Teacher and Technician sheet

In this practical students will:

- Gain an appreciation of how using a mixture of different sized mineral and rocks with a binder increases the difficulty of separation and increases the stability and strength of a composite substance such as mortar and concrete.
- To use tests to see how varying the proportions of cement, water and different aggregates affects the properties of concrete.
- Using their scientific knowledge and understanding to explain their results.
- Theorising what is happening chemically as the concrete sets.

Introduction for Teachers:

School students working on a cement and concrete project can look at the ingredients of concrete, vary the proportions of water and concrete, mix additives into the mix, check for temperature changes, find the pH, and learn about the product. Note this will make a demand to develop an adequate background on the part of the teacher hence the following notes should help that process.

This investigation opens with a research task in which the students create a living list (one that grows as time goes on). This activity is best started by asking the questions supported by the following paragraphs a - c:

- Where have you seen concrete being used?
- How do you know it was concrete?

a) Concrete, cement and mortar surrounds us. When we walk to school, take the bus, walk into a building, or cross a bridge, concrete, cement and mortar are there. They are exciting materials that affects our lives. Cement and concrete can be seen as synonymous to modern life, but by nature concretes, cements and mortar are different.

b) Cement, an ultra-fine grey powder, binds sand and rocks into a mass or matrix of concrete. Cement is the key ingredient of concrete.

c) Making concrete is similar in principle to baking a cake: selected ingredients are mixed together, heated, and allowed to set. Just as cakes vary according to the type of ingredients and the method used to add them together, so the texture, strength, resilience and colour of concrete can vary.

Ask the individual students to make their own list of uses of concrete this they share with another pair and then in two pairs and finally as a class.

The list of uses can be quite long. To introduce some decision making in compiling the list, the students should discuss and stress the importance of concrete in our lives and use that discussion as a prioritising factor.

Display the class list in the classroom so that students can add to it over the investigation time.

Students should understand the difference between cement and concrete. They should have a working knowledge of the science underlying the composition and behaviour of the material and appreciate how the chemistry affects the material. To help develop this the background notes should help teachers set the scene for the science of concrete and cement.

After the investigations have concluded a discussion would be held discussing the ubiquitous nature of cement, concrete, and their qualities as a material.

Background Notes: (Words in bold are important ideas)
How old is concrete?
The Greeks discovered the power of a volcanic rock known as the **Pozzolanas** which included Santorin earth. This had been used in the Eastern Mediterranean since 500–400 BCE. The Romans eventually fully developed the potential of **lime-pozzolana paste** when they used pozzolana as a binder in Roman concrete for buildings and underwater construction. Roman concrete was also used to make roads. The word concrete comes from the Latin word "*concretus*" (meaning compact or condensed).

Roman concrete, known as **opus caementicium**, was used in construction during the late Roman Republic and through the whole history of the Roman Empire. It **was hydraulic-setting** (water-setting) cement with many material qualities similar to modern **Portland cement**.

Roman concrete was used frequently with a brick-facing. The concrete varied in its **aggregate** and this allowed different arrangements of materials leading to the Concrete Revolution, in which structurally complicated forms, such as the **Pantheon dome** were constructed.

The mineral **Pozzolana**, also known as **pozzolanic ash** (Latin: *pulvis puteolanus*), is a **siliceous** and **aluminous** material. When mixed with water at room temperature and **calcium hydroxide** it reacts to form **insoluble calcium silicate hydrate** and **calcium aluminate hydrate** compounds. These compounds are the materials possessing cementation properties and bind the aggregates together.

Pozzolana is derived from one of the primary deposits of **volcanic ash** used by the Romans at Pozzuoli near Naples. We still use the name pozzolana but it is applied to any volcanic material (pumice or volcanic ash), composed of fine **volcanic glass**.

The Roman civil engineer **Vitruvius** (c.80-70BCE – c .15 BCE) speaks of four types of pozzolana: black, white, grey, and red, all of which can be found in the volcanic areas of Italy, such as Naples. Vitruvius, writing around 25 BC in his *Ten Books on Architecture*, distinguished types of aggregate appropriate for the preparation of lime mortars. For structural mortars, he recommended *pozzolana*, brownish-yellow-gray in colour near Naples and reddish-brown at Rome.

Vitruvius specifies a ratio of 1 part lime to 3 parts pozzolana for cements used in buildings and a 1:2 ratio of lime to pozzolana for underwater work, essentially the same ratio mixed today for concrete used at sea.

The recipe for Roman Concrete was lost between 500CE and the 1300s. Then between the 1300s and the mid-1700s, the use of cement gradually returned. The *Canal du Midi* was built using concrete in 1670, and there are concrete structures in Finland that date from the 16th century.

What is concrete?
Concrete is a mixture of three ingredients:

- **cement** (the **bonding agent**)
- **aggregate** (the **filler or bulk** of the concrete – usually sand and gravel)
- water (the **catalyst** for the cement).

