MAT1600
Introduction to Materials Engineering: CERAMICS

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Materials Covered

- Background to ceramics (cement and concrete).
- Portland cement manufacture, phase composition and hydration.
- Concrete: compositions, structure, processing, properties and durability.
- Glass: type, composition, manufacturing and property.
- Brick: type, composition, manufacturing, property and durability.

Outline of Lecture 1

- General Introduction of Ceramics
- Cement
- Concrete
- Advantages of Concrete
- Applications of Cement/Concrete.

Ceramics

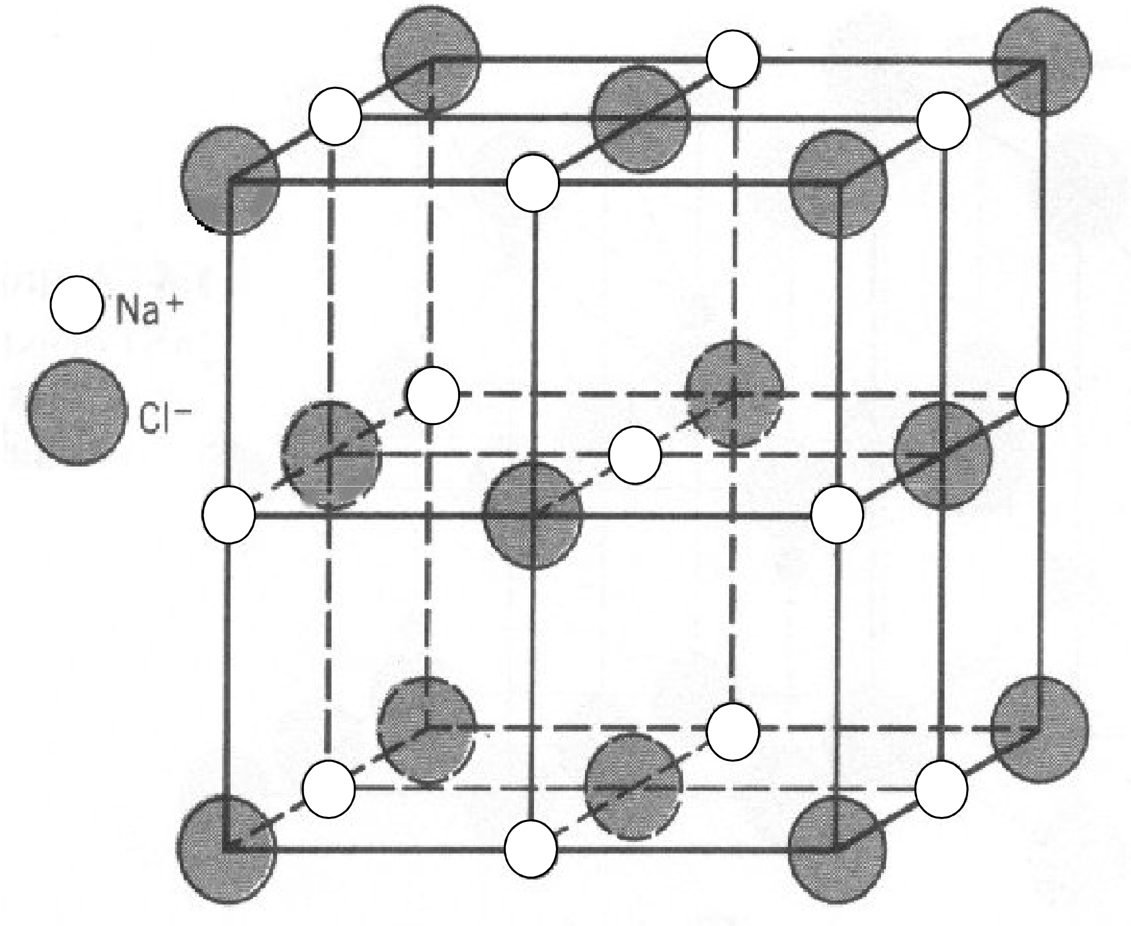
- **Definition: An inorganic compound consisting of a metal (or semi-metal) and one or more nonmetals.**
- **Characteristics:**

1) Inter-atomic bonds are ionic and/or covalent.

