Composite Materials - Teachers' Notes

By Hilary Byrne

Introduction

In this experiment, students are lead to consider the material that an object is made of (in this case a polystyrene plank) and what gives it strength (or not). This is done through a quick and easy loading experiment, which gets the students to test the limits of their set up to the moment of destruction.

The students are then challenged to come up with ways to improve the strength by adding tape. A little extra rivalry can be gently encouraged between groups in the class, perhaps with a prize for the best performing construction!

This investigation can be used to demonstrate forces on and within objects. It also covers the broader topic of materials science, covering aspects of scientists working with engineers, and how science can contribute to a better society.

Since pre-historic times humans have used naturally found materials such as wood, stone and bone as both tools and construction materials. We refer to ancient historical periods by the predominant material used by humans at that time i.e. Stone Age, Bronze Age and Iron Age.

Most of the materials that you see around you today are artificial, produced by humans in industrial processes using natural raw materials, scientific knowledge and engineering know-how. Glasses, plastics, paper, many fibres and fabrics, concrete, most metal alloys, most dyes and colours, and ceramics are all common materials that are made by people because they have desirable properties that make our lives easier, safer, longer and more enjoyable.

High strength materials, like metals and concrete, are typically heavy. Historically this was less of a problem when materials and energy were relatively cheap. As we move into a resource constrained world with increasing awareness about human impact on climate and the environment, we want to use less raw materials and energy. Composite materials are lighter-weight materials that are replacing some of the traditional materials used in the construction of buildings and vehicles, but which also offer the same or better levels of protection and strength.

Research by scientists leads to the discovery and creation of new materials, and engineers design both the processes which produce these materials economically, and many of the products which are made from these materials. In designing new products, engineers constantly look for ways to improve performance. This might include lower weight, lower cost, higher strength, increased safety, lower impact on the environment, and other desirable aims. The desire for improved material characteristics drives further scientific research that might lead to refinement of existing materials, or the development of new materials altogether.

Part 1 - Demonstration

This is a demonstration by the teacher.

Question / Aim

Discuss the initial questions with the class:

What could be the same between the materials used in a modern racing car and a surfboard?

> *Both need to be strong and light, and a little flexible to withstand forces and impacts. The racing car is carbon fibre and a surfboard is fiberglass over polystyrene. They both use fibres set in resin to increase the strength while delivering a light product.*

Why do we make composite materials?

> *These structures are stronger and lighter than other materials.*

How do you think "sandwich structure" composite materials are made?

> *Layers of different materials with different properties are "glued" together.*

Lightweight strands of carbon fibre have very high strength when stretched in tension, but crumple if pushed from the sides or ends. These fibres can be set ('cured') into a hard plastic resin and the resultant carbon fibre composite material is lightweight and combines the tensile strength of the fibres with the rigid structure of the resin matrix when it sets solid.
Carbon fibre and fiberglass are good examples of resin composite materials. These materials are a bit tricky to use in a class so we substituted for readily available and easy to use products. We have focused on sandwich materials.

Today you are a scientist who has been paid to design a stronger composite product for as little cost as possible.
The following demonstration is to prepare you for the task.

Plan

You will need:

> 2 x Polystyrene plank
> Blocks to place under the ends of the plank (a couple of books will do fine)
> Weights
> Ruler
> Tape

Preparation: depending on the thickness of your polystyrene, you may need more or less weight to reach breaking point. Test this in advance of the class. Thinner polystyrene is better than thicker, it is surprisingly strong stuff!

Conduct

1. Simple polystyrene plank

- Place the ends of the polystyrene plank up on the blocks (textbooks or retort stands can also be used instead of blocks). A few centimetres at each end should rest on the supports. It is also a good idea to tape the ends of the polystyrene down, in case it bends so much that the ends move off the blocks.

- Add weights to the centre of the plank.
- Point out the plank bending to the students.
- Demonstrate using the ruler to measure the height of the plank above the desk and how this changes as weights are added.

