraulic Cementitious Materials Using Isothermal Conduction Calorimetry

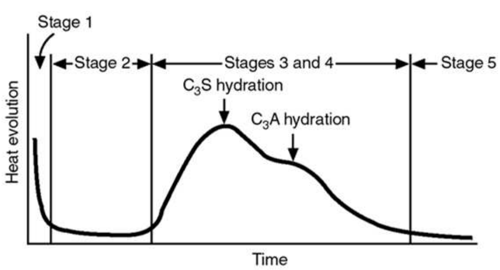
What is Isothermal Calorimeter?

Temperature around a paste or mortar sample is maintained constant to simulate different curing temperatures and allow for unbiased comparisons of cements.

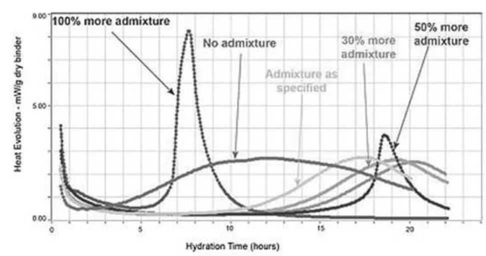
Calorimetry measures the heat generated. Provides information on:

- Setting Time,
- Hydration Rates,
- Admixture Interactions, and
- Compressive Strength.

Heat Evolution

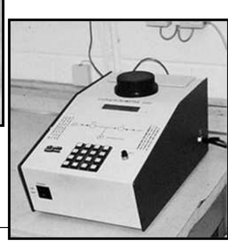


ASTM C1702 – Isothermal Calorimetry



Density of Cement

Le Chatelier flask (ASTM C 188 or AASHTO T 133)



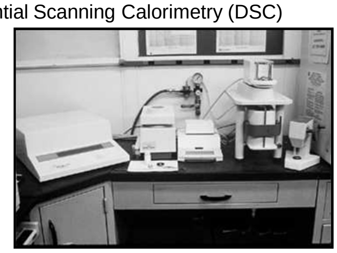
Helium pycnometer

Thermal Analysis

Thermogravimetric analysis (TGA)

Differential Thermal Analysis (DTA)

Differential Scanning Calorimetry (DSC)



Differential Scanning Calorimetry Thermogram of a Cement Paste after

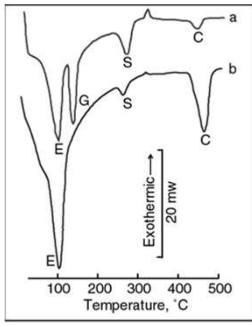
(a) 15 min

(b) 24 h of Hydration

C = calcium hydroxide

E = ettringite

G = gypsum

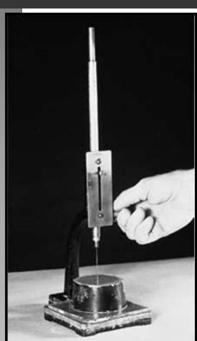


Cement Testing – Physical Requirements

Paste Testing

- Normal Consistency (ASTM C187)
- Vicat Time of Setting (ASTM C191)
- Soundness Test (ASTM C151)

ASTM C191 - Time of Setting of Hydraulic Cement by Vicat Needle



A paste that is proportioned and mixes to normal consistency is molded and placed in a moist cabinet and allowed to start setting

Periodic penetration tests are performed on this paste by allowing a 1-mm Vicat needle to settle into the past

Scope

These test methods determine the **time of setting** of hydraulic cement by means of the Vicat needle. Two test methods are given;

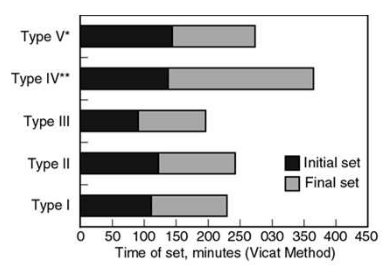
- **Method A** is the Reference Test Method using the **manually** operated standard Vicat apparatus, while
- **Method B** permits the use of an **automatic** Vicat machine that has, in accordance with the qualification requirements of this method, demonstrated acceptable performance.