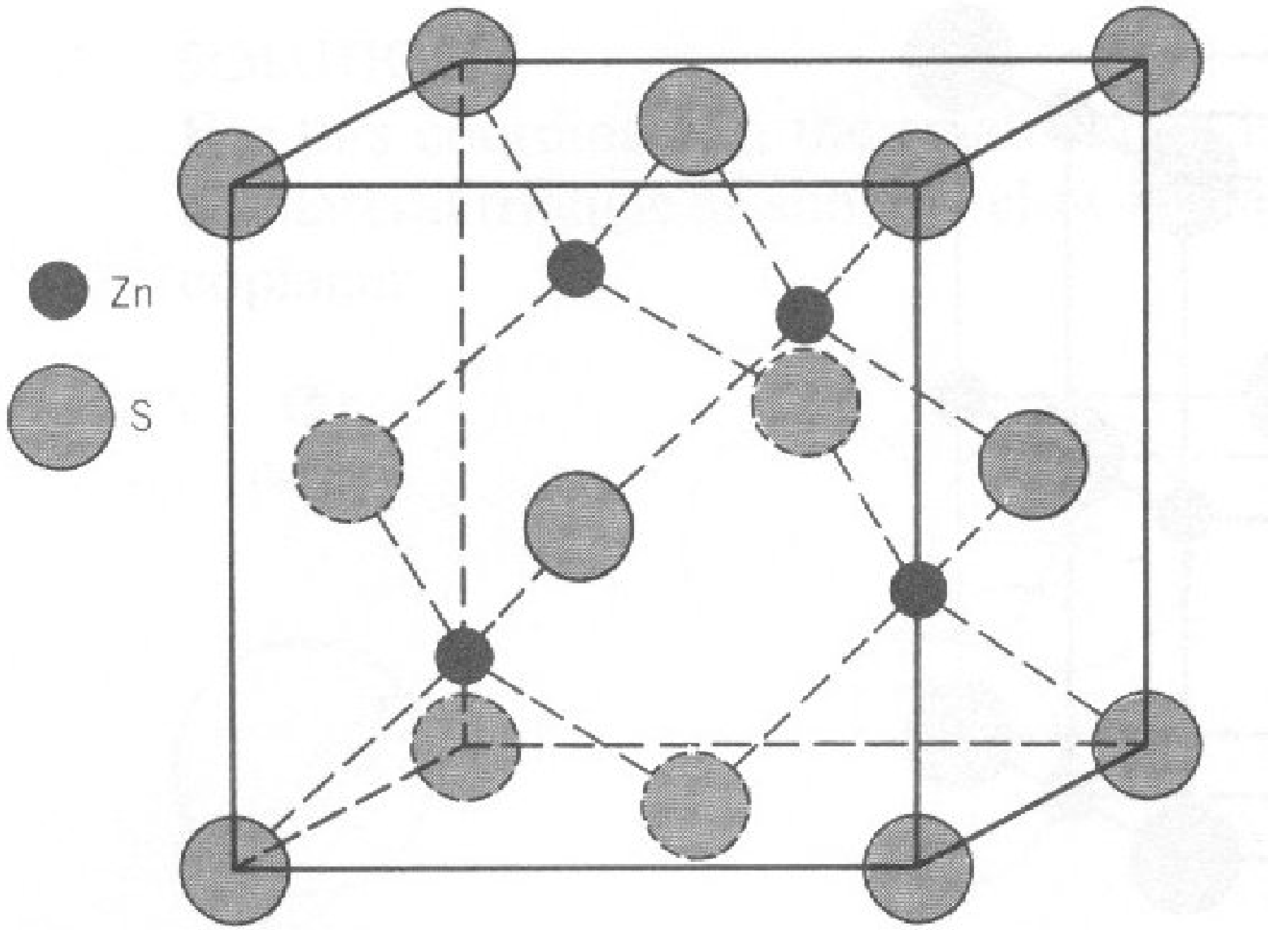
2) structure: crystalline or non-crystalline (amorphous).

3) The term "ceramics" comes from the Greek word *keramikos* ("burned stuff"). → a high-temperature heat treatment process called FIRING.

NaCl (Ionic Bonding)



SiC (Covalent Bonding)



Ceramic Crystal Structure: BONDING

- **Bonding:**
  - --Ionic and/or covalent.
  - --% ionic character increases with difference in electronegativity.
- **Large vs small ionic bond character:**

