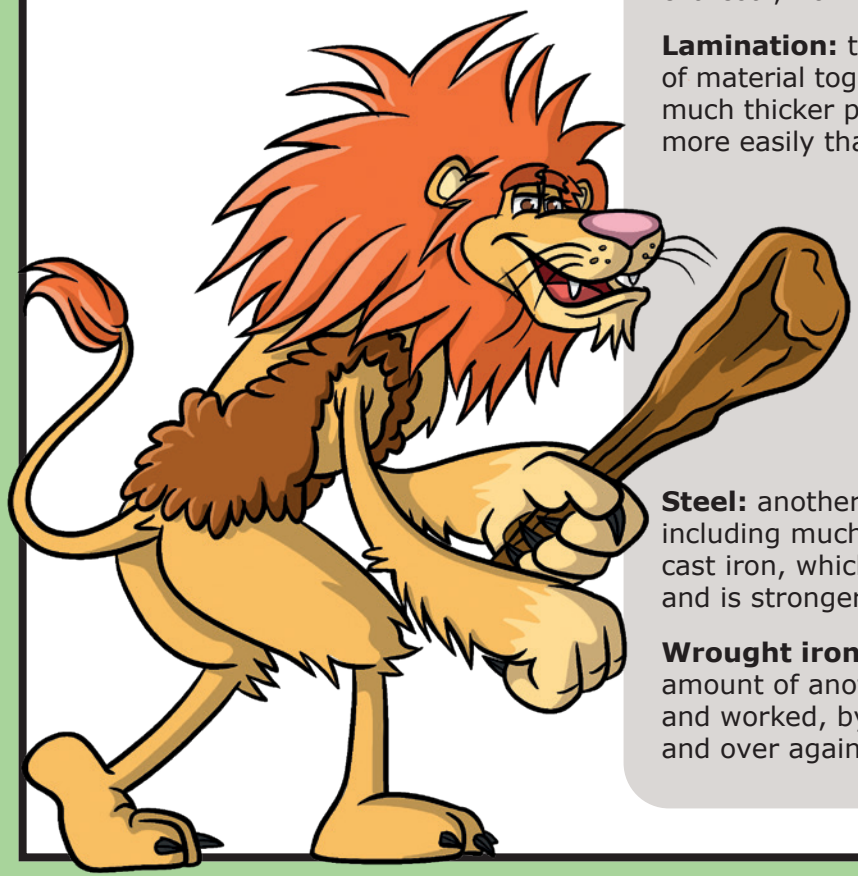
Chapter Aiii: Materials

AIMS & OBJECTIVES

- To learn about the materials which are used to build bridges
- To describe ways by which materials can be strengthened
- To understand how concrete is made

CONTEXT

There are many different materials used in bridge engineering. Each material has its own strengths and weaknesses, and can be used in different ways for different designs. Engineers can design a bridge that makes the most of the materials used, and accounts for any weaknesses in the material.



LANGUAGE OF BRIDGES:

Cast iron: iron with additional carbon and other impurities mixed in, and then shaped using a cast, or mould, while hot.

Cement: a fine power that hardens when water is added and used as the binding material in concrete. It is most commonly 'Portland Cement', produced by heating limestone and clay in a kiln, and then adding gypsum.

Composite: a material made from two or more different materials combined together.

Concrete: a construction material that could be described as artificial rock, made up of fine and coarse aggregates, such as sand or gravel, and cement.

Iron: a type of metal, and one of the most commonly found in the Earth's crust. It is found in iron ore.

Iron ore: a type of rock found in the Earth's crust from which iron can be extracted. When the iron ore is heated to a very high temperature with charcoal, iron is produced.

Lamination: the process of gluing very thin layers of material together – such as wood – to form a much thicker piece, which can be bent or shaped more easily than a similar single piece of wood.

Wood was one of the earliest building materials used in structures, and can still be used today.

Steel: another iron and carbon mixture, although including much less carbon than either wrought or cast iron, which means it is much easier to shape and is stronger.

Wrought iron: iron mixed with a very small amount of another element, carbon. It is heated and worked, by being squashed and beaten over and over again, by a blacksmith.

You will need...

