Introduction to Road Materials Engineering

Part 9: Introduction to Concrete Technology

Presented by SARF

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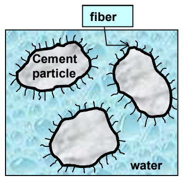
Basics of concrete technology

What is concrete ?

- Concrete has two main components – aggregates and paste.
- The aggregates consist of stone and sand – the paste consists of cement, water and some air.
- After mixing the concrete hardens to the required strength and durability.

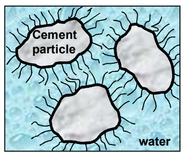
2

The Hydration Reaction



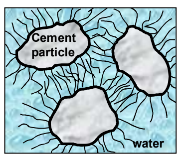
Stage 1

Stage 1:
Fibers start forming, but are still very short. The mix is still workable, i.e. it can be poured and formed very easily. This stage takes between 0 and 45 minutes after pouring has started.



Stage 2

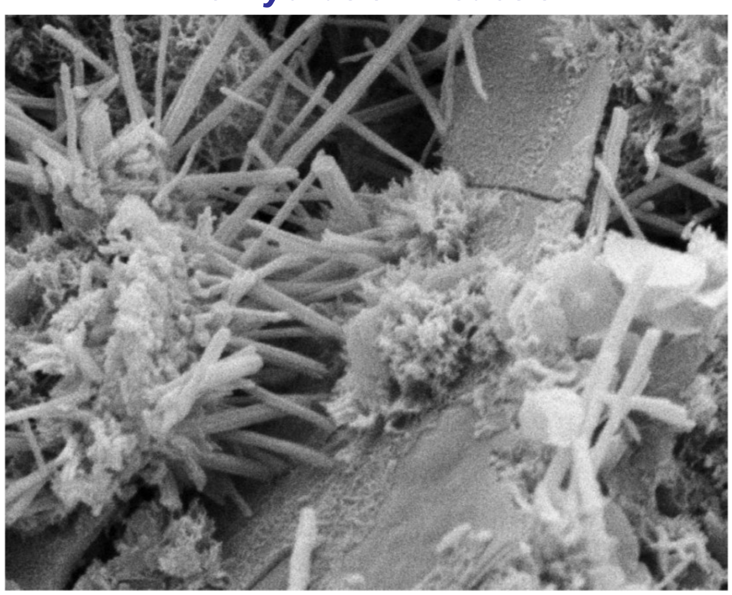
Stage 2:
The fibers are growing and are almost interlocking. The mix gets less workable. The duration of this stage is between 45 minutes and 2 hours after pouring of the concrete has started.



Stage 3

Stage 3:
The fibers are interlocking. Because of this the mix is not workable anymore and is setting. To reach this stage takes between 2 and 4 hours after the pouring of the concrete has started.

The Hydration Reaction



Cement in the mix – forms a "glue" which hardens to give strength

The strength of concrete depends primarily on the water/cement ratio.

If additional water is added to a concrete mix, the "glue" is diluted thus reducing the strength

The water/cement ratio also determines the durability, impermeability and abrasion resistance of concrete

After setting the concrete hardens and continues to gain in strength due to a process know as hydration

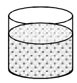
If the concrete is allowed to dry out it will not continue to gain in strength – therefore proper curing is very important

How is cement made?

https://www.youtube.com/watch?v=n-Pr1KTVSXo

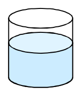
NOTE: Some authorities use CEMENT/WATER RATIO while others use WATER/CEMENT RATIO

CEMENT/WATER RATIO (C/W)



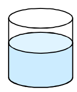
170kg cement

C/W = 170/100 = 1.7



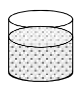
100kg water

WATER/CEMENT RATIO (W/C)



100kg water

W/C = 100/170 = 0.59



170kg cement

Typical W:C Ratio's

Type of concrete	Water:cement ratio
High performance concrete	0,25 – 0,40
Conventional concrete	0,45 – 0,80
Sand-cement floor screeds	0,55 – 0,60
Bedding mortar for masonry; cement plaster	1,00 – 1,15

Advantages of low water/cement ratio:

- Increased strength
- Lower permeability
- Increased resistance to weathering
- Better bond between concrete and reinforcement
- Reduced drying shrinkage and cracking
- Less volume change from wetting and drying

Stone in the mix – provides bulk and stability to the mix

The most economical mix is one that has the highest proportions of aggregate to paste and yet has the required workability .

High stone content = reduced workability

The quantity of stone that can be used in a mix depends on the average particle size of the sand. The finer the sand the more stone can be accommodated in the mix.

Large stone is more economical than small stone in a concrete mix

Sand in the mix – used as a void filler, also reduces friction (harshness) between the stone particles

Round or cubical sand particles produces smooth flowing mixes with good workability. Flat, flaky particles produce a harsh mix with poor workability.

