CEMENT

Chapter 08

Binders

There are several different materials which have adhesive (binding) properties:

A) Glues: materials of gelatinous nature derived from animal or vegetable sources, or synthetic adhesives such as polymers.

B) Bituminous Materials: complex hydrocarbons

C) Various calcium compounds: gypsum, lime, portland cement.

All calcium-based binders (cements) will harden and develop binding property when mixed with water.

Cementitious Materials

These materials gain binding properties upon hydration or reaction with $Ca(OH)_2$.

- Non-hydraulic cements: may set and harden in air only. After hardening they are not stable upon exposure to moisture: **Lime and gypsum**.
- Hydraulic cements: may set and harden in air and under water. After hardening these are stable upon exposure to water: **Hydraulic lime, portland cement.**

Portland Cement (PC)

Portland cement is a hydraulic binder produced by intergrinding a small amount of gypsum and portland cement clinker that is obtained by burning an appropriate combination of calcareous and clayey materials.

Due to the presence of small amounts of iron oxide, PC is normally grayish in color.

Portland Cement (PC)

When PC is mixed with water, a plastic paste is formed which can be molded into any shape.

As time goes by, the paste gains rigidity and hardens.

This property of setting and gaining of strength is due to the chemical reactions taking place between the water and the compounds in the PC that are developed during burning process of the raw materials.

Portland Cement

PC is used in making mortars and concretes.

Cement Paste: mixture of cement and water

Mortar*: obtained by inclusion of fine aggregate (sand) in the cement paste.*

Concrete*: made by adding coarse aggregate (gravel) to the mortars*

Manufacture of PC Clinker and PC

Limestone ($CaCO_3$) and clay are the two main raw materials used for manufacturing PC clinker. Clays have various amounts of SiO_2 and Al_2O_3; kaolin, pure clay is composed of $Al_2O_3.2SiO_2.2H_2O$.

The manufacturing process of clinker consists of

- grinding the raw materials,

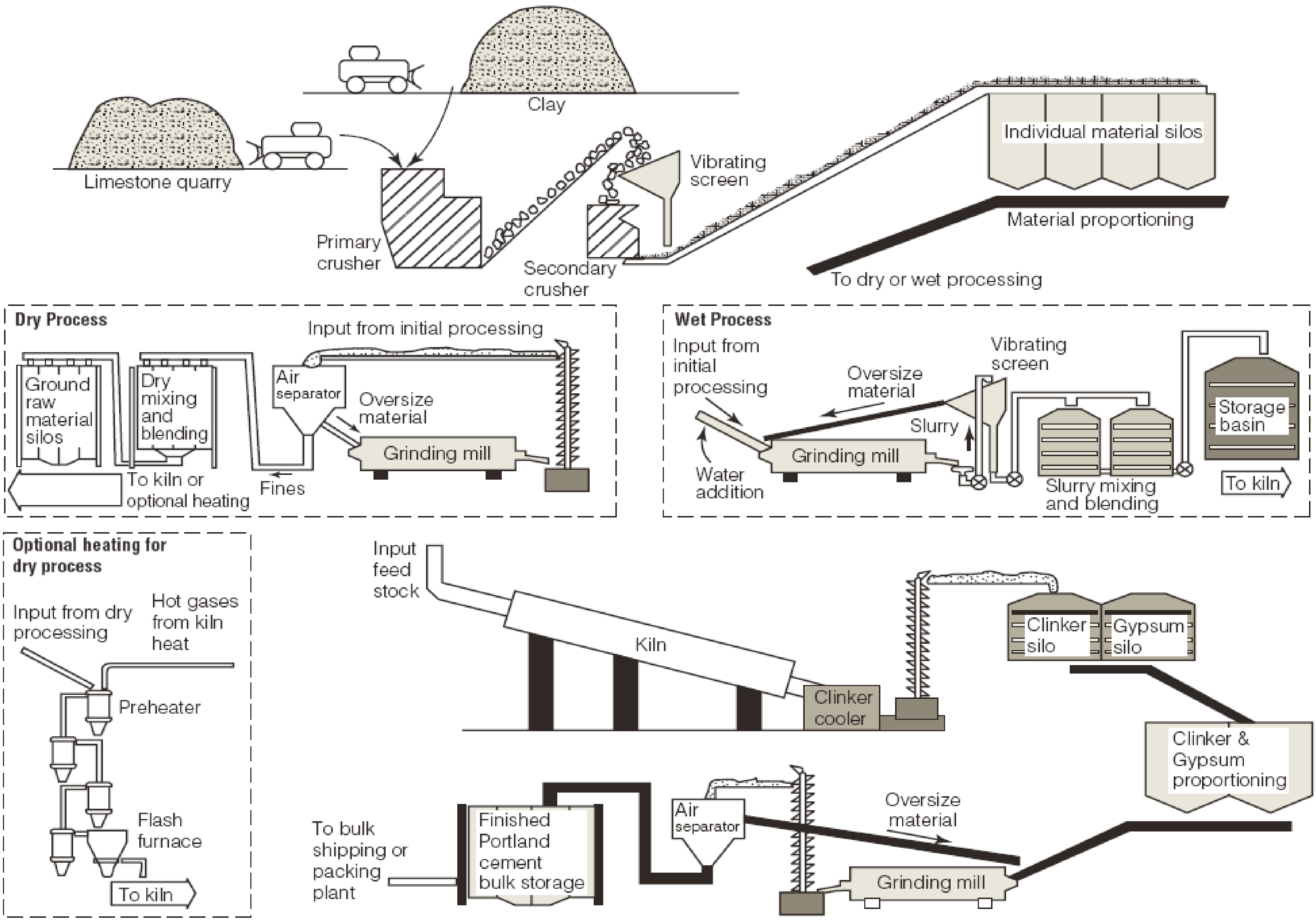
- mixing them in appropriate proportions (raw mix),

- burning the raw mix in a rotary kiln at a temperature of 1400-1500 °C until the material sinters or partially fuses into balls known as **clinker**.