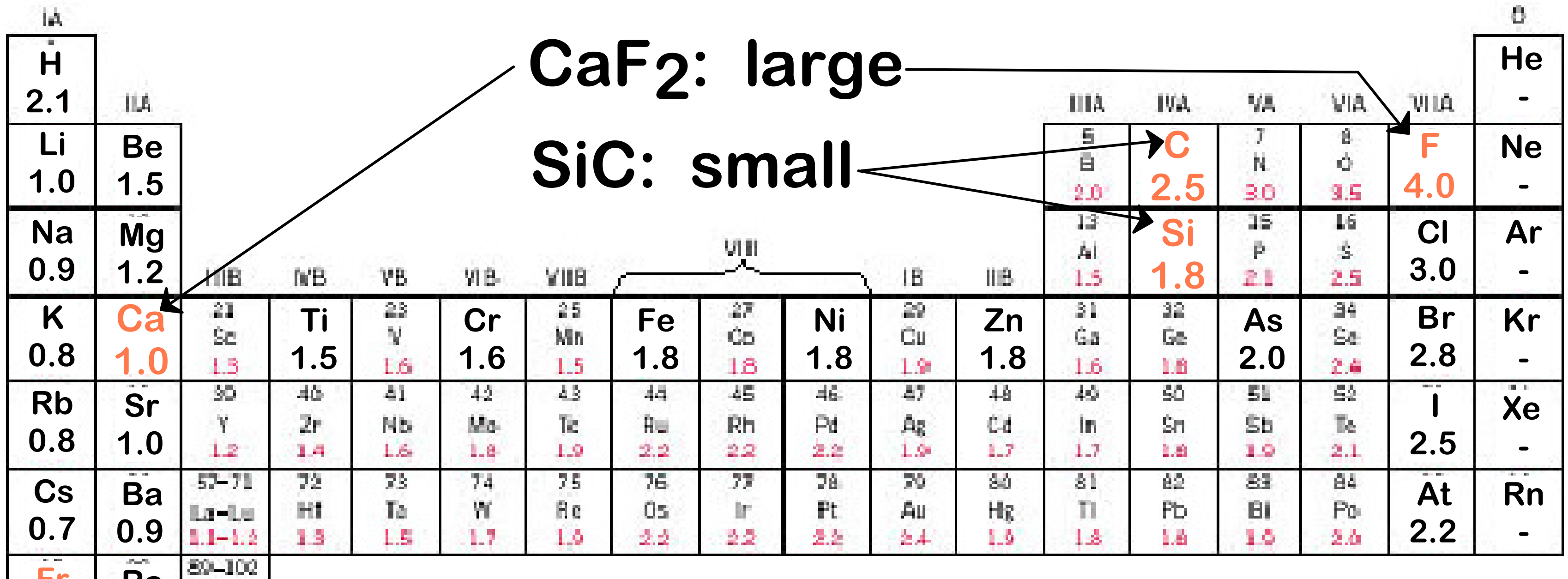


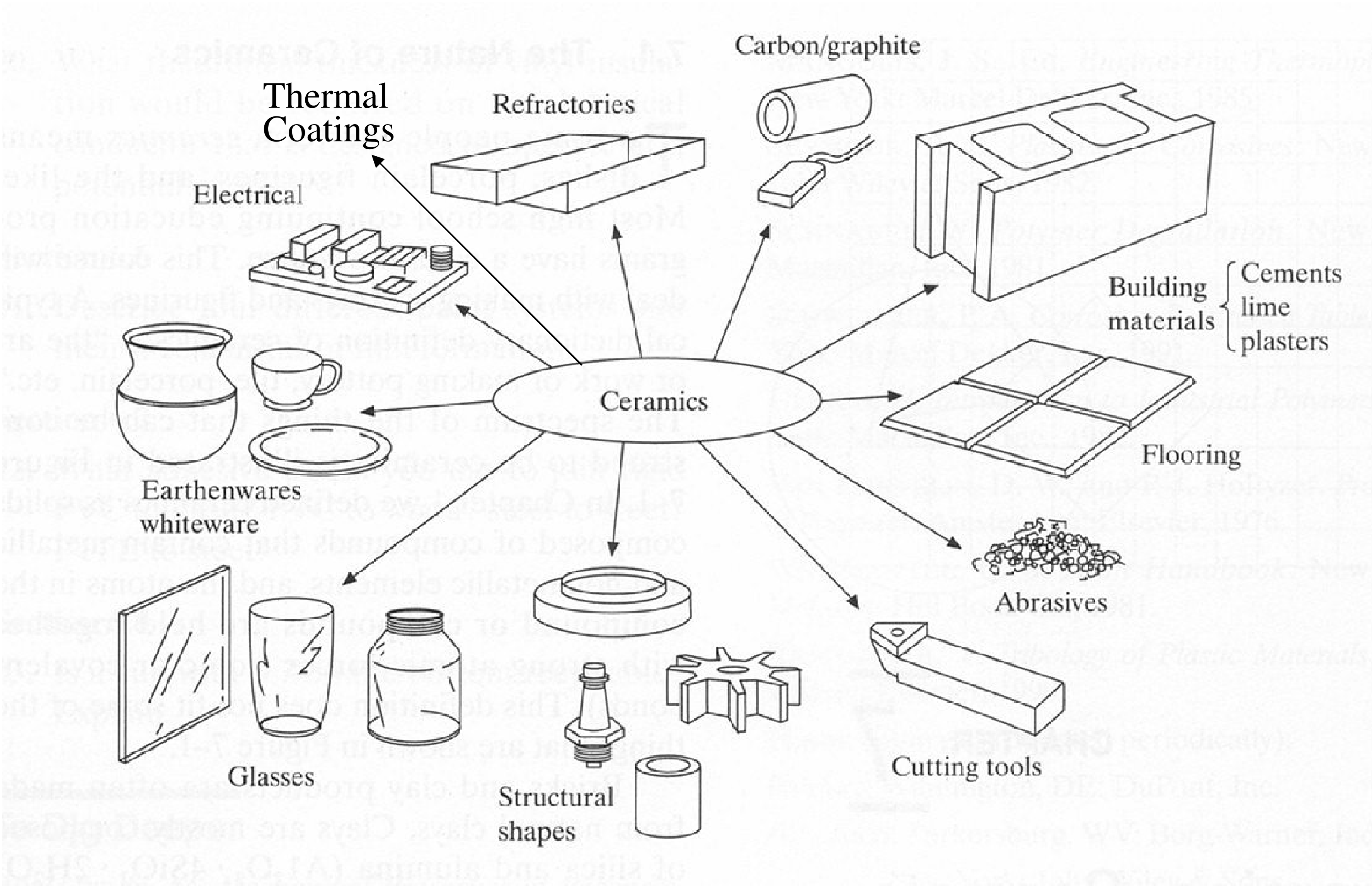
Table of Electronegativities

Classification of Ceramics

Ceramic Materials

- Glasses
  - -optical
  - -composite reinforce
  - -containers/ household
- Clay products
  - -whiteware
  - -structural
- Refractories
  - -bricks for high *T* (furnaces)
- Abrasives
  - -sandpaper
  - -cutting
  - -polishing
- Cements
  - -composites
  - -structural
- Advanced ceramics
  - -engine rotors valves bearings
  - -sensors