The grading of the sand is important to the concrete's workability, particularly the smaller sieve sizes.

Workability refers to:

- The ease with which the concrete can be transported to the site.
- The ease concrete can be placed into the formwork, including the way the concrete flows into corners and around obstructions.
- The ease concrete can be compacted: the concrete must be compacted fully on site with the equipment available, in such a way that most air is driven out of the concrete.
- The ease the concrete can be finished, including honey combing (i.e. holes in the concrete because compaction was not adequate), sand streaking on the surface etc.

Workability can be affected by the following:

- The amount of cement paste: The more cement paste is mixed with the aggregate, the more workable the concrete mix will be. A higher cement content in the concrete mix while the water content remains the same will make the mix stickier.
- The proportions in which the components of a concrete mix are combined will significantly influence the workability of the mix. If the fines are increased the cohesiveness of the mix increases. If the fines in the mix are decreased the stickiness of the mix decreases, while there is a possibility of segregation and bleeding if over-vibrated.
- If rounded aggregate particles are used instead of rough, angular particles the aggregates can move more freely around each other which will improve workability.
- When the stone content is increased in a concrete mix, the mix tends to become harsher which will result in more difficult compaction.
- In well-proportioned concrete mixes, a smaller stone size tends to improve workability although water requirements for a given slump increases.

- The workability of a concrete mix is usually the sum of consistence (consistency) and cohesiveness of the concrete mix.
- Consistency refers to the stiffness, sloppiness or fluidity of a concrete mix.
- The main factor that influences consistency of a concrete mix is the water content.

Cohesiveness:

- Cohesiveness describes how well a concrete mix keeps together when it still in the plastic, i.e. not yet hardened, state.
- This means that cohesiveness describes the ability of the concrete mix to remain well mixed.
- The degree of segregation of the aggregates in the mix is also taken into account, when talking of cohesiveness.
- If segregation of the aggregates in the mix takes place chances are that the mix will not compact well and that honeycombing can take place.

How to improve the cohesiveness of a concrete :

- If the concrete mix is too dry, increase the slump, i.e. add more water.
- If the concrete mix is too wet, reduce the slump, i.e. use less water. Care must be taken that the concrete stays sufficiently workable, so that full compaction can be reached.
- Use less stone or smaller stone.
- Increase the fines content by adding a finer blending sand to the mix. The cementituous content can also be increased.
- Add a mineral admixture like Condensed Silica Fume (CSF).
- Add an air-entraining agent, by which air bubbles are incorporated into the concrete mix.

Segregation:

- Segregation can be defined as the separation of the constituents of the fresh concrete resulting in non-uniform proportions.
- It normally occurs because the coarse aggregate separates out, creating zones with an abnormally high stone content; this leads to zones of incomplete compaction and honeycombing.
- Also, if the stone has a particle relative density substantially higher than that of the sand, it may settle within the mixture, creating a thick layer of mortar and laitance at the top surface which could lead to cracking and dusting.
- Wet mixes with poorly graded aggregates and a high stone content are most prone to segregation.

Bleeding:

Bleeding is a form of segregation where the heavy aggregates sink to the bottom of the concrete mix and some of the mixing water rises to the surface of the mix.

Bleeding can be reduced by one of the following:

- Increase the proportion of minus-300µm material in the mix.
- Increase the cementituous content, by using CSF or a very finely ground GGBS.
- Reduce the water content which will give a lower slump.
- Use an air-entraining ad-mixture.

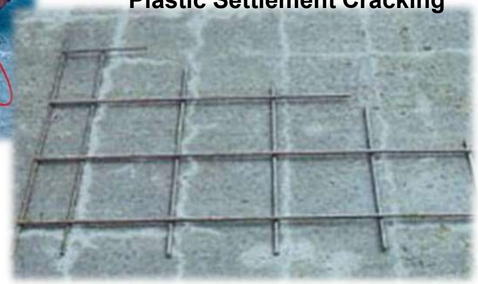
Plastic Cracking:

There are two types of plastic cracking:

1) Plastic shrinkage cracking
2) Plastic settlement cracking

Plastic Shrinkage Cracking

Plastic Settlement Cracking



Plastic shrinkage cracking:

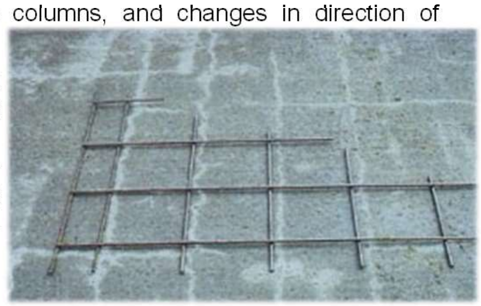
- This type of cracking is the result of the water on the concrete surface evaporating on account of exposure to wind and sun.
- They can often occur in both reinforced and unreinforced horizontal slabs, and form cracks that are roughly parallel and 200 to 600 mm apart.
- When the rate of evaporation is more than the rate of bleeding, the surface of the concrete loses water and the volume of the concrete will decrease.
- Because the concrete is already getting hard stresses will build up in the concrete which lead to cracks.
- As a result of this cracks can run through the whole concrete slab from top to bottom.