Summary of Test Method

Initial time of set is the time elapsed between the initial contact of cement and water and the time when the penetration is measured to be **25 mm**

Final time of set is the time elapsed between the initial contact of cement and water and the time when the needle does not leave a complete circular impression in the paste surface

Setting Times for Portland Cements



*Average of two values for final set

**Average of two values for initial set; one value for final set

Setting Time Requirements by Specification

ASTM C150 – Portland Cement Specification

- Initial Set = not less than 45 min. and not more than 375 min.

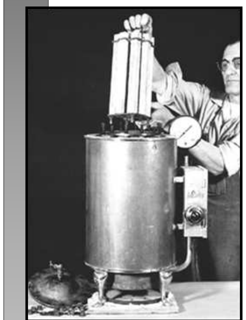
ASTM C595 – Blended Cement Specification

- Initial Set = not less than 45 min. and not more than 7 hrs.

ASTM C1157 – Hydraulic Cement Specification (Performance Specification)

- Initial Set = not less than 45 min. and not more than 7 hrs.

Soundness Test



ASTM C 151 - Standard Test Method for Autoclave Expansion of Hydraulic Cement

ASTM C151 – Soundness Testing

Determination of the ***expansion*** of a ***hardened cement paste*** when exposed to the ***autoclave conditions*** in this method.

The autoclave expansion test provides an ***index*** of ***potential delayed expansion*** caused by the hydration of ***CaO*** or ***MgO***, or both, when present in hydraulic cement.

What are we testing for…..?

Expansion reactions primarily associated with autoclave expansion:

$MgO \rightarrow Mg(OH)_2$
Periclase → Brucite

$CaO \rightarrow Ca(OH)_2$
fCaO → Portlandite

- Portlandite also forms from C_3S and C_2S reactions and is consumed with carbonation (forming $CaCO_3$)

Apparatus: Autoclave

Autoclave - a high-pressure steam vessel capable of:

- Raising Generating Steam and Pressure to 2 MPa [295 psi] in 45 to 75 min,
- Maintain the 2 ± 0.07 MPa [295 ± 10 psi] pressure for 3 h, and
- Lowering the pressure below 0.07 MPa [10 psi] at the end of 11/2 h.

Soundness Requirements by Specification

ASTM C150 – Portland Cement Specification

- I, II, III, IV, and V: Max. Expansion, 0.80%

ASTM C595 – Blended Cement Specification

- "The specimens shall remain firm and hard and show no signs of distortion, cracking, checking, pitting, or disintegration when subjected to the autoclave expansion test."
- Max. Expansion, 0.80%
- Max. Contraction, 0.20%

ASTM C1157 – Hydraulic Cement Specification (Performance Specification)

- Max. Expansion, 0.80%

Cement Testing – Physical Requirements

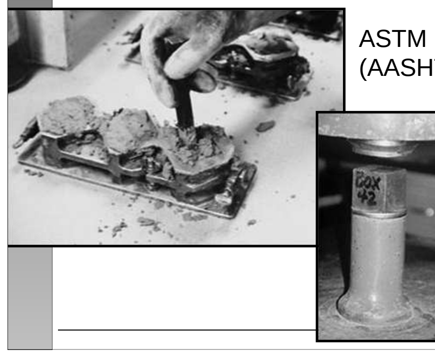
Paste Testing

- Normal Consistency (ASTM C187)
- Vicat Time of Setting (ASTM C191)
- Soundness Test (ASTM C151)

Mortar Testing

- Consistency of Mortar (ASTM C1437)
- Compressive Strength (ASTM C109)
- Air Content (ASTM C185)
- Sulfate Expansion (ASTM C1038)
- Sulfate Resistance (ASTM C1012)

Mortar Cubes



ASTM C 109
(AASHTO T 106)

Procedure: Composition and Mixing Mortars

Mortar consists of 1 part cement and 2.75 parts of graded sand.