- Various everyday materials: string, toilet paper or paper towel tubes, straws, fabric e.g. towels/t shirts/dusters, elastic bands, uncooked spaghetti, cardboard boxes, sponges, drinking glasses. You will need sufficient for every group to have access to each material.
- Handouts: *Materials and their properties 1 & 2*
- Large bundle of drinking straws held together in two places by elastic bands

- Handout: *Wooden bridges*
- Exploring Lamination, per group:
  - 8 pieces of coloured card, approximately 10x15cm (index card size), ideally at least two different colours
  - 2 large cups or glasses
  - At least 30 flat metal washers (M12 size/24mm diameter)
  - Glue stick
  - Ruler and pencil
- Making concrete, per group:
  - Handout: *Mixing Concrete Instructions*
  - 3x 125g yogurt pots or other sturdy containers
  - Plastic spoons
  - Water in jugs or plastic bottles
  - Sand
  - Cement
  - Fine gravel
  - Large disposable bowls with capacity of at least 1 litre
  - Cardboard mould (2cm x 2cm x 20cm): use the *Cuboid Net* handout and make these from card in advance (making sure the glue is dry before using) – a small toothpaste tube box is a reasonable alternative
  - Safety glasses
  - Dust masks
  - Plastic gloves
  - Newspaper/plastic
  - Slotted masses, or other similar small masses or uniform items such as metal hex nuts

Something to Try:

Ask learners to think of as many different materials as they can that could be used for bridge building, and share with the group.

There are many materials available to engineers, which include wood; stone; bricks; various metals such as cast iron, wrought iron, steel and aluminium; concrete; and modern materials such as glass-reinforced plastic.

Ouse Valley Viaduct made out of brick
(Photo by Viktor Forgacs on Unsplash)

Here are a series of activities you can use to demonstrate the properties and behaviour of a range of materials.

Invite learners to consider the materials used for everyday objects. You could use the *Materials and their properties* handout to guide learners to consider the different properties. Different materials have different strengths and different applications. Once they have a list of everyday objects and their materials, compare and consider why those materials were used. This links to uses in the construction industry.

Links to *Learning About Bridges Chapter Aii: Loads and Forces*

LINK

WOOD

Wood was one of the earliest materials used in structures, and it is still in use today. Wood grows in many forms from lightweight balsa wood to very dense iron wood. Properly used and treated, wood can be strong and durable, with a life measured in hundreds of years. Wood can be attacked by insects and fungus unless it is carefully treated. Wood is a natural material.

Historically, engineers had to work with relatively short pieces of wood, limited by the height and straightness of trees. Wood had different strengths in different directions. We can consider the trunk of a tree to be like a bundle of drinking straws. Cells run in tubes along the length of the trunk and support the weight of the tree and carry the sap to the leaves.

You can demonstrate that the bundle of straws is strong if you stand it up and push down hard on the open end (compression) and if you hold both ends and pull it along the length of the straws (tension). Show that it is easy to crush the straws out of shape by pushing on them from the side or pulling the straws apart.

Mathematical Bridge Cambridge
(Photo by Karen Cann on Unsplash)

Wood is weaker when the load is placed on the side of the tubes.

The load causes a hinge and the beam fails.

Wood is stronger when the load is placed on top of the tubes.

The load compresses the tubes.

When engineers are using wood for bridge building they need to make sure the main forces are travelling along the wooden beams.

More recently, engineers have developed the technique of gluing together thin layers of wood to form very long and wide beams, which can even be made into curved shapes. This process is called lamination. Nowadays wood is mainly used only for footbridges with relatively short spans, although laminated wood bridges can be much longer.

EXPLORING LAMINATION

1 Take 8 index cards, or if you don't have index cards, different coloured standard craft card cut into 10cmx15cm rectangles.

2 Glue four index cards together, like a sandwich and leave to dry.

3 Using the ruler, find the centre of the card and draw a circle using one of the washers as a template, around the centre point.

4 Repeat this for both sides of the glued card, and on each side of the unglued cards. (This tells you where the washers should be stacked, to be a fair test).

5 Set the two cups upside down on the table so they are 10cm apart. Take care when using glass beakers. Tape them to the table (particularly if you are using plastic/paper cups) to stop them moving.

6 Stack the unglued cards together and place them across the top of the two cups like a bridge. Carefully stack the washers in the circle on the top card, counting them as they are added. Keep going until the cards collapse.

7 Repeat this step with the glued cards, stacking the washers in the circle on the card.

8 Ask learners to consider which pair of cards held more washers and why?

Look at the *Wooden bridges* handout for some examples of bridges built using wood.

IRON

Iron comes from special rocks in the ground called iron ore. When iron ore is heated with some charcoal to very high temperatures, the metal iron is released.

People have been doing this for thousands of years, but it wasn't until the 18th century that it became a more industrialised process, using coke (coal heated without oxygen) and limestone. This happens inside a blast furnace. The iron produced is called pig iron, due to the shape of the casts used to collect the molten iron. Iron is less brittle than stone. It is less likely to split and crack. Compared to wood, iron is extremely strong. It is easy to shape iron into various forms using quite simple tools. The main disadvantage of iron is rust, but this can be prevented by regular painting or galvanising, which means coating the iron with another metal called zinc.