You can test to destruction! (i.e. until the plank breaks), but sometimes it is more fun if you let the students discover this for themselves.

2. Sandwich structure

- With a second polystyrene plank, place a strip of tape along the top and bottom.
- Repeat as above.
- The sandwich structure plank will hold more weight.

Use plenty of tape – the students are challenged later to do it with as little as possible. You can prepare the taped plank in advance.

Analysis

Draw and label the equipment and describe what happened.

Students should draw and label the equipment as this will be used in planning their own experiment next.

Discussion

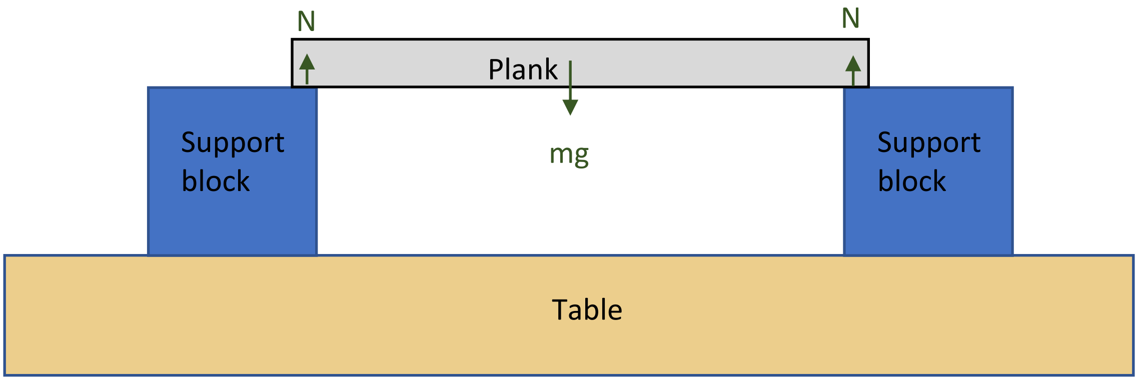
Discuss what you saw.

The students should be convinced that the sandwich structure is stronger.

You can introduce a short discussion of the forces involved, if this is appropriate to your class's ability.

1. Simple polystyrene plank

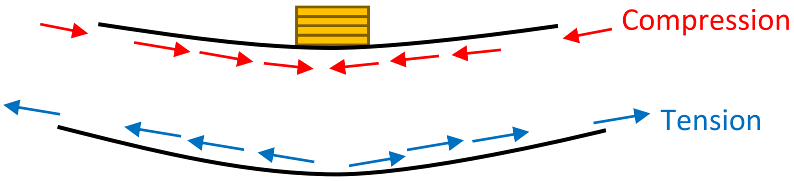
The plank itself is very light. When you first place it on the supports there is no bending, it appears to be rigid.



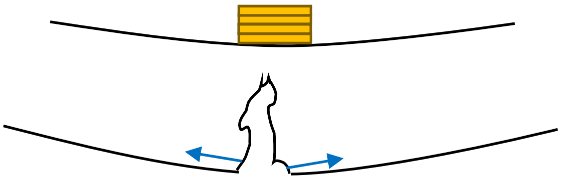
The support blocks provide a normal force upwards that balances the downwards weight force of the plank. It is in equilibrium (i.e. there is no unbalanced force and no movement).

When we add weights, the plank bends a little.

We can point out a bit more about the structure of materials by illustrating a particle model of these solids. When the plank bends, the length of the top surface must be reduced while the length of the bottom surface is increased.



This means the particles in the top surface are in compression, they are pushed closer together. As the particles move closer together they begin to feel a push from the next particle. This balances the external compression and stops the particles moving any closer.
When the bottom edge of the plank is stretched, it is in tension. The tension is attempting to pull neighbouring particles away from each other. Similarly to above, as they move apart from their natural position in the solid, they also begin to feel a force, this time a pull back towards the neighbouring particle. They will stop moving apart when this balances the external tension.