Use water/cement = 0.485 for portland cements and 0.460 for air-entrained portland cements.

Mix per ASTM C305.

Number of Specimens	6	9	12
Cement, g	500	740	1060
Sand, g	1375	2035	2915
Water, mL			
Portland (0.485)	242	359	514
Air-entraining portland (0.460)	230	340	488
Other (to flow of 110 ± 5)	...	...	...

Source: ASTM C109

Procedure: Molding Test Specimens

Procedure: Molding Test Specimens

1. Place 25 mm Layer

2. Tamp 32 Times.

3. Fill Mold, Tamp as Specified, and Bring in Forced out Mortar.

Procedure: Molding Test Specimens

4. Draw Flat Side Trowel at Right Angle to Length of Mold.

5. Draw Flat Side of Trowel Lightly Down Length of Mold.

6. Cut off Mortar By Drawing Trowel with A Sawing Motion.

Procedure: Determination of Compressive Strength

Procedure: Determination of Compressive Strength

Immediately after completing the molding process, place the test specimens in a moist closet or room.

Test the concrete cube specimens immediately after removing from the moist closet in the case of 24-hr specimens.

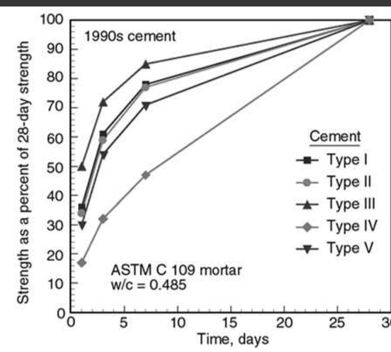
Test Age	Permissible Tolerance
24 h	±½ h
3 days	±1 h
7 days	±3 h
28 days	±12 h

Source: ASTM C109

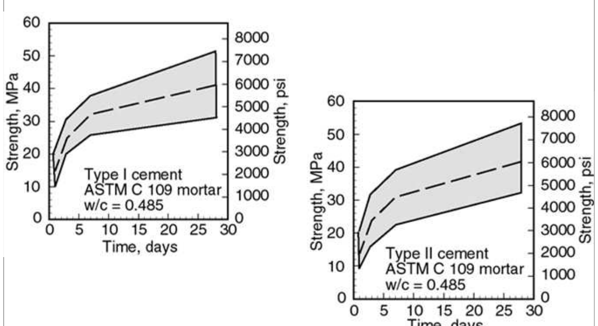
If more than one specimen is removed from curing, keep the samples in water at 23 ± 2°C

Procedure: Determination of Compressive Strength

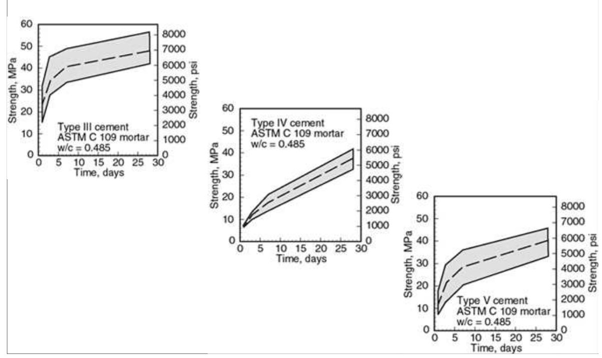
Strength Development of Mortar Cubes



Strength Development Type I and II Cements



Strength Development Type III, IV, and V Cements



ASTM C185 – Air Content

Proportion the standard mortar using

- 350 g Cement
- 1400 g 20-30 Standard Sand
- Sufficient water to give a flow of 87 ½ ± 7 ½ %.

