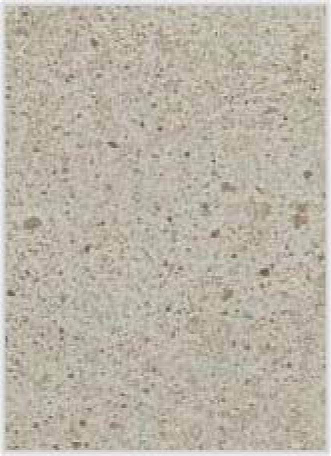
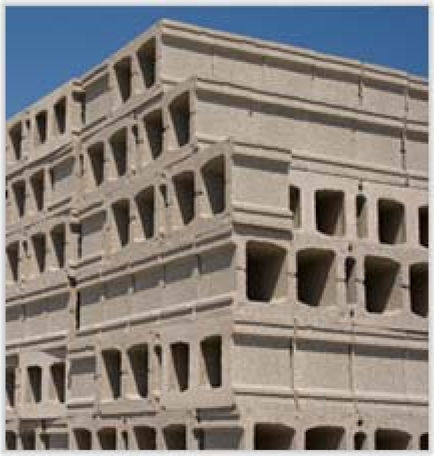
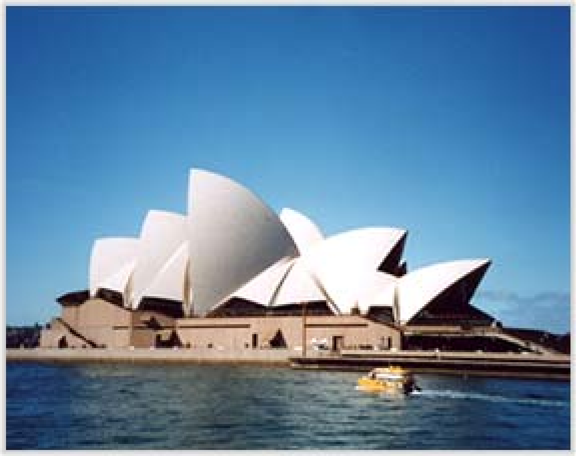
Description

Image

Caption

1. Concrete texture. © Dave Morris at Flickr - (CC BY 2.0) 2. Concrete blocks. © iStockphoto 3. Reinforced concrete, Sydney opera house. © John Fernandez

The material

Concrete is a composite, and a complex one. The matrix is cement; the reinforcement, a mixture of sand and gravel ('aggregate') occupying 60-80% of the volume. The aggregate increases the stiffness and strength and reduces the cost (aggregate is cheap). Concrete is strong in compression but cracks easily in tension. This is countered by adding steel reinforcement in the form of wire, mesh or bars ('rebar'), often with surface contours to key it into the concrete; reinforced concrete can carry useful loads even when the concrete is cracked. Still higher performance is gained by using steel wire reinforcement that is pre-tensioned before the concrete sets. On relaxing the tension, the wires pull the concrete into compression; the concrete does not crack until the loads applied to it overcome this compression stress ('pre-stressed concrete').

Compositional summary

6:1:2:4 Water:Portland cement:Fine aggregate:Coarse aggregate

General properties

Density	144	-	162	lb/ft^3
Price	* 0.0181	-	0.0272	USD/lb
Date first used	1756			

Mechanical properties

Young's modulus	2.18	-	3.63	10^6 psi
Shear modulus	* 0.943	-	1.58	10^6 psi
Bulk modulus	* 1.03	-	1.73	10^6 psi
Poisson's ratio	0.15	-	0.2	
Yield strength (elastic limit)	0.145	-	0.435	ksi
Tensile strength	0.145	-	0.218	ksi
Compressive strength	2.03	-	7.25	ksi
Elongation	0			% strain

Hardness - Vickers	* 5.7	-	6.3	HV
Fatigue strength at 10^7 cycles	* 0.0783	-	0.122	ksi
Fracture toughness	0.319	-	0.41	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.01	-	0.03	

Thermal properties

Melting point	1.7e3	-	2.24e3	°F
Maximum service temperature	896	-	950	°F
Minimum service temperature	-262	-	-244	°F
Thermal conductor or insulator?	Poor insulator			
Thermal conductivity	0.462	-	1.39	BTU.ft/h.ft^2.F
Specific heat capacity	0.199	-	0.251	BTU/lb.°F
Thermal expansion coefficient	3.33	-	7.22	µstrain/°F

Electrical properties

Electrical conductor or insulator?	Poor insulator			
Electrical resistivity	1.85e12	-	1.85e13	µohm.cm
Dielectric constant (relative permittivity)	* 8	-	12	
Dissipation factor (dielectric loss tangent)	* 0.001	-	0.01	
Dielectric strength (dielectric breakdown)	20.3	-	45.7	V/mil

Optical properties

Transparency	Opaque

Processability

Moldability	3	-	4
Machinability	1		

Durability: water and aqueous solutions

Water (fresh)	Excellent
Water (salt)	Excellent
Soils, acidic (peat)	Excellent
Soils, alkaline (clay)	Excellent
Wine	Excellent