Eventually, when enough weights are added, the tension along the bottom edge of the plank is so great that the pull between neighbouring particles can no longer match it. The particles continue to move apart and the solid structure is broken - the plank cracks.

2. Sandwich structure
What does the tape do?
Tape is very strong when pulled. It takes a much greater pull to break it than to break the polystyrene. Adding this to the bottom of the plank where the cracks will appear increases the strength.

Conclusion
The conclusion is provided:

- *A polystyrene plank is not very strong*
- *When additional materials are layered onto the polystyrene it becomes a composite material and its properties change – it becomes stronger.*

Part 2 – Initial Investigation

Question / Aim
Students will reproduce your demonstration, taking their own careful measurements. Checking the graph they produce in this part ensures that students can perform the experiment well enough to explore further in Part 3.

Plan
Students should be able to reproduce your demonstration easily in their own experiment.
They may decide to measure deflection using the top edge of the plank or the bottom edge, but this won't affect the results. Sometimes students try measuring the angle of deflection with a protractor. This is also a valid way to measure the deflection and the graph they get will be similar to the deflection (length) vs mass shown below.

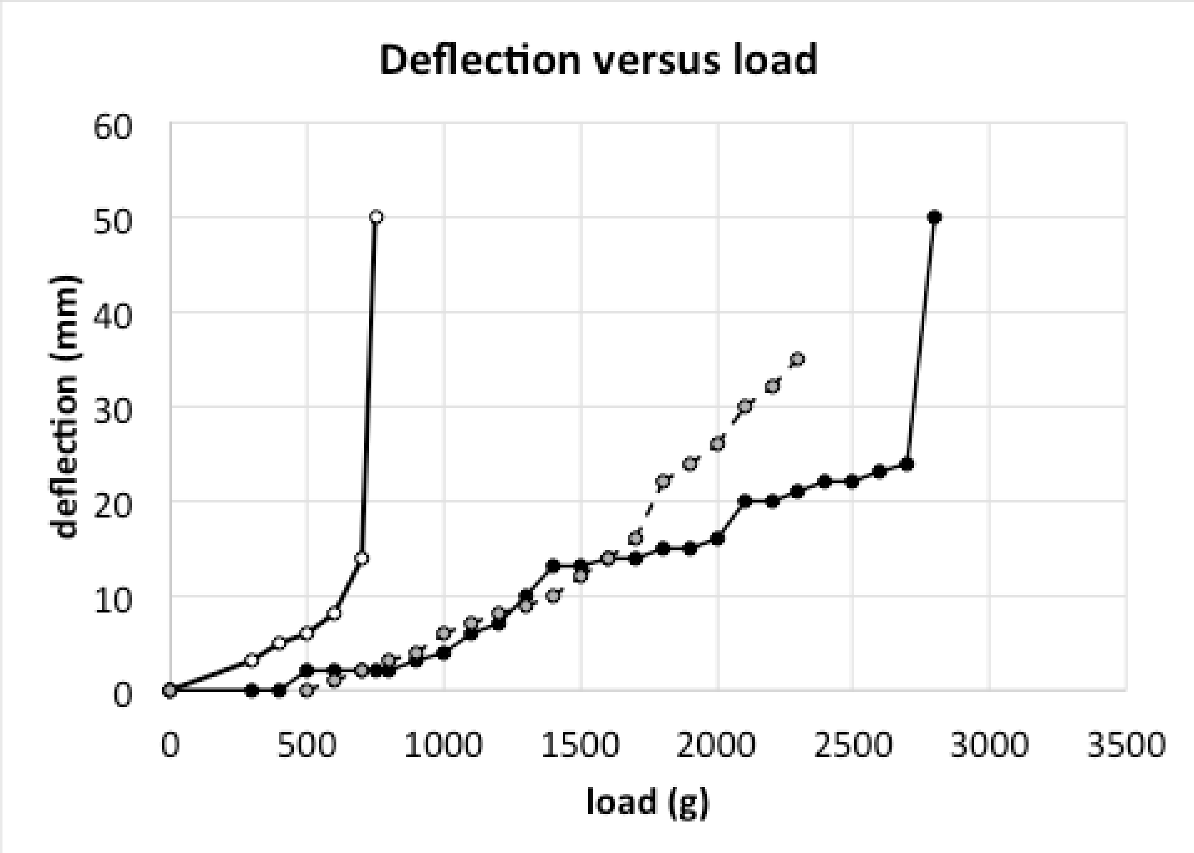
Conduct
The students are given a table structure to record their data.
Weights should be added as close to the centre of the plank as possible.
The students should measure carefully how much bending there is with each weight added.

