

An aerial photograph of a city skyline. In the foreground, several modern high-rise buildings are visible, some with glass facades and others with more traditional architectural styles. In the background, a prominent skyscraper is under construction, featuring a dark, cylindrical upper section and a spire. The sky is overcast with soft, grey clouds. A black rectangular box with a white border is superimposed over the center of the image, containing the title text in red.

Introduction to Concrete

CONCRETE DEFINITION AND HISTORICAL DEVELOPMENT

- The word “concrete” is derived from the Latin *concretus*, meaning “**to grow together.**”
- Concrete is a **composite material** composed of coarse granular material (the aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space among the aggregate particles and glues them together.
- The simplest definition of concrete can be written as:-
 - **concrete = filler + binder**

Naming of concrete

- Depending on binder used, concrete can be named in different ways.
 - Non hydraulic cement concrete;
 - Hydraulic cement concrete;
 - Asphalt concrete;
 - Polymer concrete.

History of concrete

- Non-hydraulic cement concretes are the oldest used in human history.
- As early as around 6500 B.C, non-hydraulic cement concretes were used by the Syrians and spread through Egypt, the Middle East, Crete, Cyprus, and ancient Greece.
- The non-hydraulic cements used at that time were gypsum and lime.

History ...

- Historically Romans used pozzalana, animal fat, milk, and blood as admixtures for building concrete.
- To trim down shrinkage, they were known to have used horsehair.
- Historical evidence shows that the Assyrians and Babylonians used clay as the bonding material.
- Lime was obtained by calcining limestone.

Gypsum and lime

- The **Egyptians** used **gypsum** mortar in construction, and the gypsum was obtained by calcining impure gypsum.
 - E.g. the Pyramid of Cheops.
- The **Chinese** also used **lime mortar** to build the Great Wall in the Qin dynasty (220 B.C)

Hydraulic lime

- A hydraulic lime was developed by the **Greeks** and **Romans** using limestone containing **argillaceous** (clayey) impurities.
- Thus, hydraulic lime mortars were used extensively for hydraulic structures from second half of the first century B.C to the second century AD.

Hydraulic lime

- **Smeaton** conducted extensive experiments with different **limes** and **Pozzolans**, and found that limestone with a high proportion of clayey materials produced the **best hydraulic lime** for mortar to be used in water.
- He made concrete by mixing coarse aggregate (pebbles) and **powdered brick** and mixed it with cement, very close to the proportions of modern concrete.

Calcining impure limestone

- After Smeaton's work, development of hydraulic cement proceeded quickly.
- **James Parker** of England filed a patent in **1796** for a natural hydraulic cement made by calcining **nodules of impure limestone containing clay**.
- **Vicat** of France produced **artificial hydraulic lime** by calcining synthetic mixtures of limestone and clay.

Modern Portland cement

- Portland cement was invented by Joseph Aspdin of England in 1824.
- Isaac Johnson who first burned the raw materials to the clinkering temperature in 1845 to produce modern Portland cement.

Concrete

- **Aggregates** are another **main ingredient** of concrete, and which include sand, crushed stone, clay, gravel, slag, and shale.
- Plain concrete made of Portland cement and aggregate is usually called the **1st generation** of concrete.
- The 2nd generation of concrete refers to **steel bar-reinforced concrete**.
- **Prestressed concrete** was referred to as the 3rd generation of concrete.

Reinforced concrete

- Coignet started experimenting with iron-reinforced concrete in 1852 and was the first builder ever to use this technique as a building material.
- In 1853, he built the first iron-reinforced concrete structure; a four-story house at 72 Rue Charles Michels (Paris).
- The first RC bridge was built in 1889 in the Golden Gate Park in San Francisco, California.

High compressive strength

- Pursuing high compressive strength has been an important direction of concrete development.
- As early as 1918, Duff Adams found that the compressive strength of a concrete was inversely proportional to the **water-to-cement ratio**.
- Before 1960s concrete with a compressive strength of 30 MPa was regarded as high-strength concrete.

High compressive strength

- Since the 1960s, the development of HSC has made significant progress due to two main factors:
 1. The invention of water-reducing admixtures (**WRA**) and
 2. The incorporation of mineral admixtures, such as **silica fume**, **fly ash**, and **slag**.
- **WRA** is a chemical admixture that can help concrete keep good workability under a very low *w/c*; *the latter are finer mineral particles that can react with a* **hydration product in concrete, Ca(OH)_2** , to make concrete **microstructure denser**.

High Strength Concrete (*HSC*)

- In the 1980s, the industry was able to produce a 95-MPa concrete to supply to the 225 West Whacker Drive building project in Chicago.
- The highest compressive strength of 130 MPa was realized in a 220-m-high, 58-story building, the Union Plaza constructed in Seattle, Washington.