There are three main types of iron that were used to build bridges:

Wrought Iron is iron mixed with a very small amount of another element called carbon. Carbon is used to make the inside of ordinary writing pencils. The word wrought means worked. To make wrought iron, the mixture of iron and carbon must be heated, squashed and beaten flat over and over again. A blacksmith can then bend the wrought iron into whatever shape is needed because it is very malleable (or flexible).

Cast Iron usually has more carbon and other impurities mixed in. It is shaped by heating the iron until it becomes a liquid and then pouring it into a cast or mould. The Iron Bridge over the River Severn was the first major bridge to be built from cast iron. It was built in 1779, although its history begins earlier with the development of iron production using coke, rather than charcoal, as the source of carbon in a nearby town. The bridge was needed to help transport the iron produced throughout the country, and the grandson of the man who pioneered the iron process actually cast the iron for the bridge.

Photo by Hannah Gibbs on Unsplash

Steel is another metal made from a mixture of iron and carbon. It contains much less carbon than wrought iron or cast iron and this makes it stronger and easier to shape. Before the 1850s, steel was very expensive and difficult to make. It was only produced in small quantities and used mainly for tools, cutlery and swords. Then an English engineer called Henry Bessemer invented a new way of making steel more cheaply. Engineers realised that steel had greater strength and would last longer. The first major bridge made of steel was the Eads Bridge over the Mississippi River in the USA which was completed in 1874. Today, steel is the most common metal used for building bridges.

Photo courtesy of Jasonjsmith via Wikimedia

CEMENT AND CONCRETE

Many people think cement is a modern material invented in the 20th century. However, by the middle of the 1st century AD, the Romans knew how to make cement and used it widely in their bridge building.

The Latin name for cement is opus caementicium.

The Romans made their cement using ash which had been blown out of the volcano Vesuvius. They collected the ash from a town called Pozzuoli and so the cement became known as pozzolana. The amazing thing about pozzolana is that it is waterproof and hardens even when it is wet. It also has a similar strength to the modern version!

Photo courtesy of MM via Wikimedia

Links to *Learning About Bridges Chapter Aiv: Working with Water*

It wasn't until Joseph Aspdin developed Portland Cement in 1824 that concrete became possible, with reinforced concrete being developed in 1849 by Joseph Monier. This meant the material could be used for larger constructions, such as bridges and industrial buildings.

Concrete is a common construction material, because it is strong, durable, versatile and relatively economical.

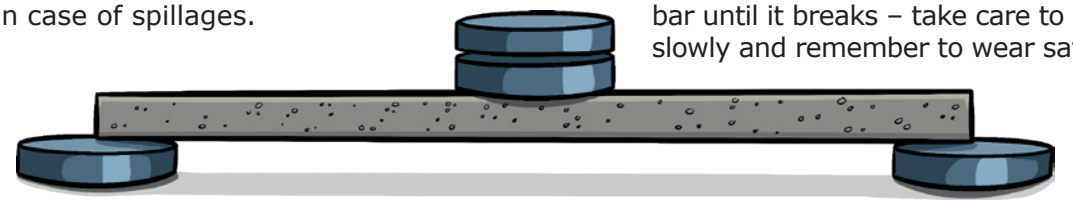
Challenge Time!

Making concrete can be interesting and exciting for primary age learners and is easy to manage safely as long as some basic precautions are followed. (You will also need to consider your own risk assessment procedures.)

- Cement is an alkali which can cause skin burns if not handled carefully.
- Children helping with the mixing should wear safety glasses, masks and plastic gloves.
- Take care when mixing to avoid creating dust.
- Do not wash spare concrete or cement down the sink or into drains as it will harden in the pipes.
- This activity is best done outside in case of spillages.
- Cover benches or tables with newspaper or plastic sheeting.
- Follow the instructions on *Mixing concrete instructions* handout.

STRENGTH TESTING THE CONCRETE

- Once the concrete has cured for at least a week, the strength of the various mixtures can be tested using slotted masses, or small weights if you do not have slotted masses available.
- Place each bar on a slotted mass (or two identical books) so it is slightly raised above the surface of the table.
- Then place the masses in the centre of the bar until it breaks – take care to do this slowly and remember to wear safety glasses.



You can demonstrate concrete and reinforced concrete using food! Rocky road is a type of cake, made up of biscuit and marshmallow pieces stuck together with a chocolate and syrup mixture. Easy recipes can be found via a quick internet search.