Ceramic Products



Physical Properties of Ceramics (1)

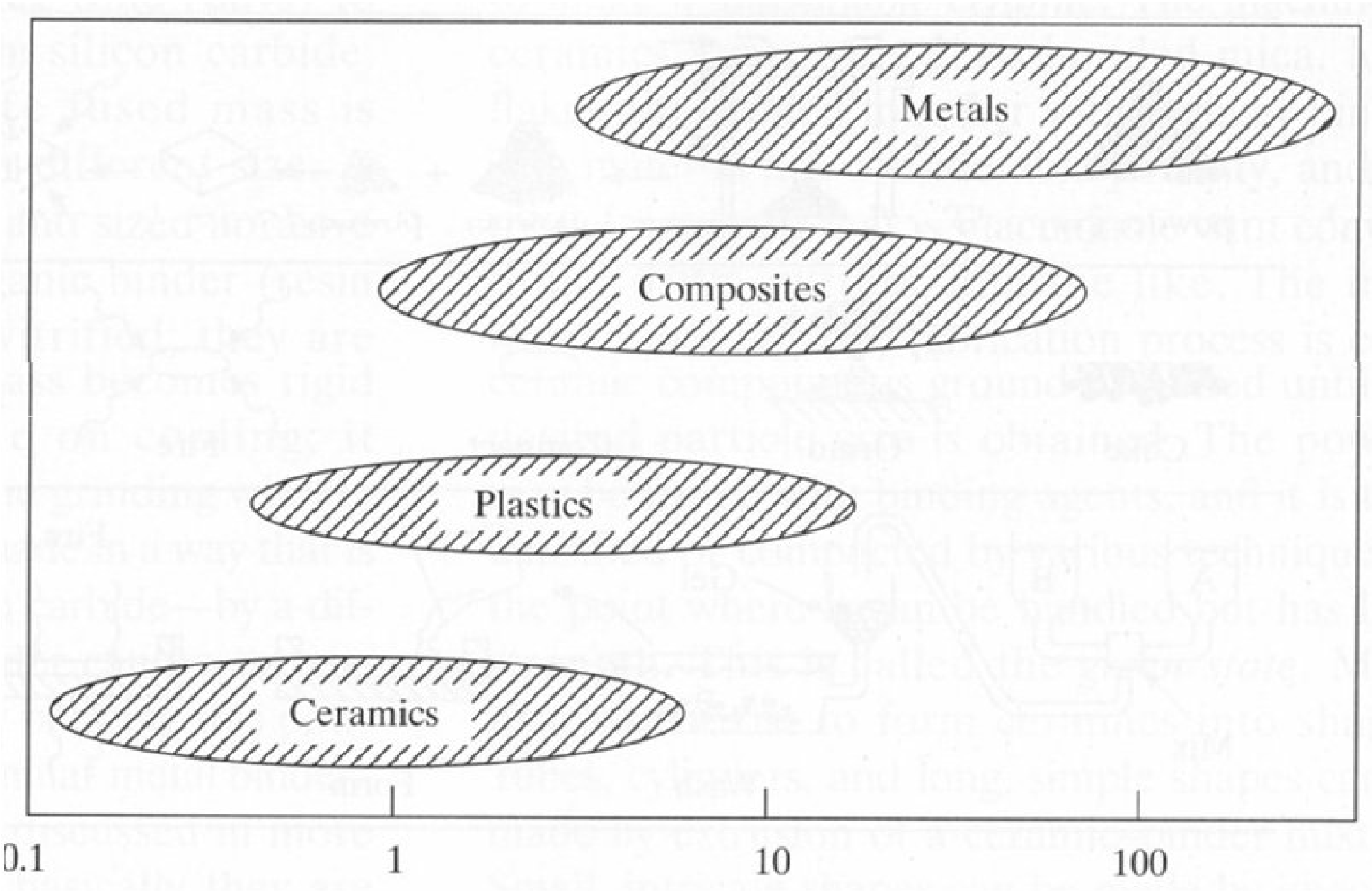
- **Density: in general <metals.**
- **Melting temperatures: >most metals.**
- **Electrical and thermal conductivities: <metals, but vary in a wide range $\rightarrow$ some ceramics are insulators while others are conductors.**

Physical Properties of Ceramics (2)

- **Thermal expansion:** <metals, but effects are more damaging because of their brittleness.

- **High hardness, brittle (low toughness):** almost no ductility →causing problems in both processing and performance of ceramic products.

