Mixing concrete by hand on a Habitat for Humanity building project in Thailand, Mike Stone.

NZASE resource

Porous concrete

Concrete is a composite material made of a binder (cement and water) and a filler (aggregate, a mix of stones). Its chemistry is complex but simple principles can be explained. NZASE Science Communicator Mike Stone investigates how concrete is being adapted to modern needs.

Early concrete

The earliest concrete was made by the Romans, using a recipe that has not been found or replicated since. When they mixed volcanic ash with lime (calcium oxide) and added water, Romans made their *opus caementicum*.

Roman concrete, photo Roy Kaltschmidt, Berkeley Lab.

As mortar, it could hold together large stone boulders in walls. If gravel was added it formed hard slabs, which were used to pave roads that still exist today. The concrete they made for structures in the sea lasts better than our modern concrete.

But lime and volcanic ash were not available everywhere, and in 1824 English mason Joseph Aspdin invented modern Portland cement.

The chemistry

Aspdin drew on the Roman idea, using readily available limestone and sand instead of ash. But limestone, calcium carbonate, is insoluble so could not be hydrated. Instead, Aspdin made lime, calcium oxide, by heating calcium carbonate to 900°C. Lime reacts with water to make calcium hydroxide, a hard stone-like material, effectively cured cement. This reaction is very exothermic.

Lime is now produced in a rotating kiln, with both the fuel burnt in the kiln and the reaction itself producing CO_2. The production of concrete produces eight percent of overall global emissions, making it a target for governments aiming for net zero.

Modifying cement

To meet current needs, Portland cement is modified.

- **Non-hydraulic cement** can cure without water. It is made from limestone, gypsum and oxychloride and is used to construct bridges and water reservoirs. This cement hardens with age.
- **Hydraulic grey** Portland cement is made from lime with additives (from the clay added to the kiln). Put simply, these include:
  - → Aluminium oxide, which when hydrated turns into a gel and holds water for a long time.
  - → Silicon dioxide, which gives the cement flexibility and chip resistance.
  - → Ferric oxide, which makes the cement stronger overall and enhances its tensile strength.
  - → Manganese oxide, which gives cement its grey colour.
- **Hydraulic white** Portland cement

The original Appian way. Freed76, Flickr.

has the same ingredients as the grey version but with less ferric and manganese oxides. It is also processed at a higher temperature and ground more finely. It is decorative in floors, columns and statues.

- Gypsum, calcium sulphate, can be added to make the cement set more slowly (as does sugar).
- Calcium chloride can be added to make the cement set more quickly.
- Polymers can be added for flexibility, better adhesion and to resist chipping.

Making concrete

Concrete is made by adding two ingredients to cement:

- **Water** – when mixed with cement, water forms a paste that binds the aggregate together. It causes the concrete to harden, a process called hydration. During hydration, the compounds in cement form chemical bonds with water molecules, becoming hydrates.

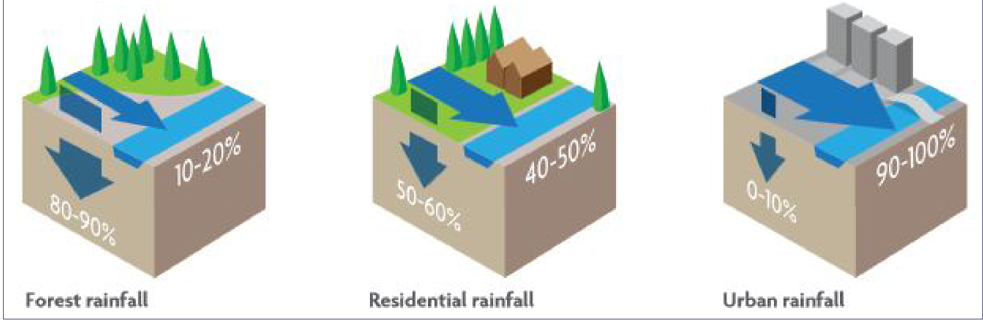
The water needs to be pure to prevent other reactions from occurring that may interfere with the hydration process and weaken the concrete. The water-to-cement ratio is the most critical factor to produce concrete that is strong and workable (ie, able to be shaped into different forms).

- **Aggregates** – usually a mix of fine sand, medium-sized river gravel and larger, coarse rocks.