This mimics concrete, which is cement, with other aggregates such as gravel and sand, all mixed together and left to set. You can model reinforced concrete by using the rocky road mixture and layering the mixture with a network of strawberry laces in the pan, so you have a criss-cross pattern.

HOT TOPICS!

"As useful as a chocolate teapot" usually means that the something is useless or not suited to the purpose suggested. However, Nestle UK found a way to challenge this. You could find out a bit more about this by searching the internet for "Nestle chocolate teapot" – you may even find a video explaining how it's made.

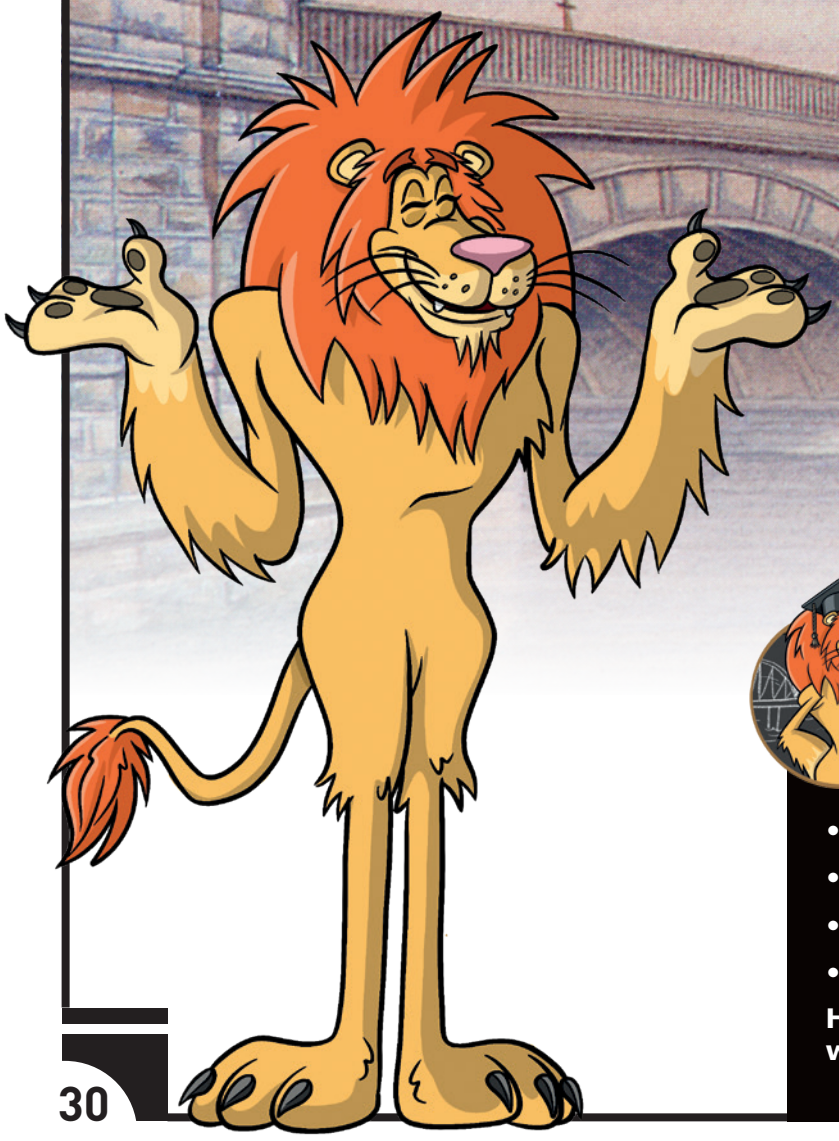
Plastics and their uses are a popular topic in the media. You could consider why we use a material that lasts (as far as humans are concerned) forever, for single-use products. You could explore different ways of overcoming our plastics problem, including development of Ecobricks and why they are necessary. You can find lots of information about them with a simple internet search.

You could explore more about Roman construction and civilisation, including Roman life in Britain after the invasion in 43AD.

What different construction materials can you spot on your journey to and from school? Are there any unusual construction materials? Can you see or guess why each material has been chosen for that particular place or structure?

DID YOU KNOW?

The Victorian Rochester Bridge – which was refurbished to become the steel Old Bridge that currently stands – was made from cast iron.



Langdon presents:

- *Materials and their properties* handout
- *Examples of wooden bridges* handout
- *Making concrete* handout
- *Cuboid net* handout

Handouts can be found at www.rochesterbridgetrust.org.uk