Fracture Toughness



Fracture Toughness (MPa√m)

<u>Strength of Ceramics</u>

- Theoretically, should be > metals because their covalent and/or ionic bonds are stronger than metallic bonds.
- However, metallic bonding allows for slip, the basic mechanism by which metals <u>deform plastically</u> when subjected to high stresses
- Bonding in ceramics is more rigid and does not permit slip under stress
- The inability to slip makes it much more difficult for ceramics to absorb stresses

Compressive Strength of Ceramics

- Ceramics are substantially stronger in compression than in tension (why?).

- For engineering and structural applications:

  Design → so that they are loaded in compression rather than tension or bending.

What Is A Cement?

- **Dictionary definition**
  - **Substance applied as a paste and hardening into a stony consistency for binding together stones or bricks. (comes from Latin *cementum* meaning building stone)**
- **Working definition**
  - **Any substance which can be mixed as a paste and undergoes a chemical reaction to harden or set, usually without high temperatures being needed.**

Binders

- Glues and Adhesives
  - Usually rely on evaporation of solvent or water to provide bond.
  - May dissolve part of surface and reprecipitate it as solvent dries.
  - Can penetrate pores.
  - Bond is physical.

- Cements
  - Rely on chemical reaction to form new compound, usually a polymer.

Cements

- Organic cements
  - Epoxy cements
  - Polyesters
  - UV (Ultra-violet) cured polymers

- Inorganic cements
  - Portland cement
  - High alumina cement
  - Blended cements
  - New systems
  - Dental and bio-cements

Hydraulic v's Non-hydraulic Cement

- **An hydraulic cement is one which will set under water and is water stable when hard.**
  - ➢ **Portland cement**
  - ➢ **High alumina cement**
  - ➢ **Blended cement**
  - ➢ **Magnesium phosphate cement**
  - ➢ **Dental cement**

- **Non hydraulic cements are not stable in water or not set under water.**
  - ➢ **Plaster of Paris**
  - ➢ **Lime mortar**
  - ➢ **Specialty cements eg Sorel cements**

Non-hydraulic Cement

- **Plaster of Paris (Invented in 1375, Paris)**

  - **Made by heating gypsum to form hemihydrate or bassinite, $CaSO_4.0.5H_2O$.**

    $$CaSO_4.2H_2O + heat \rightarrow CaSO_{4.}0.5H_2O + 1\tfrac{1}{2}H_2O\uparrow$$

  - **Hemihydrate reacts with water to recrystallise as gypsum in a through solution process**

  - $CaSO_{4.}0.5H_2O + 1\tfrac{1}{2}H_2O \rightarrow CaSO_4.2H_2O\downarrow + heat$

Plaster of Paris

- **Set material is not stable to water.** **Solubility:**

  1) Gypsum: is 2.4 g/l (1.4 x10^{-2}moles/l) so it will leach.

  2) $CaSO_4.0.5H_2O$: 3.0g/l (2.1 x 10^{-2} moles/l)

  3) $CaSO_4$ (anhydrite): 2.1g/l (1.5 x 10^{-2}moles/l).

- **Used to manufacture plaster of Paris moulds, plaster of Paris sculptures and many useful plaster of Paris casts, bandages.**

Non-hydraulic Cement

- **Lime mortar**

  Limestone is heated to give burnt lime, which is reacted with water to give slaked lime. This is mixed with further water and sand and allowed to slowly react with CO_2 from the atmosphere.

$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2\uparrow$$

$$CaO + H_2O \rightarrow Ca(OH)_2 + \text{heat}$$

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3\downarrow$$

Carbonated mortar is stable to water but $Ca(OH)_2$ is soluble at 1.6 g/l (0.022 moles/l)

Hydraulic Cements

- Roman cement

  Slaked lime when mixed with amorphous aluminosilicate will set hard under water

- Portland cement.

  Calcium silicate based cement, named because of its resemblance to Portland stone, a good building material based on limestone. Bulk is normally called Ordinary Portland Cement (OPC).

- Calcium aluminate cements

  Rapid setting cement based on calcium aluminates, now mainly used for refractories.

Hydraulic Cements

- **Blended cements**

  Blends of OPC with a reactive additive such as blast furnace slag or pulverised fuel ash.

- **Special cements**

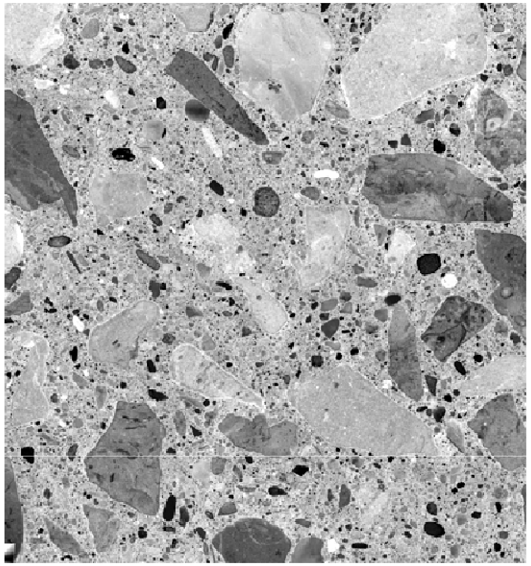
  Specialty cements such as calcium sulphoaluminate cement and magnesium phosphate cement

- **Dental cements**

  Specialty glass frits made from alumina, silica and other metal oxides and fluorides and reacted with acids such as citric acid or phosphoric acid.