Manufacture of PC Clinker and PC

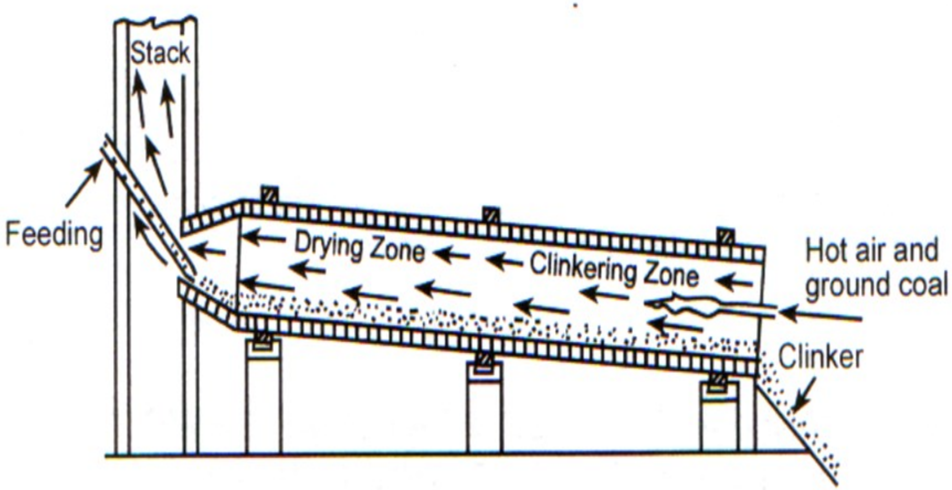
PC is obtained by grinding the cooled clinker together with a small amount of gypsum rock.

The mixing and grinding of the raw materials are done either in a dry state or in water. These mixing processes are referred to as the "dry process" or the "wet process".

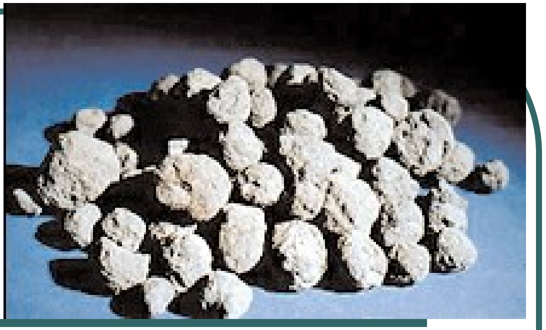

Clay
Limestone quarry
Primary crusher
Secondary crusher
Vibrating screen
Individual material silos
Material proportioning
To dry or wet processing
Dry Process
Input from initial processing
Ground raw material silos
Dry mixing and blending
Air separator
Oversize material
Grinding mill
To kiln or optional heating
Fines
Wet Process
Input from initial processing
Oversize material
Vibrating screen
Slurry
Grinding mill
Water addition
Slurry mixing and blending
Storage basin
To kiln
Optional heating for dry process
Input from dry processing
Hot gases from kiln heat
Preheater
Flash furnace
To kiln
Input feed stock
Kiln
Clinker cooler
Clinker silo
Gypsum silo
Clinker & Gypsum proportioning
To bulk shipping or packing plant
Finished Portland cement bulk storage
Air separator
Oversize material
Grinding mill

The rotary kiln is a long steel cylinder lined with refractory brick. The kiln is inclined a few degrees from the horizontal and is rotated about its axis at a speed of about 60 to 150 revolutions/hour.

Pulverized coal or gas is used as the source of the heat. The heat is supplied from the lower end so that the maximum temperatures near the lower end of the kiln is about 1400-1500°C. The temperature in the kiln becomes lower toward the upper end, where it is around 150°C. The mixture of raw materials is fed from the upper end of the kiln. The raw mix moves downwards due to the inclination and rotation of the kiln.



Production of PC



Once the clinker passes the flame, it enters a short cooling zone and drops off in temperature. The clinker leaves the kiln at about 1000°C and falls into a cooler.

The burning process of the raw mix is sometimes made in two stages. First, raw mix is burned to about 800-900°C in preheaters, and then this material is introduced directly into the rotary kiln. A shorter rotary kiln (l/d ~15) is sufficient for a system having preheaters.

PC is produced by intergrinding cooled clinker with 2-6% gypsum rock in ball mills. PC is packed into paper bags or is transported in bulk. In Turkey and other European countries a bag contains 50 kg cement.

Oxide (Chemical) Composition of Portland Cement

PC is composed of four major oxides: CaO, SiO_2, Al_2O_3 and Fe_2O_3, which account for about 90% of the cement.

In addition to major oxides, PC contains small quantities of minor oxides such as *MgO, SO_3 and alkalies (Na_2O and K_2O)*

The term minor refers to the quantity of these oxides rather than their importance.

Oxide	Common Name	Content, %
CaO	Lime	60 - 67
SiO_2	Silica	17 - 25
Al_2O_3	Alumina	3 - 8
Fe_2O_3	Iron	0.5 - 6.0
MgO	Magnesia	0.1 - 4.0
Na_2O and K_2O	Soda and Potassa*	0.2 - 1.3
SO_3	Sulfuric anhydride	1.0 - 3.0

*Soda and potassa are known as "alkalies"

Oxide (Chemical) Composition of Portland Cement

Except for SO_3, all the oxides in portland cement are obtained by burning raw mix which consists of calcareous and clayey materials.