Perhaps ask the students to record how much of the plank is resting on the support structures – you may see a difference in strength between groups because of this.

Place the weights on carefully and slowly when near breaking point!

Polystyrene is surprisingly strong, you might want to use quite thin pieces if you have limited weight and want to take the plank to breaking point. When using thin pieces of polystyrene, sometimes the weights are too large to balance on the top of the plank. For this reason it can be a good idea to tie a string or a rubber band around the polystyrene, which you can then hang the weights from.

Analysis
The graph should look something like this (open and filled circles for part 1):



The graph shows the deflection of the polystyrene (vertical axis) when load (i.e. weights, horizontal axis) is applied to the centre of the polystyrene.
The data that is the most to the left-hand-side (white data points) are for polystyrene with no tape. The last data point is at 750g. The polystyrene broke with a load of 800g.
The middle set of data (gray data points) represents the polystyrene with tape on the bottom and half of the top. The last data point is at 2300g. The polystyrene broke with a load of 2350g.
The data on the right-hand-side (black data points) represents the polystyrene with full-width tape on the bottom and top. The last data point is at 2800g. The polystyrene broke with a load of 2850g.

Discussion

Can you explain why you think the sandwich structure works to alter the strength and rigidity?
This question is worth engaging in with a class discussion – unpack the ideas around sandwich structures and how they can increase strength and rigidity (and question what these qualities are useful for?).

What is the role of the tape and what properties make it work well?
The tape provides the fibre and a glue to fuse the layered sandwich materials. The fibre can support far more tension than the polystyrene.

Would one piece of tape above or below the polystyrene be as effective?
One piece below is all that is needed. The top layer is ineffective at increasing the strength of the layered structure.

Conclusion
Students now have some measurements to help quantify the strength of the sandwich structure compared to the plank alone.

Part 3 – Further Investigation

Question / Aim
Following on from Part 2, this part motivates students to think about engineering principles by asking them to make a structure that is not only strong but also cost effective. This part is more open-ended than the previous parts.

Students should now experiment with different amounts of material. Encourage your students to try different combinations/thicknesses of polystyrene and tape so there is more variety when discussing their results as a class.

Plan
To save time, the class could brainstorm designs together, then each group could test one design and pool the results at the end.

<Variations/Extensions>

- Provide different types of tape – normal sticky tape of different widths, cloth tape, stretchy plumbers tape …
- Allow the students to use different lengths of polystyrene plank – shorter ones should hold more weight than longer ones. (Or equivalently, move the support blocks closer together.)

You will need to decide (in discussion with the class?) on how to measure 'cost effectiveness'.

- You can put a $ value on each polystyrene plank and each cm of tape used (tape should be more expensive than the polystyrene).
- Is strength or cost most important?
- Will you take the cheapest design as long as it holds a minimum weight, or is a slightly more expensive design better if it holds significantly more weight? You could score this second option by giving a $ discount on the cost for each extra 100g supported

Conduct
Students should be confident conducting this part after doing Part 2.

Analysis
If testing many designs, the graph may become very cluttered. Students should make sure they can distinguish between each of their data sets.

Discussion
Which group has the best design, and what about that design makes it so good?

If not discussed during the planning section, explore the meaning of “cost effective”.

Conclusion

Can students articulate what it means for their design to be cost effective, and what design aspects make it the best?