<u>Concrete</u>

- The word “concrete” originates from the Latin verb “concretus”, which means to grow together.

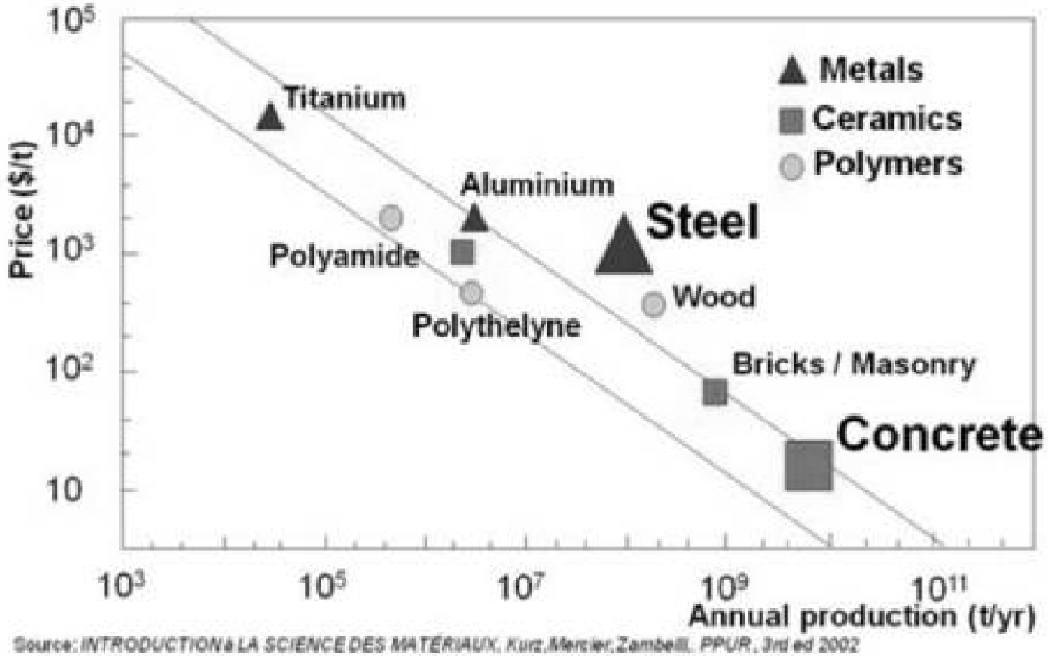


- It is a mixture of <u>cement, water, aggregates</u>, and in some cases, <u>additives/admixtures</u>.
- The cement and water form a <u>paste</u> that <u>hardens</u> and <u>bonds</u> the aggregates together.

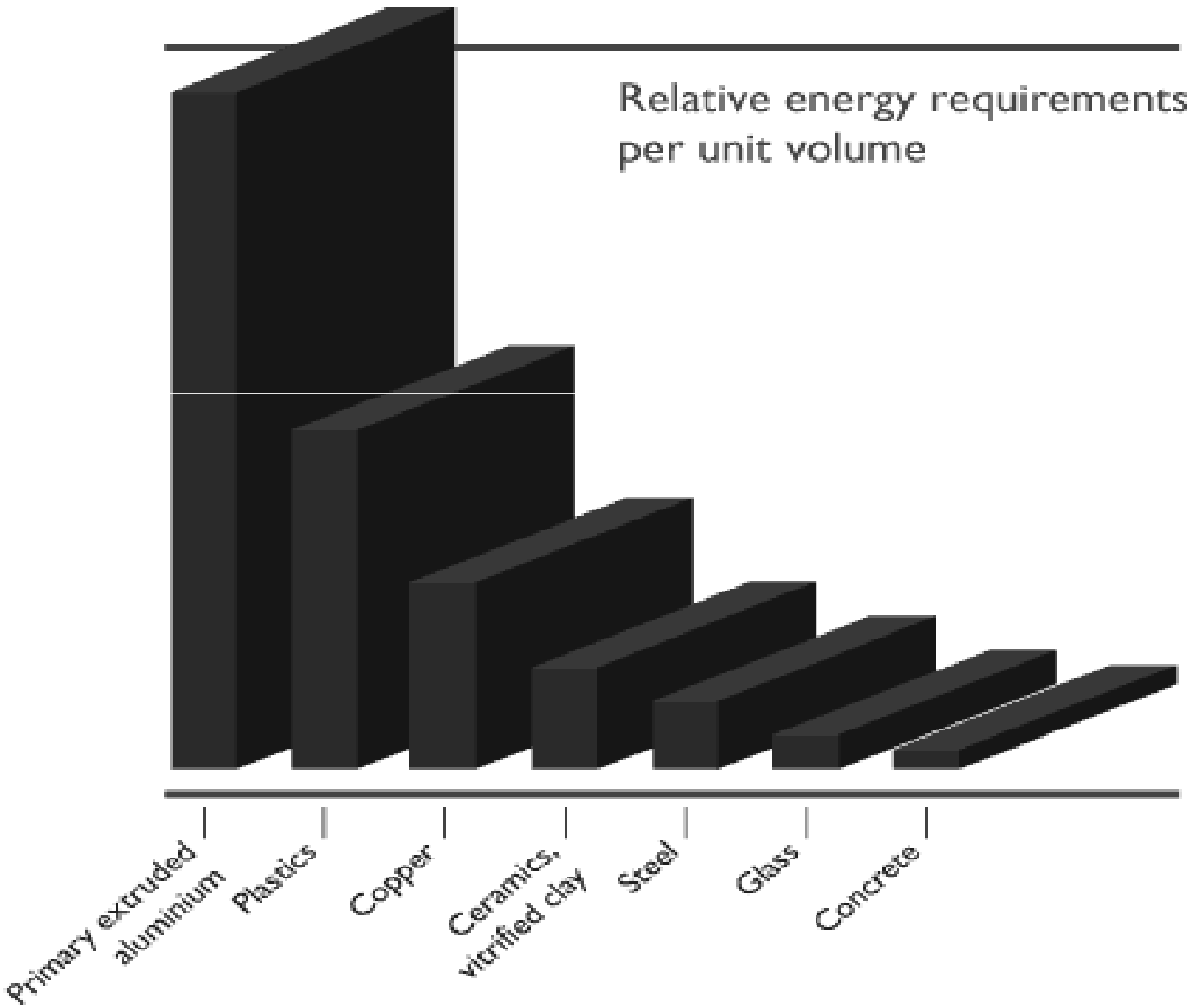
→ “man made rock/stone”.