Durability: acids

Acetic acid (10%)	Acceptable
Acetic acid (glacial)	Limited use
Citric acid (10%)	Acceptable
Hydrochloric acid (10%)	Acceptable
Hydrochloric acid (36%)	Unacceptable
Hydrofluoric acid (40%)	

	Unacceptable
Nitric acid (10%)	Acceptable
Nitric acid (70%)	Unacceptable
Phosphoric acid (10%)	Acceptable
Phosphoric acid (85%)	Limited use
Sulfuric acid (10%)	Limited use
Sulfuric acid (70%)	Unacceptable

Durability: alkalis

Sodium hydroxide (10%)	Excellent
Sodium hydroxide (60%)	Excellent

Durability: fuels, oils and solvents

Amyl acetate	Excellent
Benzene	Excellent
Carbon tetrachloride	Excellent
Chloroform	Excellent
Crude oil	Acceptable
Diesel oil	Excellent
Lubricating oil	Excellent
Paraffin oil (kerosene)	Excellent
Petrol (gasoline)	Excellent
Silicone fluids	Excellent
Toluene	Excellent
Turpentine	Excellent
Vegetable oils (general)	Excellent
White spirit	Excellent

Durability: alcohols, aldehydes, ketones

Acetaldehyde	Excellent
Acetone	Excellent
Ethyl alcohol (ethanol)	Excellent
Ethylene glycol	Excellent
Formaldehyde (40%)	Excellent
Glycerol	Excellent
Methyl alcohol (methanol)	Excellent

Durability: halogens and gases

Chlorine gas (dry)	Limited use
Fluorine (gas)	Limited use
O2 (oxygen gas)	Excellent

Sulfur dioxide (gas)	Unacceptable			

Durability: built environments

Industrial atmosphere	Acceptable			
Rural atmosphere	Excellent			
Marine atmosphere	Excellent			
UV radiation (sunlight)	Excellent			

Durability: flammability

Flammability	Non-flammable			

Durability: thermal environments

Tolerance to cryogenic temperatures	Limited use			
Tolerance up to 150 C (302 F)	Excellent			
Tolerance up to 250 C (482 F)	Excellent			
Tolerance up to 450 C (842 F)	Excellent			
Tolerance up to 850 C (1562 F)	Unacceptable			
Tolerance above 850 C (1562 F)	Unacceptable			

Geo-economic data for principal component

Annual world production, principal component	1.48e10	-	1.53e10	ton/yr
Reserves, principal component	* 4.92e11	-	5.02e11	I. ton

Primary material production: energy, CO2 and water

Embodied energy, primary production	108	-	141	kcal/lb
CO2 footprint, primary production	0.0903	-	0.0998	lb/lb
Water usage	* 0.387	-	0.428	gal(US)/lb
Eco-indicator 95	3.8			millipoints/kg
Eco-indicator 99	3.86			millipoints/kg

Material processing: energy

Grinding energy (per unit wt removed)	* 223	-	247	kcal/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.155	-	0.171	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	✔			
Embodied energy, recycling	* 82.1	-	90.8	kcal/lb
CO2 footprint, recycling	* 0.0631	-	0.0698	lb/lb
Recycle fraction in current supply	12.5	-	15	%
Downcycle	✔			

Combust for energy recovery	✖
Landfill	✔
Biodegrade	✖
Toxicity rating	Non-toxic
A renewable resource?	✖

Environmental notes

Calcining is energy intensive and the conversion of chalk, $CaCO_3$ to lime, CaO releases CO_2 - a greenhouse gas. Concrete is used on a vast scale; the energy and the CO_2 are a real concern, with no obvious solutions.

Supporting information

Design guidelines

Freshly mixed concrete is fairly fluid. Poured into wooden molds (“sets”) it can be shaped to floors, walls and more elaborate structures. If they carry tension, steel reinforcement must be used; with this, more daring, slender or cantilevered structures become possible - a possibility daringly exploited by the French architect Le Corbusier, the first to realize the potential of reinforcement. Pre-stressing allows still more slender structures; the bridge in the picture is an example. Concrete, however, does not weather gracefully; unlike wood, stone and brick, it stains, discolors and cracks in a way that is visually unattractive and can expose the reinforcement to corrosive attack.

Technical notes

The world of concrete has developed a language of its own. Concrete is aggregate (sand plus gravel) bonded by 20-30% of Portland cement paste. Portland cement is made by calcining (heating at 1500C) a mixture of chalk and clay. They combine to give compounds of CaO ('C') and SiO_2 ('S') and Fe_2O_3 ('F'), referred to as C3S (=3CaO.SiO_2), C3A (=3CaO.Al_2O_3) and the like, releasing carbon dioxide. When, in powdered form, these are mixed with water they react to give hydrated compounds (C-S-H) that interlock and become solid. The reaction is slow, so the mix remains fluid enough to be cast for some hours allowing it to be transported and cast. Although the sets can be removed after 7 days, full strength is not developed for several months.

Typical uses

General civil engineering construction and

Links

Reference

ProcessUniverse

Producers