Why is cement used in concrete?
The **quality** and **quantity** of the cement will affect the **strength of the bond** between the **particles** of aggregate.

What is aggregate?
The **shape** of the aggregate affects the overall strength of the concrete. For concrete to be effective it requires **angular solids**. Angular means a particle with sharp pointed edges and these lock together, whereas rounded particles only butt up against each other.

Why is water added?
The **amount** of water added to the mix is very important:

- if too much water is added, the **bonding effect** of the cement is lost;
- if too little water is added, the **bonding action** will not be complete.

ROYAL SOCIETY OF CHEMISTRY

Two other main factors affect the quality of concrete.
These are **density** and **curing time**.

How does the density of the concrete affect the final material?
The denser the concrete, the more particles are **interlocked** and the stronger it will be. A dense concrete mix is shaken thoroughly in moulds, and more concrete is added to the space as the mix settles down (just as rice grains settle in a packet).

Commercially dense concrete has other properties apart from strength. These include good **resistance to sound and water penetration**, and **low shrinkage** as it dries out.

What is curing time and how long does it take?
Commercially, curing is helped by heating, steam and pressure.
Best quality concrete is steamed at 160°C at 6 times atmospheric pressure for 24 hours.

Concrete can take up to 20 years to gain maximum strength.

Curriculum Range:
The teacher's task is to appropriately match the activity with the academic and maturation level of the students. Most students from age 10 to 17 can perform these activities. It also gives students the opportunity to research historical ideas and the chemistry of concrete.

The aim is to gain some understanding of the way the materials are used to create artefacts. It links with:

- Setting up simple practical enquiries, comparative and fair tests;
- Reporting on findings from enquiries and observations, including oral and written explanations, displays or presentations of results and conclusions;
- Using straightforward scientific evidence to answer questions or to support their findings;
- Build a more systematic understanding of the chemistry of cement, mortar and concrete by exploring the way they can be made with useful properties;
- Ask questions and develop a line of enquiry based on observations of the real world, alongside prior knowledge and experience;
- Use appropriate techniques, apparatus, and materials during laboratory work, paying attention to health and safety;
- Make and record observations using a range of methods for different investigations; and evaluate the reliability of methods and suggest possible improvements;
- Present observations using appropriate methods;
- Interpret observations and identify patterns using those observations to draw conclusions;

- Present reasoned explanations, including explaining data in relation to predictions and hypotheses;
- Learn about concepts of hydration and how the chemistry of hydration can affect the properties of substances.

Health and Safety:
Working with cement is safer with waterproof protective gloves and safety glasses. The alkalinity of wet cement and concrete can cause skin irritation or even chemical burns under prolonged exposure.

Try to keep cement dust away from the students since it can be an irritant. A well ventilated work area is a good precaution. Students should wash thoroughly when they are finished working with cement and concrete.

Technical Notes:
The concrete will have lost only a fraction of the water to evaporation from the exposed surface. This can be estimated by using a cup of water placed next to the mould of concrete. The water level in the cup is marked at the start.

You can compare the loss of water from the concrete with that of the cup of plain water that also lost some water due to evaporation. Both of these amounts of water are small when compared to the original amount of water added to the concrete that does not evaporate to make the hardened concrete.

By comparing the total mass of the original ingredients to the mass of the final concrete and the comparison of water evaporation it will become clear that the concrete does not dry out.

One thing to point out to the students is the fact that the concrete mixture may lose a little more water than the cup with the water only.

The reason for that is if you look carefully at the concrete’s surface using a magnifying lens they will see it is not smooth.

This rougher surface area makes it possible for water to evaporate faster than the water in the cup alone. Again, this amount of water is negligible when compared to the water added to the concrete mixture and went into the chemical reaction to make the hardened material.

Going further:
- 3 Polystyrene cups;
- Water;
- Top pan balance

ROYAL SOCIETY OF CHEMISTRY

- 2 Teaspoons
- A small bag of mortar mix;
- A small bag of concrete mix.

Further work could be undertaken looking at the introduction of additives into the mix, checking for temperature changes in the mix and the effect of making concrete in different temperatures, finding any pH changes, and learning about the uses of different forms of concrete. Another, interesting experiment, is to see what part that water plays in the process of hardening or curing.

A common expression on a building site is, “Don’t walk on the concrete until it dries!” One of the easiest ways to show that the curing of concrete is not due to drying but the water actually becomes a part of the chemistry of concrete is to use the principle of the conservation of mass.

Students can see proportioning in action by adding 3 to 5 times more water than required to cement and concrete mixes. This will demonstrate how many sizes of particles are needed in a concrete mix. Students will test two mixes: water mixed with concrete mix (cement, small and large aggregate), water, and water mixed with mortar (cement and small aggregate).