Concrete

- Concrete is the world‘s most versatile, durable and reliable construction material. The most used material next to water.
- Around 2,9 billion tonnes of cement in 2007. →7 billion m^3 of concrete per year.
- Concrete is also a very economical material.



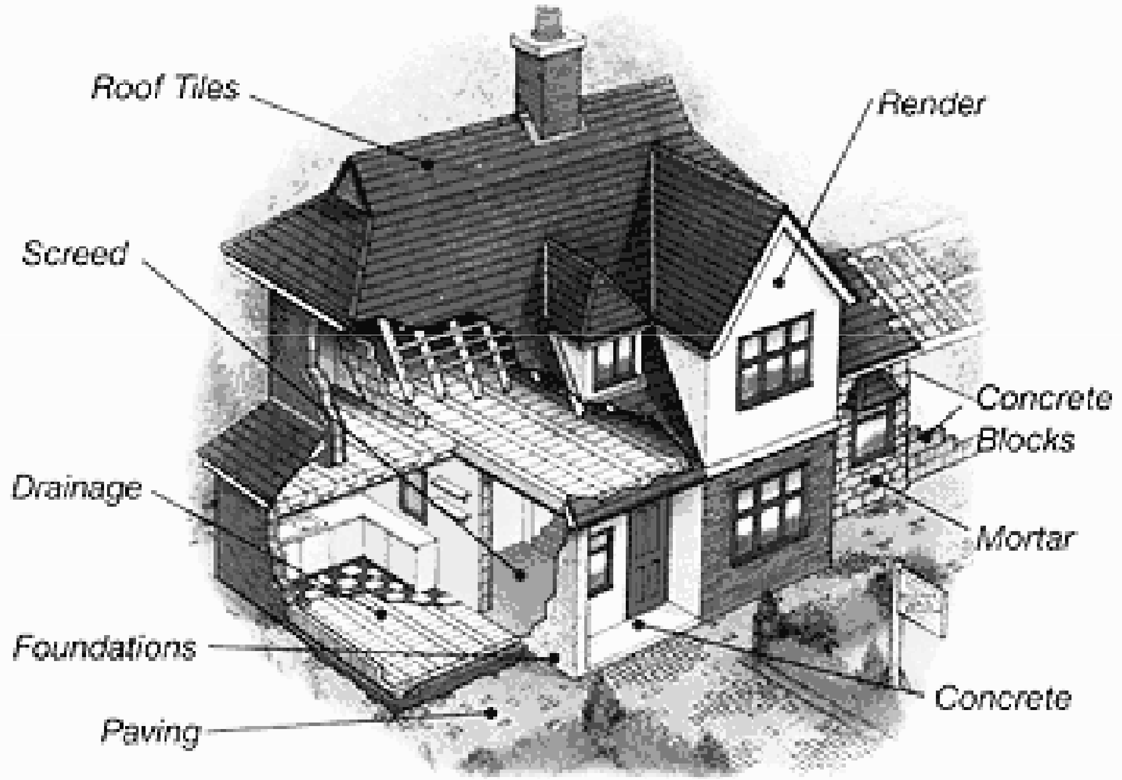
Concrete - Green Building Material



<u>Green Material?</u>

- 1 tonne of cement produces ~1 tonne CO_2 (4-5% of the global CO_2 emissions).
  - Most arises from <u>decomposition of $CaCO_3$</u> but about 12% comes from energy needed to manufacture.
  - Modern plants have large <u>heat exchangers as well as recycle streams</u> and can get down to around <u>0.87 tons CO_2</u> per ton of cement.
  - One reason for blended cements which use a waste product