Plastic shrinkage cracking can be prevented by the following:

- Cover the concrete surface with plastic sheeting after the surface has been finished.
- Apply a curing compound to the surface. These are chemical liquid that have been specially designed to prevent damage to the concrete.
- Keep the surface of the concrete damp by applying a permanent fog-spray.
- Erect wind breaks and sun shades around the concrete structure.
- Pour the concrete during the cooler parts of the day.

Plastic Settlement Cracking:

- After the concrete has been compacted, there is a tendency for solid particles to settle and displace some mixing water which rises to the surface (bleeding).
- If this settlement of solid particles is restrained plastic settlement cracking can occur.
- Restraint may be present in the form of reinforcement, especially top bars in beams and slabs and stirrups in columns, and changes in direction of formwork, e.g. in T beams.
- To prevent plastic settlement cracking the bleeding potential of the concrete mix must be reduced.
- If plastic settlement cracks appear while the concrete has not hardened yet, the mix can be re-vibrated.



Main components of Portland Cement

Portland Cement is the basis for all our commonly used cements and consists of limestone and shale which is blended in specific proportions and fired at high temperatures to form clinker. A small amount of gypsum is added to the cooled clinker, it is then ground to a fine powder

Cement extenders and fillers

These materials are added to Portland Cement to effect cost savings and improve some properties such as durability and impermeability

- *Ground granulated blast furnace slag (GGBS)*
- *Fly ash (FA)*
- *Condensed silica fume (CSF)*
- *Limestone filler*

Extenders:

- **Ground Granulated Blast Furnace Slag (GGBS):**
  This is the waste product that is left after iron has be extracted from iron ore during smelting in a blast furnace.
- **Fly-ash (FA):**
  FA is the waste product of the burning process of coal while generation electricity in a power station. FA is the finer fraction of the powder that is extracted by filters from the flue gases which are the result of burning pulverized coal. FA is a Pozzolan, which means that, in the presence of water, FA reacts with lime to form cementing compounds.
- **Condensed Silica Fume (CSF):**
  This is the condensed by product of the ferro-silicon smelting process. CSF is a very fine powder, finer than cement. CSF is also a Pozzolan. Because of the hydration of Portland cement produces lime, Pozzolan are very well suited to be used with Portland cement.

	Effect	
Extender	**Fresh Concrete**	**Hardened Concrete**
GGBS	• Improves workability slightly • Retards setting slightly	• Slows development of strength • Increases later age strength • Reduced permeability • Increases rate of carbonization • Reduced generation of heat during cementing reaction
FA	• Improves workability • Reduces water requirements for given slump • Retards setting slightly	• Slightly reduces rate of strength development • Increases later age strength • Reduces permeability • Improves sulphate resistance • Reduced generation of heat during cementing reaction
CSF	• Reduces workability • Increases cohesiveness • Reduces bleeding significantly	• Increases strength • Reduces permeability

Admixtures are commonly used to enhance the properties of concrete

Air-entrainers

Improve workability of harsh mixes, reduce bleeding. Must be carefully controlled as overdosing will reduce concrete strength

Plasticizers & Superplasticizers

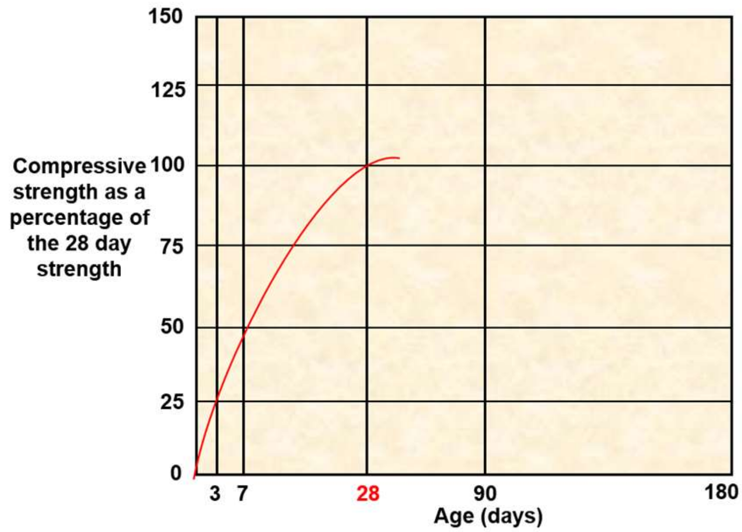
Improve workability of harsh mixes, better flowability, pumping qualities