$CaO \rightarrow$ from limestone

SiO_2 and $Al_2O_3 \rightarrow$ from clay

$Fe_2O_3 \rightarrow$ usually impurity in clay

$SO_3 \rightarrow$ mainly from gypsum rock interground with clinker.

The amount of gypsum rock can be approximated by multiplying the amount of SO_3 by 2.15.

$CaSO_4.2H_2O$: 172, SO_3: 80, $172/80 \cong 2.15$

Oxide (Chemical) Composition of Portland Cement

The amount of SO_3 indicates the amount of gypsum present in the cement. Gypsum retards the very quick setting (flash setting) of PC. On the other hand, if too much gypsum is added, it leads to disruptive expansion of hardened paste or concrete. *ASTM C150 allows a maximum of 3% $S0_3$ in ordinary portland cement. TS EN 197-1 limits the SO_3 content of CEM III to max 4% and other types of cements to 3.5%.*

High content of MgO and free lime cause expansion upon slaking. The reaction of these oxides with water in the cement are rather slow. Therefore, the reactions usually take place after the cement is set or hardened. Expansion in a hardened paste or concrete leads to cracking. ASTM allows 5% MgO and 3% free lime in ordinary portland cement.

Oxide (Chemical) Composition of Portland Cement

The presence of alkalies generally does not cause any problem except when the cement is used with certain types of reactive aggregates in making concrete. ***The alkalies (in the form of hydroxides) can react with reactive silica of the aggregate and result in the formation of alkali-silica gel which can absorb water and swell a lot. The formation of this reaction may take months or years.***

Therefore, the expansion in hardened concrete causes disintegration and cracking. Some standards limit the total alkali content (%Na_2O+0.658%K_2O=equivalent Na_2O) to 0.6% when the cement is to be used with reactive aggregates.

Alkali-Silica Reactivity

Compound Composition of PC

The oxides interact with each other in the rotary kiln to form a series of complex compounds.

Portland cement clinker is usually regarded as constituted of four main compounds as shown below

Name	Chemical Formula	Abbreviation
Tricalcium silicate	$3CaO.SiO_2$	C_3S
Dicalcium silicate	$2CaO.SiO_2$	C_2S
Tricalcium aluminate	$3CaO.Al_2O_3$	C_3A
Tetracalcium alumino ferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF

Influence of Compound Composition upon PC Characteristics

When portland cement is mixed with water, the compounds in cement undergo chemical reactions with water indepently, and different products result from these reactions. The combined effect of the chemical reactions with water determines the behavior of the PC.

Property	Relative Behavior of Each Compound			
	C_3S	C_2S	C_3A	C_4AF
Rate of reaction	Moderate	Slow	Fast	Moderate
Heat liberation	High	Low	Very High	Moderate
Contribution to strength				
Early days	High	Low	Low*	Low
Ultimate	High	High	Low	Low

Average values for the compound compositions of the ASTM types of Portland Cement

ASTM Type	Name	Compound Compozition (Typical, %)				General description to use
		C3S	C2S	C3A	C4AF	
Type I	Ordinary (Normal) Portland Cement	49	25	12	8	For general purposes
Type II	Modified PC	46	29	6	12	For use when moderate sulfate reaction or moderate heat of hydration is desired such as in concrete pipes, retaining walls, etc.
Type III	High Early Strength PC	56	15	12	8	For use when high early strength is desired, such as in precast work, in repair, concreting at low temperatures, etc.
Type IV	Low Heat PC	30	46	5	13	For use when low heat of hydration is required, such as in mass concretes for dams.
Type V	Sulfate Resistant PC	43	36	4	12	For use when high sulfate resistance is desired, such as in concrete for foundations, canal linings, etc.

HYDRATION OF PORTLAND CEMENT

$2C_3S + 6H \dashrightarrow C_3S_2H_3 + 3CH + 120$ cal/g

$2C_2S + 4H \dashrightarrow C_3S_2H_3 + CH + 62$ cal/g

(tobermorite gel)

$C_3A + C\bar{S}H_2 + 10H \rightarrow C_4A\bar{S}H_{12}$ calcium-alumino-monosulfohydrate

(monosulfate)

$C_3A + 3C\bar{S}H_2 + 26H \rightarrow C_6A\bar{S}_3H_{32}$ calcium-alumino-trisulfohydrate

(ettringite)

Hydration of Portland Cement (Highlights)

- Chemical reactions with water are called '**hydration**'
- Each compound in the cement reacts with water independently during hydration.
- The main hydration product of calcium silicate compounds are $\underbrace{C_3S_2H_3}_{\text{tobermorite gel}}$ and $\underbrace{CH}_{\text{calsium hydroxide}}$.
- Calcium-silicate hydrate gels are called C-S-H gels. C-S-H gels are poorly crystalline (nearly amorphous)
- C_3S and C_2S are the two compounds that contribute to strength as they hydrate. C-S-H gels provide the binding characteristics of cement!

Hydration of Portland Cement (Highlights)

- The reaction of C_3A with water is very rapid leading to the formation of crystalline alumino hydrates.
- The rapid hydration of C_3A causes immediate stiffening of the cement known as '**quick set' or 'flash set**'.
- In order to prevent this flash set, a small amount of gypsum rock is added to the clinker during the grinding process of the cement production.