Mixing Mortar per Practice C305

Procedure: Mass per 400 mL of Mortar

Procedure: Mass per 400 mL of Mortar

1. Place Mortar in Three Equal Layers

2. Tamp each Layer 20 Times.

3. Tap the Sides of the Measure at Five Different Points.

Procedure: Mass per 400 mL of Mortar

4. Cut off Mortar Plane with Sawing Motion with Straightedge or Trowel.

5. Wipe off Adhered Mortar and Water to Outside of Mold.

6. Determine Mass of Measure and Constituents.

Calculation: Air Content

- Calculate the air content of the mortar, expressed as
- When,
  - Portland Cement SG = 3.15
  - 20-30 Standard Sand SG = 2.65

$$\textit{Air Content, volume}\ \% = 100 - W\left[\frac{(182.7+P)}{(2000+4P)}\right]$$

W= Mass of 400 mL of Mortar, g
P = Percentage of Water(%)

Air Content Requirements by Specification

ASTM C150 – Portland Cement Specification

- "*Compliance with the requirements of this specification does not necessarily ensure that the desired air content will be obtained in concrete*."
- I, II, III, IV, and V: Max. Air Content, 12%
- IA, IIA, and IIIA: Max. Air Content, 22%, Min. Air Content 16%

ASTM C595 – Blended Cement Specification

- Max. Air Content, 12%

ASTM C1157 – Hydraulic Cement Specification (Performance Specification)

- *"Air content shall be reported on all certificates of test results requested from the manufacturer."*
- ***No Limit***

Sulfate Expansion (Internal Sulfates)


Designation: C1038/C1038M – 14b

Standard Test Method for Expansion of Hydraulic Cement Mortar Bars Stored in Water

ASTM C1038 - Standard Test Method for Expansion of Hydraulic Cement Mortar Bars Stored in Water

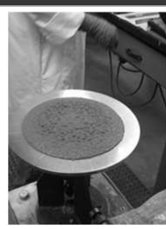
Purpose

Determine the amount of ***expansion*** of a ***mortar bar*** when it is stored in ***water***.

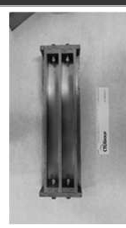
The amount of mortar-bar expansion may ***relate*** to the amount of ***sulfate*** in the ***cement***; ***expansion*** may become ***excessive*** when the cement contains too much ***sulfate***.

Procedure: Mixing and Molding

1. Mix Cement Mortar per ASTM C305. Proportions are Provided in ASTM C1038.



2. Determine Water Content per ASTM C1437



3. Mold Four Specimens per Mix

Procedure: Curing and Testing

4. Moist Cure Specimen(s) for 22 ± 0.5 hr per ASTM C511.

5. Then at 23.0 ± 2.0°C [73.5 ± 3.5°F] for at least 30 min prior to making the initial measurement.

6. Store in Lime-Saturated Water until Age of 14 Days and Measure Length Change

Sulfate Expansion Requirements by Specification

ASTM C150 – Portland Cement Specification

- Only Required if SO_3 greater than chemical requirements
- Expansion < 0.020% at 14 days

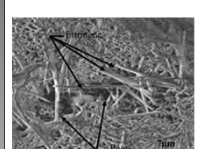
ASTM C595 – Blended Cement Specification

- Only Required if SO_3 greater than chemical requirements
- Expansion < 0.020% at 14 days

ASTM C1157 – Hydraulic Cement Specification (Performance Specification)

- ***Required Testing***
- Expansion < 0.020% at 14 days

Sulfate Resistance (External Sulfates)




ASTM C1012 - Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution

Scope

This test method provides a means of assessing the ***sulfate resistance*** of ***mortars*** made using portland cement, blends of portland cement with pozzolans or slags, and blended hydraulic cements.

The standard exposure solution used in this test method, unless otherwise directed, contains 352 moles of Na_2SO_4 per m^3 (50 g/L).

Other sulfate concentrations or other sulfates such as $MgSO_4$ may be used to simulate the environmental exposure of interest.