High-Performance Concrete (*HPC*)

- It is defined as a concrete that can meet special performance and uniformity requirements, which **cannot always be achieved routinely** by using only conventional materials and normal mixing, placing, and curing practices.
- The requirements may involve **enhancement** of the characteristics of concrete, such as **placement** and **compaction** without **segregation**, **long-term** **mechanical properties**, higher **early-age strength**, better **toughness**, higher volume stability, or longer service life in **severe environments**.

Ultra-High-Strength Concrete (*UHSC*)

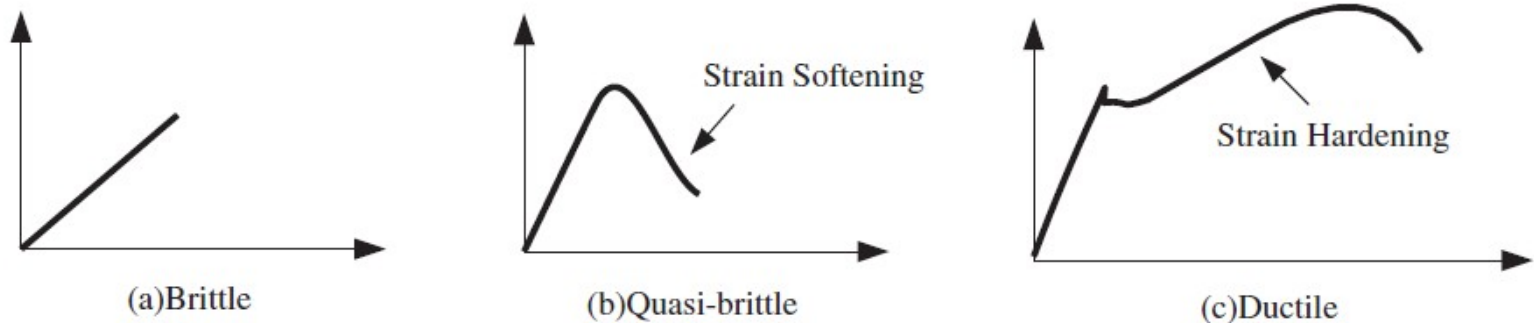
- In the 1990s, a new “concrete” with a compressive concrete strength higher than 200 MPa was developed in France.
- The *UHSC* has reached a compressive strength of 800 MPa with heating treatment.
- However, it is very brittle, hence, incorporating fibers into UHSC is necessary.
- After incorporating fine steel fibers, flexural strength of 50 MPa can be reached.

Characteristics of concrete

- **Advantages of concrete**
- *Economical*: The 3 major components of concrete are available in every corner of the world → avoiding the transport expenses.
- **Ambient** *temperature-hardened material*
- Ability to be **cast**
- **Energy** *efficient*
- Excellent resistance to **water**
- **High-temperature** *resistance*
- Ability to consume **waste**
- Ability to work with **reinforcing** steel
- Less **maintenance** *required*

Limitations of concrete

- *Quasi-brittle* failure mode
- *Low tensile strength*
- *Low toughness (ductility)*
- *Low specific strength* (strength/density ratio)
- *Formwork* is needed
- *Long curing time*
- *Working with cracks*



Three failure modes of materials

Types of concrete

- Classification in accordance with unit weight

Classification	Unit Weight (kg/m ³)
Ultra-lightweight concrete	< 1200
Lightweight concrete	1200 < UW < 1800
Normal-weight concrete	~2400
Heavyweight concrete	>3200

Classification in accordance with compressive strength

Classification	Compressive Strength (MPa)
Low-strength concrete	< 20
Moderate-strength concrete	20–50
High-strength concrete	50–150
Ultra-high-strength concrete	> 150

Classification in accordance with additives

Classification	Additives
Macro Defect Free (<i>MDF</i>)	Polymers
Fiber Reinforced Concrete (FRC)	Different fibers
Densified with Small Particles (DSP) concrete	Large amount silica fume
Polymer concrete	Polymers

Factors influencing concrete properties

1. *w/c ratio* (or *w/b* or *w/p ratio*): The influence of *w/c* on the concrete compressive strength has been known since the early 1900s (Abrams, 1927), leading to Abrams's law:

$$f_c = \frac{A}{B^{1.5(w/c)}}$$

where f_c is the compressive strength, A is an empirical constant (usually 97 MPa), and B is a constant that depends mostly on the cement properties (usually 4).

2. Cement content: Cement paste has 3 functions in concrete: **binding, coating, & lubricating.**

3. Aggregate

- *Maximum aggregate size*
- *Aggregate grading*
- *Aggregate shape and texture*
- *Sand/coarse aggregate ratio*
- *Aggregate/cement ratio*

4. Admixtures

5. Mixing procedures

6. Curing

Questions

- Why is concrete so popular?
- What are the weaknesses of concrete?
- What are the factors influencing concrete properties?
- How would you like to improve concrete workability (fluidity or cohesiveness)?
- How can you enhance concrete compressive strength?