Computation Method of Determining the Compound Composition of PC

This method is the simplest and most popular for determining the approximate compound composition of portland cement or clinker. In this method oxide composition of cement or clinker are placed in Bogue′s Equations given below:

$\%C_3S = 4.071(\%C) - 7.600(\%S) - 6.718(\%A) - 1.430(\%F) - 2.852(\%\bar{S})$

$\% C_2S = 2.867(\%S) - 0.7544(\%C_3S)$

$\%C_3A = 2.650(\%A) - 1.692(\%F)$

$\% C_4AF = 3.043(\%F)$

In calculating the compound composition of a clinker the last part of the equation for finding the $\%C_3S$ (i.e, $2.852x\%\bar{S}$) is omitted.

The percentages of each oxide to be placed in Bogue's Equations should not be rounded off and used as approximate values. A small change in the percentages of the oxides results in great variations in the compound composition and resultantly on the properties of cement.

The compound composition of blended cements cannot be calculated by Bogue's Equations.

THE TYPES OF CEMENTS PRODUCED IN TURKEY

Types of cements, TS EN 197-1 covers 27 standard cements classified into five main types:

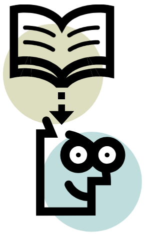
CEM I Portland cement (ordinary)

CEM II Portland composite cement

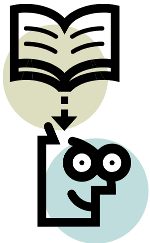
CEM III Blast furnace slag cement

CEM IV Pozzolanic cement

CEM V Composite cement



Main type	Name	Symbol	
CEM I	Portland cement	CEM I	
CEM II	Portland blast furnace slag cement	CEM II/A-S CEM II/B-S	Blast furnace slag
	Portland silica fume cement	CEM II/A-D	Silica fume
	Portland pozzolan cement	CEM II/A-P CEM II/B-P	Natural pozzolan
		CEM II/A-Q CEM II/B-Q	Calcined pozzolan
	Portland fly ash cement	CEM II/A-V CEM II/B-V	Low lime fly ash
		CEM II/A-W CEM II/B-W	High lime fly ash
	Portland burned schist cement	CEM II/A-T CEM II/B-T	Burned schist
	Portland limestone cement	CEM II/A-L CEM II/B-L	organic material content<0.5%
		CEM II/A-LL CEM II/B-LL	organic material content<0.2%
	Portland composite cement	CEM II/A-M CEM II/B-M	



Main type	Name	Symbol
CEM III	Blast furnace slag cement	CEM III/A CEM III/B CEM III/C
CEM IV	Pozzolanic cement	CEM IV/A CEM IV/B
CEM V	Composite cement	CEM V/A CEM V/B

In addition to TS EN 197, TS 21 covers “ White portland cement”, TS 22-1 or 2 EN 413-1 or 2 cover “Masonry cement Part 1: “Properties” or Part 2:”Test methods”.

The Composition of TS EN 197-1 Cements

Cement type	clinker	S	D	P	Q	V	W	T	L-LL	Minor
CEM I	95-100									0-5
CEM II/A-S	80-94	6-20								0-5
CEM II/B-S	65-79	21-35								0-5
CEM II/A-D	90-94		6-10							0-5
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

The Composition of TS EN 197-1 Cements

Cement type	clinker	S	D	P	Q	V	W	T	L-LL	Minor
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
CEM II/A-T	80-94							6-20		0-5
CEM II/B-T	65-79							21-35		0-5
CEM II/A-L (LL)	80-94								6-20	0-5
CEM II/B-L (LL)	65-79								21-35	0-5

The Composition of TS EN 197-1 Cements

Cement type	clinker	S	D	P	Q	V	W	T	L-LL	Minor
CEM II/A-M	80-94	6-20								0-5
CEM II/B-M	65-79	21-35								0-5
CEM III/A	35-64	36-65								0-5
CEM III/B	20-34	66-80								0-5
CEM III/C	5-19	81-95								0-5
CEM IV/A	65-89		11-35							0-5
CEM IV/B	45-64		36-55							0-5
CEM V/A	40-64	18-30		18-30						0-5
CEM V/B	20-38	31-50		31-50						0-5

K: Portland Cement clinker
S: Ground granulated blast furnace slag
P: Natural puzolan
V, W : Fly ash (V=F type, W= C type)
L, LL : Limestone powder (L: organic carbon content max %0.5, LL: organic carbon content max %0.20 by weight)
D: Silica fume
P, Q : Puzolans

General designation of Portland Cement (European Norms)

Example: CEM II A-M (P-L) 42.5R

Cement type
I
II
III
IV

Amount of clinker
A: High
B: Moderate
C: Low

Composition

Strength class (MPa)
32.5
42.5
52.5

Strength development
N : Normal
R: Rapid (High early strength)

The oxide composition of three clinkers are given above. Calculate the compound composition of the clinkers. Determine the most suitable clinker for the production of cement suitable for the following applications:

A) cold weather concreting

B) hot weather concreting

C) retaining wall exposed to moderate sulfate attack

D) concrete pipe exposed to sewage attack

	% in clinker		
Oxide	A	B	C
CaO	64.5	63	66
SiO_2	21	22	20
Al_2O_3	6	7.7	5.5
Fe_2O_3	2.5	3.3	4.5
others	6	4	4

For clinker A

% C_3S = 4.071(64.5) - 7.6(21) - 6.718(6) - 1.43(2.5)=59

% C_2S = 2.867(21) - 0.7544(59)= 16

%C_3A = 2.650(6) - 1.692(2.5)=12

% C_4AF = 3.043(2.5)=8

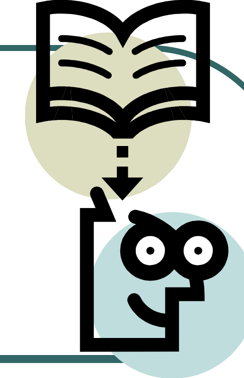
Similarly the compound composition of other clinkers can be calculated as follows:

	clinker		
compound	A	B	C
C_3S	59	33	73
C_2S	16	38	2
C_3A	12	15	7
C_4AF	8	10	14

Cement produced from clinker C is the most suitable one for cold weather concreting due to the highest C_3S content among clinkers. Clinker B is suitable for the cement for hot weather concreting since C_3S is minimum and C_2S is max.