Procedure: Mixing and Molding

1. Mix Cement Mortar per ASTM C305. Proportions are Provided in ASTM C109.

2. Mold Six Mortar Bars and Up To 21 Cubes for Compressive Strength.

3. Cure the specimens at 35 ± 3°C (95 ± 5°F) for 23 1⁄2 h ± 30 min. At 23 1⁄2 ± 6 30 min, remove molds from container and demold the specimens

Procedure: Curing and Testing

4. After demolding, if the mean strength of the two cubes is 20 MPa [2850 psi] or more, observe and record comparator readings of mortar bars and place all the bars in the sulfate solution.

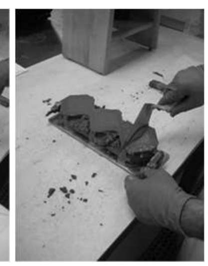
If 20 MPa [2850 psi] is not achieved, store the demolded cubes and mortar bars in the curing tank and test additional cubes

5. Store sulfate solution at 23.0 ± 2.0°C [73.5 ± 3.5°F]. Measure at 1, 2, 3, 4, 8, 13, and 15 weeks and subsequent at 4, 6, 9, 12, 15, and 18 months.

Procedure: Molding Test Specimens

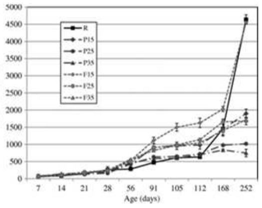
4. Draw Flat Side Trowel at Right Angle to Length of Mold.

5. Draw Flat Side of Trowel Lightly Down Length of Mold.



6. Cut off Mortar By Drawing Trowel with A Sawing Motion.

Fly Ash vs. Pumice vs. Portland Cement



Sulfate Resistance Requirements by Specification

ASTM C150 – Portland Cement Specification

- Not Required Testing

ASTM C595 – Blended Cement Specification

- Required for only:
- Type MS (Moderate Sulfate Resistance)
  - Expansion at 180 days < 0.10
- Type HS (High Sulfate Resistance)
  - Expansion at 180 days < 0.05
  - Expansion at 1 Year < 0.10

ASTM C1157 – Hydraulic Cement Specification (Performance Specification)

- Required for only:
- Type MS (Moderate Sulfate Resistance)
  - Expansion at 180 days < 0.10
- Type HS (High Sulfate Resistance)
  - Expansion at 180 days < 0.05
  - Expansion at 1 Year < 0.10

Agenda

Cement Chemistry, Specifications, and Testing

- Portland Cement Introduction and History
- Cement Plants and Manufacturing
- Cement Classifications and Chemistry
- Chemical and Physical Cement Testing
- **Cement Specifications**

Review: Cement Tests and Specifications

Cement Paste Testing

- Normal Consistency (ASTM C187)
- Vicat Time of Setting (ASTM C191)
- Soundness Test (ASTM C151)

Mortar Testing

- Consistency of Mortar (ASTM C1437)
- Compressive Strength (ASTM C109)
- Air Content (ASTM C185)
- Sulfate Expansion (ASTM C1038)
- Sulfate Resistance (ASTM C1012)

Cement Specifications

- ASTM C150 - Portland Cement
- ASTM C595 - Blended Cement Specification
- ASTM C1157 - Hydraulic Cement Specification (Performance Specification)

Portland Cement

ASTM C150 - Standard Specification for Portland Cement

- Prescriptive and Performance-based Specification (Hybrid)

Prescriptive-based Specification: have limits on chemical composition, some physical properties, and restrictions on ingredients

Performance-based Specification: have requirements for setting time, strength, and durability

Portland Cement Types (ASTM C150)

Type I – Normal

- General-purpose portland cement

Type II – Moderate Sulfate Resistance

- Used where protection from sulfate is required for structures exposed to soil or ground water

Severity of potential exposure	Water-soluble sulfate (SO_4) in soil, % by mass*	Sulfate (SO_4)* in water, ppm	w/cm by mass, max.†‡	Cementitious material requirements
Class 0 exposure	0.00 to 0.10	0 to 150	No special requirements for sulfate resistance	No special requirements for sulfate resistance
Class 1 exposure	> 0.10 and < 0.20	> 150 and < 1500	0.50‡	C150 Type II or equivalent§
Class 2 exposure	0.20 to < 2.0	1500 to < 10,000	0.45‡	C150 Type V or equivalent§
Class 3 exposure	2.0 or greater	10,000 or greater	0.40‡	C150 Type V plus pozzolan or slag§