Cement in Houses

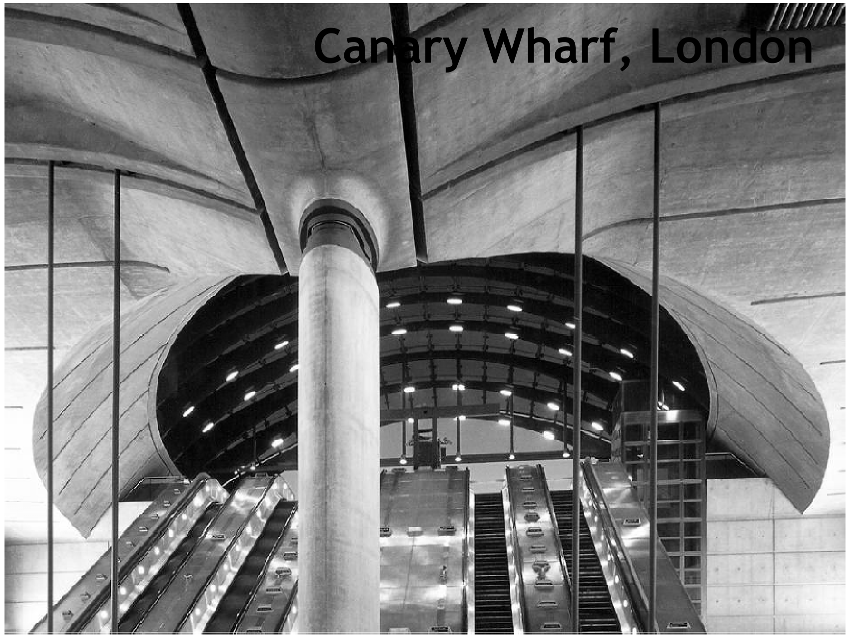


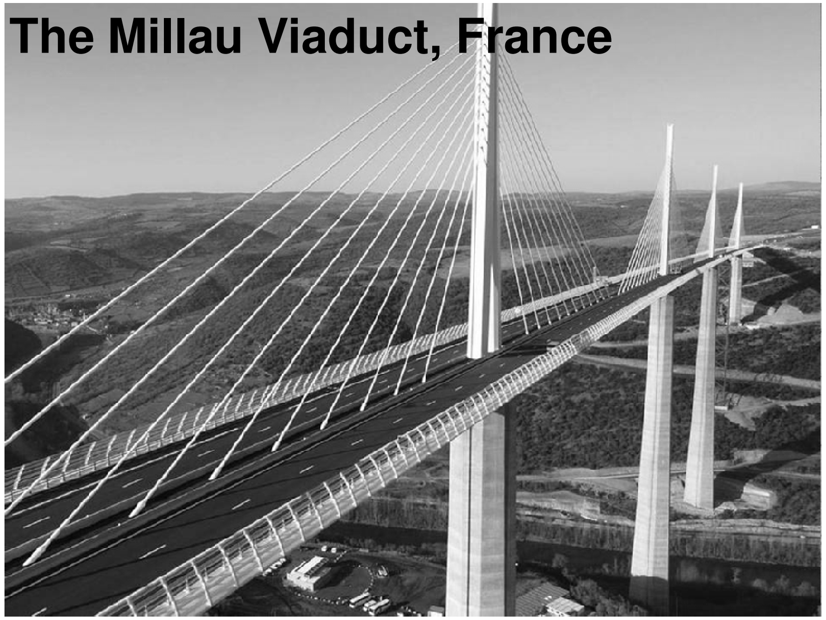
▲ Cement will almost certainly have been used in building your house

Over 18 tonnes of cement is used in making the average house.

Advantages of Concrete

- **Relatively inexpensive and readily-available.**
- **Easy to place/install. Can be “moulded” to form almost any imaginable shapes.**
- **Strong/durable. Resistant to fire, impact, water, and weather. Longer service life than most construction products and requires little maintenance.**
- **Concrete provides thermal mass and insulation – significant savings on heat and cooling equipment.**


Canary Wharf, London


The Millau Viaduct, France


Sydney Opera House, Austrailia


Tenerife Concert Hall, Spain

Use of Cement/Concrete

- **Over 80% of OPC cement is used in making concrete.**
- **Modern uses**
  - **Building (floors, beams, columns, roofing, piles, bricks, mortar, panels, plaster)**
  - **Transport (roads, pathways, crossings, bridges, viaducts, tunnels, parking, etc.)**
  - **Water (pipes, drains, canals, dams, tanks, pools, etc.)**
  - **Civil (piers, docks, retaining walls, silos, warehousing, poles, pylons, fencing)**
  - **Agriculture (buildings, processing, housing, irrigation)**
  - **Biocement, Waste encapsulation, Well cement, Soil stabilisation.**

Questions for Discussion

- Explain why the densities of single-crystal ceramics are lower than those of typical metals and why ceramics are stronger in compression than tension.
- What are the main differences between glues and cements?
- Why are the main differences between non-hydraulic cement and hydraulic cements?
- How does a plaster of Paris set/harden?
- How does a lime mortar set/harden?
- What is the difference between a cement and a concrete?