Cement from clinker C is the most suitable one for moderate sulfate attack since C_3A <8%.

For sewage attack (severe sulfate attack), sulfate resistance cement with C_3A content less than 5% is required). Thus, none of the clinkers is suitable from this point of view. However, if there is no other choice, cement produced from clinker C is the most suitable one among the clinkers because it has the lowest C_3A content.



Homework

Two portland cements with the following oxide compositions are available. Compare the cements from following points of view:

A) rate of hydration

B) heat of hydration

C) early cementitious value

D) ultimate cementitious value

	%	
Oxide	A	B
CaO	62.8	61.8
SiO_2	20.4	21.4
Al_2O_3	5.2	5.2
Fe_2O_3	3.0	3.0
MgO	4.0	4.0
SO_3	2.5	2.5

Some Physical and Mechanical Properties of PCs

- Setting time,
- Consistency,
- Fineness,
- Strength

Consistency

The time of setting and soundness of a cement paste depend on the water content of the paste.

Therefore, it is necessary to define a water content at which these tests should be conducted.

This is defined in terms of normal consistency, measured by conducting the normal consistency test.

Setting

Setting refers to change from fluid to rigid state (stiffening of PC paste).

Although there is some strength development during setting, for practical purposes, setting is distinguished from hardening, which refers to the gain of strength of a cement paste that has already set.

The length of time starting from the mixing of the cement and water until the cement paste sets is called the setting time.

In practice, the terms initial set and final set are used to describe arbitrarily chosen stages of setting.

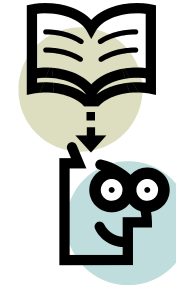
Fineness refers to the average size of the cement particles obtained by intergrinding the clinker and gypsum rock. A higher fineness means a more finely ground cement where the particles are smaller.

If cement particles are finer, there are more particles for a given weight of cement, and the total surface area of particles is greater. Since hydration starts on the surface of particles, finely ground cements have more material available for hydration than coarsely ground cements.

Increase in fineness leads to an increase in the rate of hydration and consequently to an increase in the rate of strength gain and heat evolution. However, if the cement particles are too fine, the cement particles might prehydrate, leading to low binding capacity. Moreover, the cost of grinding increases the cost of cement and fine cement shows greater shrinkage than coarse one.

When the cement particles are coarse, hydration starts on the surface of the particles but further hydration is hindered by the formation of the reaction products. Therefore, the coarse particles may not be completely hydrated. This causes low strength development and low durability in concrete.

Tests on Cement



- EN 197-1 Cement- Part 1: Composition, specifications and conformity criteria for common cements
- EN 197-2 Cement- Part 2: Conformity evaluation
- EN 196-1 Methods of testing cement- Part 1: Determination of strength
- EN 196-2 Methods of testing cement- Part 2: Chemical analysis of cement
- EN 196-3 Methods of testing cement- Part 3: Determination of setting time and soundness
- EN 196-5 Methods of testing cement- Part 5: Pozzolanicity test for pozzolanic cements
- EN 196-6 Methods of testing cement- Part 6: Determination of fineness

TS EN 196-3 Methods of testing cement- Part 3: Determination of setting time and soundness

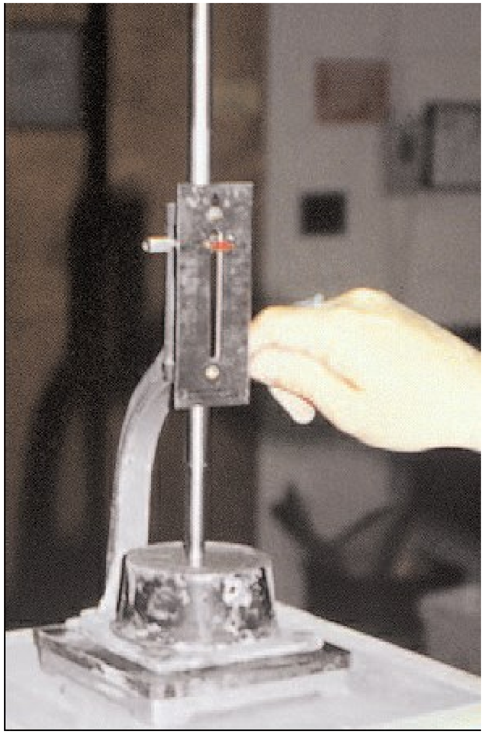
Consistency is measured by the Vicat apparatus, using a 10 mm diameter plunger with the total mass of moving parts of 300g.