Portland Cement Types (ASTM C150)

Type III – High early strength

- Chemically similar to Type I, but ground finer
- Used in precast construction

Type IV – Low heat of hydration

- Mass concrete structures
- Not commonly manufactured in North America

Type V – High Sulfate resistance

ASTM C150 Requirements

Chemical Requirements

Chemical analysis

Compound composition

Chemical limits

Physical Requirements

Fineness

Soundness

Consistency (Flow and Normal Consistency)

Setting Time

Compressive strength

Heat of hydration

Loss on ignition

Density

Air content

Sulfate expansion

Portland Cement: Prescriptive Requirements

Ingredients

- Portland Cement Clinker
- Calcium Sulfate
- Limestone (less than 5%)
- Inorganic Processing Additions (less than 5%)
- Organic Processing Additions (less than 1%)
- Air-entraining addition

Portland Cement: Chemical Requirements

Cement Type	I	II	III	IV	V
Aluminum oxide (Al_2O_3), max, %	...	6.0	...	...	...
Ferric oxide (Fe_2O_3), max, %	...	6.0	...	6.5	...
Magnesium oxide (MgO), max, %	6.0	6.0	6.0	6.0	6.0
Sulfur trioxide (SO_3),D max, %					
When (C_3A)E is 8 %	3.0	3.0	3.5	2.3	2.3
When (C_3A)E is more than 8 %	3.5	N/A	4.5	N/A	N/A
Loss on ignition, max, %					
When limestone is not an ingredient	3.0	3.0	3.0	2.5	3.0
When limestone is an ingredient	3.5	3.5	3.5	3.5	3.5
Insoluble residue, max, %	1.5	1.5	1.5	1.5	1.5
Tricalcium silicate (C_3S), max, %	...	...	...	35	...
Ferric oxide (Fe_2O_3), max, %	...	...	...	40	...
Tricalcium aluminate (C_3A), max, %	...	8	15	7	5
Sum of $C_3S + 4.75C_3A$, max, %	...	...	...	...	...
Tetracalcium aluminoferrite plus twice the tricalcium aluminate ($C_4AF + 2(C_3A)$), or solid solution ($C_4AF + C_2F$), as applicable, max, %	...	...	...	...	25

Chemical Composition and Analysis

Bogue Calculations

Portland Cement: Physical Requirements

Cement Type	I	II	III	IV	V
Air content of mortar, volume %					
max	12	12	12	12	12
Fineness, Specific Surface, m^2/kg					
Air permeability test					
min.	260	260	...	260	260
max.	...	...	...	430	...
Autoclave expansion, max. %	0.8	0.8	0.8	0.8	0.8
Compressive Strength, MPA (psi)					
1 day	...	...	12 [1740]	...	...
3 days	12 [1740]	10 [1450]	24 [3480]		8 [1160]
7 days	19 [2760]	17 [2470]	...	7 [1020]	15 [2180]
28 days	...	...	...	17 [2470]	21 [3050]
Time of setting; Vicat test:					
Time of Setting, min. (not less thar	45	45	45	45	45
Time of Setting, min. (not more thá	375	375	375	375	375

Prescriptive Requirement

Performance Requirements

Blended Hydraulic Cements

ASTM C595 - Standard Specification for Blended Hydraulic Cements

- Prescriptive and Performance-based Specification (Hybrid)

Applies to:

- blended hydraulic cements for both general and special applications, using slag, pozzolan, limestone, or some combination of these, with portland cement or portland cement clinker or slag with lime.

Classification

Type IS—Portland blast-furnace slag cement.

Type IP—Portland-pozzolan cement.

Type IL—Portland-limestone cement.

Type IT—Ternary blended cement.