The cost of concrete is kept low by making most of the volume – up to 80 percent – aggregate. The selection of aggregate is determined, in part, by the desired characteristics of the concrete.

The three ingredients – cement, water, and aggregate – are thoroughly mixed, moulded or placed as desired and consolidated. Over many years it will hydrate (where compounds bond with water) and cure (harden).

A worker pours concrete into rebar on a bridge. Reinhold Möller, CC BY-SA 4.0, Wikipedia.



The less green space available, the less rainwater can be absorbed into the ground. Runoff and groundwater will end up in streams, but at different speeds. From http://www.i-fink.com/absorbent-concrete/

Concrete is useful because it is strong, durable, non-combustible and it resists wind, water, rodents and insects. However, it has a relatively low tensile strength, low ductility and a low strength-to-weight ratio, as well as a susceptibility to cracking.

Porous concrete

In January 2023, Auckland saw 250mm of rainfall in 24 hours. This caused major flooding of urban streams but also on city streets – commuters talked of calf-high water making it difficult to drive down Queen St.

This is not surprising, as in urban areas with a lot of hard landscaping and little green space, only around 10% of rainwater can be absorbed into the ground.

Absorbant concrete, i-fink.com.

Porous concrete is made with an aggregate of larger pebbles and stones but no sand. This means there are more air gaps, so the concrete can hold large amounts of water.

A layer of permeable concrete is installed on top of a crushed stone base, which generally sits on top of the soil. Rainwater drains through the top surface, collects in the aggregate layer, and is slowly released into the ground.

A UK company making this product released a video of a truck pouring 4,000 L of water onto a parking lot. The water appeared to be absorbed instantly, as if draining into a hidden hole.

This innovative building material can help prevent flooding in two ways:

- It can absorb up to 40% of surface water before it has a chance to enter waterways. This can help prevent the surface and the waterway from flooding in heavy rainfall

- It slowly releases the absorbed water back into the ground, reducing the pressure on water systems.

While this technology is still to be perfected, with climate change bringing more intense and more frequent rain events, such solutions will be needed.

Porous concrete in Aotearoa

Porous or absorbent concrete has been suggested as a solution to severe city flooding. An Auckland City engineer said that porous concrete can provide what they term the initial abstraction, absorbing the first burst of water so that the stormwater network is not overwhelmed.

But if rain continues, it will eventually act like normal concrete, with water sitting on the surface. He says initial abstraction can be especially important in the catchment of rivers of high ecological significance, preventing the life within from being flushed away in short, sharp rain outbursts.

In Aotearoa/NZ porous concrete is available as paver blocks, such as Firth PorousPave, useful for carparks and driveways.

Questions

1. What does the tradesperson called a mason do?

2. Write balanced equations for:

a. The formation of calcium oxide during the thermal decomposition of calcium carbonate.

b. The reaction of calcium oxide with water.

3.a. Give the formulae for aluminium oxide, ferric (iron III) oxide, silicon dioxide, manganese dioxide, calcium chloride and calcium sulphate.

b. Identify the odd one out in the list in 3 a.

4. Hydrating concrete is different from hydrating a person. Explain.

5. What do these terms mean: composite, mortar, exothermic, adhesion, combustible, tensile strength, ductility, river catchment.

6. Why is newly-poured concrete often hosed down for the first day or two?

7. Discuss the benefits and risks of using porous concrete during global warming.

Activities

B. Chamberlain, et al., 1995. Concrete: A material for the new stone age. (Demonstrations and laboratory activities.)

References

Z. Faridi, 2023, The chemistry behind concrete, *Concrete Decor*.

B. Chamberlain et al., 1995, Concrete: Scientific principles. Materials science and technology teachers workshop, Uni of Illinois.

K. Ramsden, 2020, Cement and concrete: The environmental impact, Princeton Student Climate Initiative, New Jersey.

E. Matchar, 2015, This concrete can absorb a flood, *Smithsonian Magazine*.

This article was improved by critique from Ian McHale.

Ngā Kupu

Kirikiri – Gravel
Konupūmā ōkai – Calcium oxide
Konupūmā pūhaumāota – Calcium chloride
Konupūmā waihā – Calcium hydroxide
Koropungapunga – Porous
Raima – To cement; concrete, mortar
Totoka – To harden
Tukunoa – Permeable
Waipuke – To flood; flood.

Te Aka Maori Dictionary and *Paekupu*

Components of concrete that is cast in place. PLC.