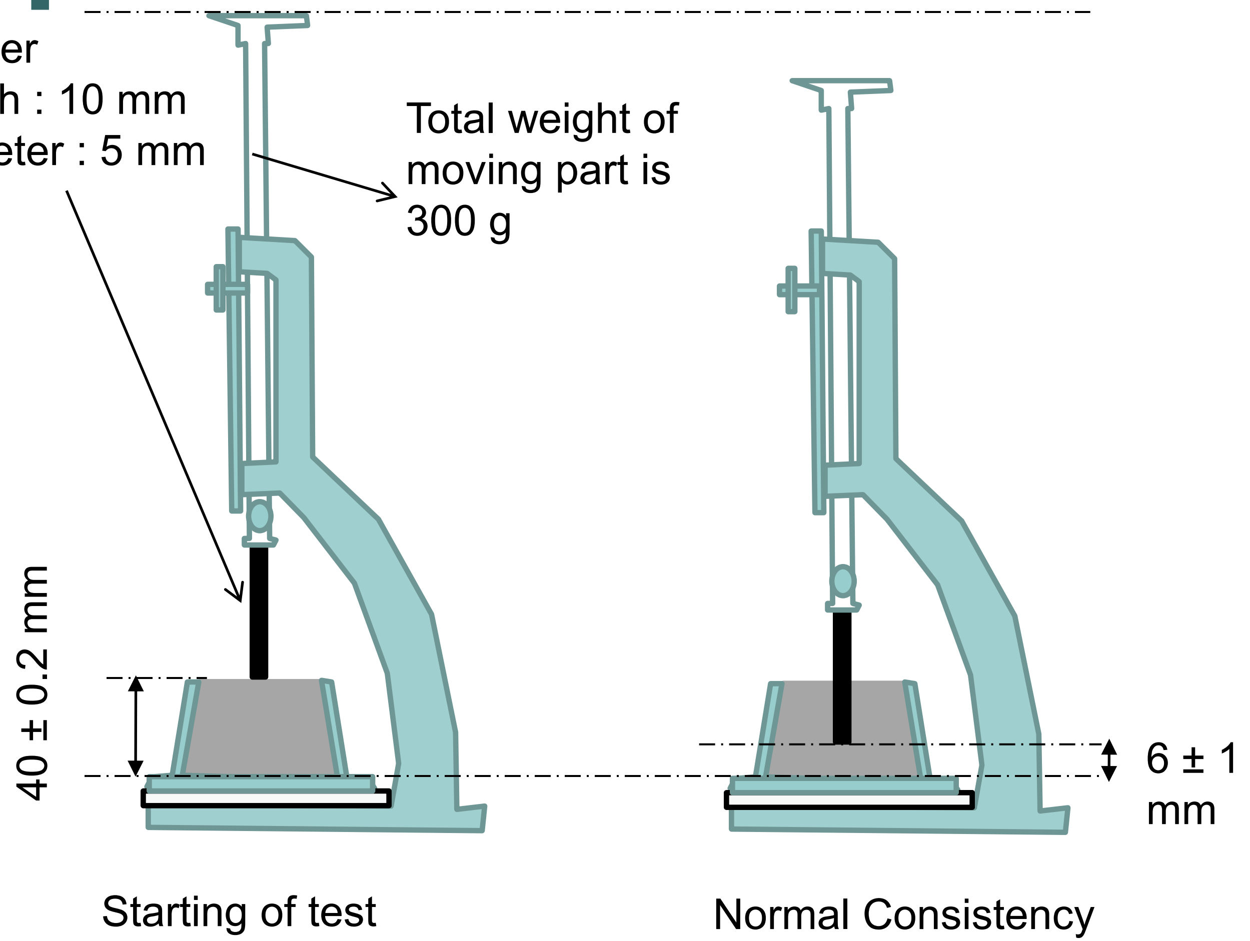
A trial paste of 500g cement and 125 g water is mixed and placed in the mold having an inside bottom diameter of 80 mm and a top diameter of 70 mm and a height of 40 mm.

The plunger is then brought into contact with the top surface of paste and released. Under the action of its weight the plunger will penetrate the paste, the depth depending on the consistency. When the plunger penetrates the paste to a point 6±1 mm from the bottom of the mold, the paste is considered to be at normal consistency.

The water content of the paste is expressed as a percentage by weight of dry cement, the usual range of values being between 26% and 33%.