Blended Cements: Chemical Requirements

- Prescriptive Limits
  - Based-on Chemical Analysis

Cement Type	IS(<70), IT(P<S<70), IT(L<S<70)	IS(≥70), IT(S≥70)	IP, IT(P≥S), IT(P≥L)	IL, IT(L≥S), IT(L≥P)
Magnesium oxide (MgO), max, %	...	...	6.0	...
Sulfate reported as SO_3, max, %	3.0	4.0	4.0	3.0
Sulfide reported as S^2, max, %	2.0	2.0	...	...
Insoluble residue, max, %	1.0	1.0	...	...
Loss on ignition, max, %	3.0	4.0	5.0	10.0

Blended Cement: Physical Requirements

Cement Type	IL, IP, IS(<70), IT(S<70)	IS(≥70), IT(S≥70)
Fineness, Specific Surface, m^2/kg	Note A	Note A
Autoclave expansion, max. %	0.8	0.8
Autoclave Contraction, max. %	0.2	0.2
Time of setting; Vicat test:		
Time of Setting, min. (not less than)	45	45
Time of Setting, hrs. (not more than)	7	7
Air content of mortar, volume %, max	12	12
Compressive Strength, MPA (psi)		
3 days	13 [1890]	...
7 days	20 [2900]	5 [720]
28 days	25 [3620]	11 [1600]

Hydraulic Cement Specification (Performance Specification)

ASTM C1157 - Standard Performance Specification for Hydraulic Cement

- **Performance-based Specification (ONLY)**

Applies to:

- covers hydraulic cements for both general and special applications. There are **no restrictions on the composition of the cement or its constituents**

Classification and Use

Type GU—Hydraulic cement for general construction.

Special types:

- Type HE—High Early-Strength.
- Type MS—Moderate Sulfate Resistance.
- Type HS—High Sulfate Resistance.
- Type MH—Moderate Heat of Hydration.
- Type LH—Low Heat of Hydration.

Hydraulic Cement: Physical Requirements

Cement Type	GU	HE	MS	HS	MH	LH
Fineness, Specific Surface, m^2/kg	Note A	Note A	Note A	Note A	Note A	Note A
Autoclave Length Change, max. %	0.8	0.8	0.8	0.8	0.8	0.8
Time of setting; Vicat test:						
Time of Setting, min. (not less than)	45	45	45	45	45	45
Time of Setting, min. (not more than)	420	420	420	420	420	420
Air content of mortar, volume %, max	12	12	12	12	12	12
Compressive Strength, MPA (psi)						
1 day	...	12 [1740]	...	...	...	...
3 days	13 [1890]	24 [3480]	11 [1600]	11 [1600]	5 [1725]	...
7 days	20 [2900]	...	18 [2610]	18 [2610]	11 [1600]	11 [1600]
28 days	28 [4060]	...	...	25 [3620]	...	21 [3050]
Heat of Hydration						
7 Days, max, kJ/kg [kcal/kg]	...	...	...	...	290 [70]	...
28 Days, max, kJ/kg [kcal/kg]	...	...	...	...	...	...
Mortar bar Expansion						
14 Days, % max	0.020	0.020	0.020	0.020	0.020	0.020
Sulfate expansion (Sulfate Resistance)						
6 Months, max, %	...	...	0.10	0.05	...	...
1 year, max, %	...	...	...	0.10	...	...

ASTM Cement Standards Summary

ASTM C150 – Portland Cement

- 5 Types of Cements
- Prescriptive and Performance Based Specification

ASTM C595 – Blended Portland Cements

- 4 Types of Blended Cements
- Prescriptive and Performance Based Specification

ASTM C1157 – Hydraulic Cements (Performance Specification)

- 5 Types of Cements Determined by Cement Applications
- Performance Based Specification

Agenda

Cement Chemistry, Specifications, and Testing

- Portland Cement Introduction and History
- Cement Plants and Manufacturing
- Cement Classifications and Chemistry
- Chemical and Physical Cement Testing
- Cement Specifications

QUESTIONS?

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