Retarders

Retard reaction of the cement – stiffens slowly. Useful in hot weather, readymix. Careful dosage rates necessary

Accelerators

Cause rapid reaction with cement and reduce setting time and accelerated early strength. Used in cold weather. Beware increased drying shrinkage



Compressive strength requirements of SABS EN 197-1

Strength class	Compressive strength, MPa			
	Early strength		Standard strength	
	2 days	7 days	28 days	
32,5N	-	≥ 16,0	≥ 32,5	≤ 52,5
32,5R	≥ 10,0	-		
42,5N	≥ 10,0	-	≥ 42,5	≤ 62,5
42,5R	≥ 20,0	-		
52,5N	≥ 20,0	-	≥ 52,5	-
52,5R	≥ 30,0	-		

Cement types

- CEM I – Portland cement
- CEM II – Portland “extended” cements
- CEM III – Blastfurnace cement
- CEM IV – Pozzolanic cement
- CEM V – Composite cements

A **pozzolan** is a siliceous or siliceous and aluminous material which, in itself, possesses little or no cementituous value but which will, in finely divided form and in the presence of water, react chemically with calcium hydroxide ($Ca(OH)_2$) at ordinary temperature to form compounds possessing cementituous properties.

Composition of cement types

Main types	Notation of products (types of common cement)		Composition, percentage by mass[a]										
			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
CEM II	Portland-slag cement	CEM II A-S	80 - 94	6 - 20	-	-	-	-	-	-	-	-	0 - 5
		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 - 94	← 6 - 20 →									0 - 5
		CEM II B-M	65 - 79	← 21 - 35 →									0 - 5
CEM III	Blastfurnace cement	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	Pozzolanic cement[c]	CEM IV A	65 - 89	-	← 11 - 35 →					-	-	-	0 - 5
		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
		CEM V B	20 - 39	31 - 50	-	← 31 - 50 →			-	-	-	-	0 - 5

Notes

(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.

Strength Gain:

N - Normal
R - Rapid

Example:

CEM II B-M 32.5 N

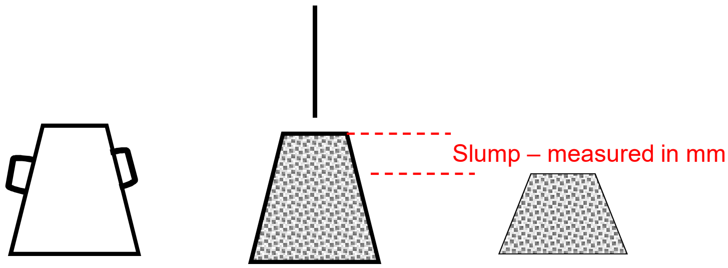
- CEM II → **Portland mixed with extenders**
- B → 21 – 35% extender
- M → Mixed extenders
- 32.5 → Minimum 28 day strength
- N → Normal strength gain

The four major reactive compounds in cement are:

Name	Abbr.	Properties and Roles
Dicalcium Silicate	C_2S	Slow strength gain; Responsible for long-term strength
Tricalcium Silicate	C_3S	Rapid strength gain; Responsible for early strength (7 day)
Tricalcium Aluminate	C_3A	Quick setting (controlled by gypsum); susceptible by Sulphate attack
Tetracalcium Aluminoferrite	C_4AF	Little contribution to strength or setting; Responsible for grey colour of OPC

Where: C = Calcium Oxide (CaO)
A = Alumina (Al_2O_3)
S = Silica (SiO_3)

Slump Test



Slump cone

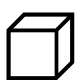
Filled with fresh concrete in layers.

Each layer is compacted using a steel rod

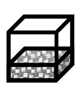
Slump measured as difference in height from top of cone to top of concrete

Compressive strength of concrete

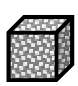
Basic steps in making, curing & compressive strength testing of concrete cubes



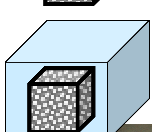
Make cubes immediately after the concrete has been mixed



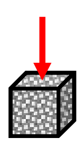
Fill the mould in 50mm layers, compacting each layer with the standard tamping bar or on a vibrating table



Finish off the top surface using a trowel



Store the cube, in the mould, in moist, humid air at 22 to 25^{o}C for 24 hours, remove the mould, cure in water at a temperature of 22 to 25^{o}C Compressive strength is usually specified at 28 days, but cubes may be tested at 7 or 14 days



The cube is placed in the press and the load at which it fails is recorded

Click Picture