Vicat Apparatus



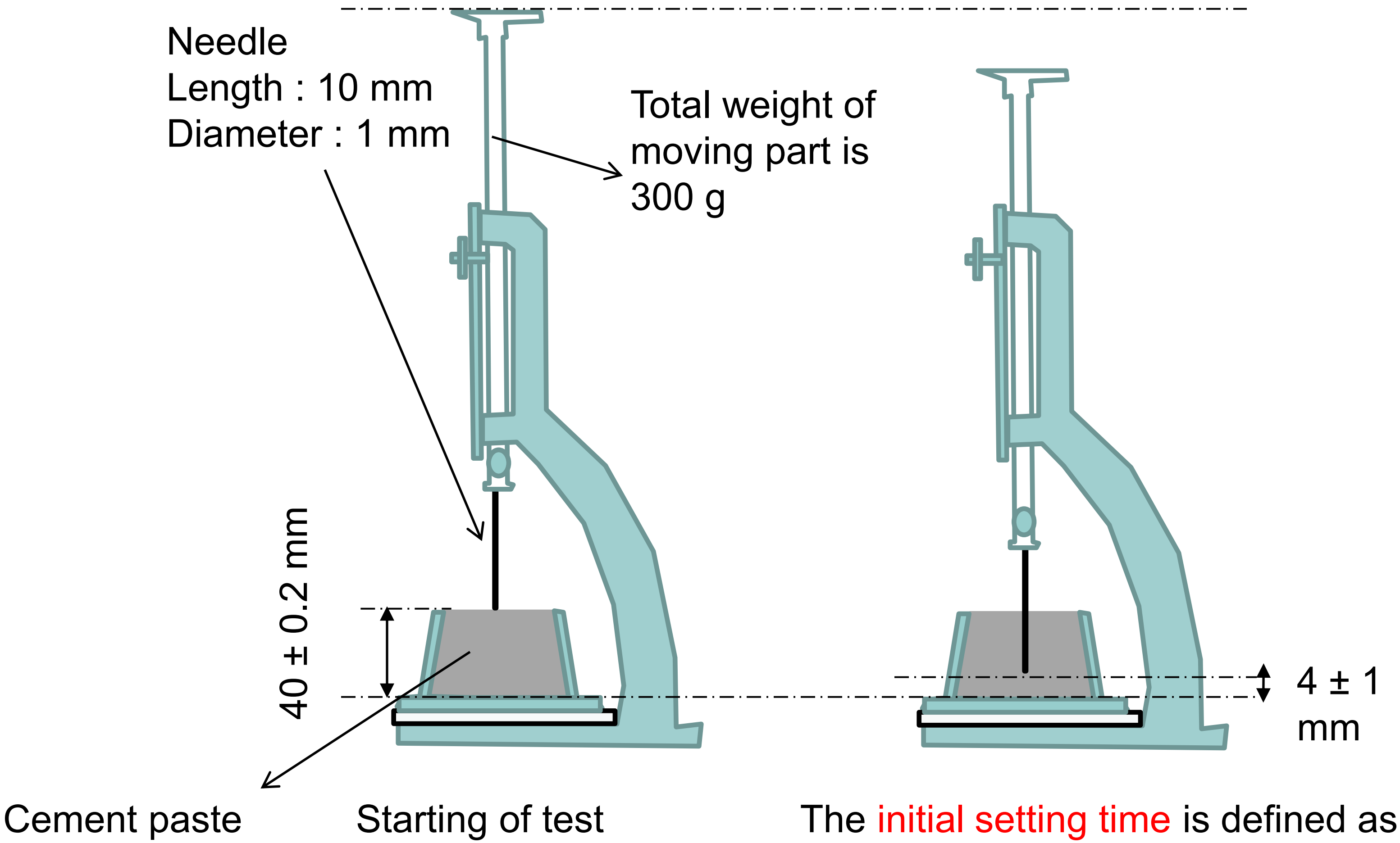


The required water content is adjusted to obtain normal consistency for determining of setting time of cement.

Setting time test is conducted by using Vicat apparatus, except that a 1-mm diameter needle is used for penetration, the mould is filled with a paste of normal consistency. The test is conducted at 10 min intervals.

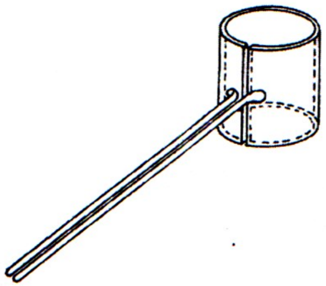
The initial setting time is defined as the length of time between the preparation of the paste and the time when the distance between needle and base plate is 4±1 mm.

The final setting time is defined as the length of time between the preparation of the paste and the time when the needle no longer sinks visibly into the paste.



The initial setting time is defined as the length of time between the preparation of the paste and the time when the distance between needle and base plate is 4±1 mm. The test is conducted at 10 min intervals.

Soundness



Soundness is defined as the volume stability of the cement paste. The cement paste should not undergo large volume changes after it has set. However, when excessive amounts of free CaO or MgO are present in the cement, these overburned oxides can slowly hydrate and cause expansion of the hardened cement paste.

The soundness test is conducted by using either Le Chatelier apparatus or Autoclave method. **Le Chatelier method determines the unsoundness due to free lime**. The apparatus consists of a small brass cylinder split along its generatrix. Two indicators with pointed ends are attached to the cylinder on either side of the split.

Soundness

A cement paste of normal consistency is placed in Le Chatelier mould and covered with glass plate. After being cured at 98%RH for 24 hrs, the distance (A) between the indicator points is measured and then the mould is heated gradually to boiling during (30±5) min and the water bath is maintained at boiling temperature for 3h ± 5 min.

At the end of the boiling period and after cooling to 20^{o}C the distance (C) between the indicator points is measured again.

For each specimen, the measurements A and C and the difference C-A are calculated.

Autoclave test is sensitive to both free CaO and MgO. In this test a cement paste of normal consistency is placed in 25 mm square cross-section and 250 mm gage length molds, cured in humid air for 24 hours.

The bar is then removed from the mold its length is measured (l_o) and then placed in an autoclave (high pressure steam boiler) which is raised to a temperature of ~200°C and a pressure of ~2 MPa in 60±15 min, then maintained at this temperature for 3 hours. After cooling the length of the specimen is measured (l). The expansion of the bar due to autoclaving $\{(l-l_0)/l_o x100\}$ must not exceed 0.8%.

EN 196-6 Methods of testing cement-Part 6: Determination of fineness

- The sieving method (from 90µm) serves only to demonstrate the presence of coarse cement particles. This method is primarily suited to checking and controlling the production process.
- With the air-permeability method (Blaine) the specific surface (mass related surface) is measured by comparison with a reference cement sample. The determination of the specific surface serves primarily to check the consistency of the grinding process of one and the same plant.

Blaine Air Permeability Method

In this method a given volume of air is passed through a prepared sample of cement having a definite porosity.

The number and size of pores in the sample of a given density is a function of the size of the particles and their size distribution, which determine the rate of air flow through the sample.

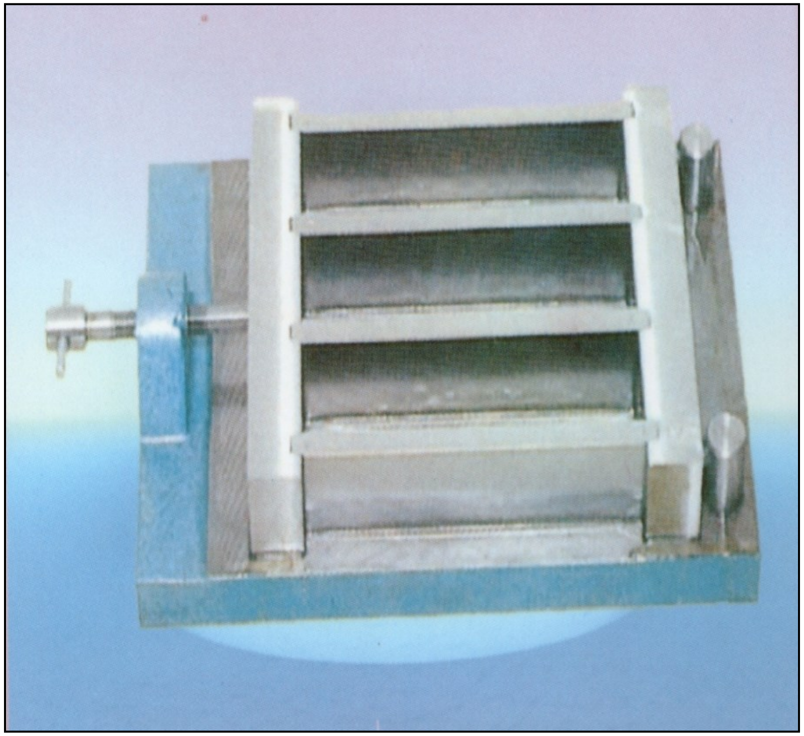
The fineness of cement is expressed in terms of cm^2/g or m^2/kg.

The Blaine fineness of Normal Portland Cement is in between 3500 – 4000 cm^2/g.

EN 196-1 Methods of testing cement-Part 1: Determination of strength

The cement mortar (consisting of 1 part cement + 3 parts standard sand + 1/2 part water, by weight) is placed in three molds that have 4 cm width, 4 cm height, and 16 cm length.

The mortar bars taken out of the molds and cured in water at 20±1°C are first subjected to bending on the day the strength is tested.



Flexural strength (σ_f)

$\sigma_f = M.y/I$ $\quad$ $M = P.l/4$: max. Bending moment

$Y = h/2$:distance between neutral axis and extreme fiber

$I = b.h^3/12$ (moment of inertia)

h: height of specimen, b: width of specimen

Thus $\quad$ $\sigma_f = 1.5\, P_{max}.l/b^3$

The average of the values found is expressed as the flexural strength. The flexural strength shows the tensile resistance in bending.

The compressive strength test is conducted on the broken halves of the mortar bars, on modified cubes of 40 mm dimensions.

$\sigma_c = P_{max}/A$, where $A = 16\ cm^2$.

The average of the results found by testing six specimens is the compressive strength of the mortar bars.

In the ASTM specification, the mortars (1:2.75, W/C:0.485) are molded in 50 mm cube molds for determination of compressive strength of cement.

$\sigma_c = P_{max}/A$, where $A = 25\ cm^2$.

From compressive strength point of view TS EN 197-1 classifies cements into three classes: class 32.5, class 42.5 and class 52.5.

These values are 28-day minimum compressive strength of cements (obtained on broken portions of 40x40x160 mm mortar specimens, modified 40 mm cube)

The mechanical and physical requirements of Turkish cements are as follows:

Cement Strength Class	Compressive strength (MPa)			Initial setting time (min.)	Le Chatelier soundness (mm)
	2-Day	7-Day	28-Day		
32.5 N	-	≥16	≥32.5-≤52.5	≥75	≤10
32.5R	≥10	-	≥32.5-≤52.5	≥75	≤10
42.5N	≥10	-	≥42.5-≤62.5	≥60	≤10
42.5R	≥20	-	≥42.5-≤62.5	≥60	≤10
52.5N	≥20	-	≥52.5	≥45	≤10
52.5R	≥30	-	≥52.5	≥45	≤10

N: normal early strength R: high early strength

Besides, for TS EN 197-1 cements the following items are also required:

CEM I and CEM III cements: LOI ≤ 5%

CEM I and CEM III cements: IR ≤ 3.5%

CEM I: SO_3 ≤ 3.5% ; CEM III and CEM IV cements: SO_3 ≤ 4%

All cement types Cl content ≤ 0.1%

Insoluble Residue (IR) & Loss on Ignition (LOI)

IR is that fraction of the cement which is not soluble in HCl; it derives mainly from the silica which has not reacted to form compounds during the burning process in the kiln.

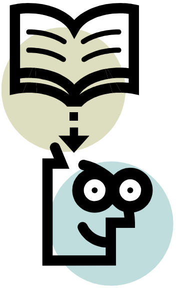
Thus, the IR is a measure of completeness of the reactions in the kiln.

LOI is the loss in weight of cement after being heated to 1000°C. Water and CO_2 are the substances expelled from cement during heating.

Water may be due to taking moisture from atmosphere by cement particles (prehydration).

CO_2 may be present in cement when free CaO and MgO absorb moisture from the air, slake, and then react with the CO_2 of the air to form $CaCO_3$ or $MgCO_3$ (precarbonation).

Example



The 28-day compressive strength test results obtained on six modified cubes (40 mm) are given below. The mortar bars are prepared with CEM I 42.5. Are the results acceptable? 88, 83, 82, 90, 94, 98 kN

Average P_{max}=(88+83+82+90+94+98)/6=89.2 kN

$\sigma_c = P_{max}/A$=89.2x1000 N/1600 mm^2=55.75 MPa

≥ 42.5 MPa and ≤ 62.5 MPa ok.