Composite Materials

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

Racing car

http://www.tuvie.com/jaguar-xjr-19-lmp1-concept-race-car-for-the-year-of-2020/

Surfing

https://en.wikipedia.org/wiki/Surfing

Hint: focus on the how each is made (manufactured).

Today's Laboratory unpacks how composite materials can respond differently to unbalanced forces.

Change to an object's motion is caused by unbalanced forces, including Earth's gravitational attraction, acting on the object (ACSSU117)

A composite material is made from two or more materials with different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components.

The individual components remain separate and distinct within the finished structure.

The new material may be preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials. More recently, researchers have also begun to actively include sensing, actuation, computation and communication into composites, which are known as Robotic Materials.

Typical engineered composite materials include:

- Composite building materials, such as cements, concrete
- Reinforced plastics, such as fiber-reinforced polymer

- Metal composites
- Ceramic composites (composite ceramic and metal matrices)

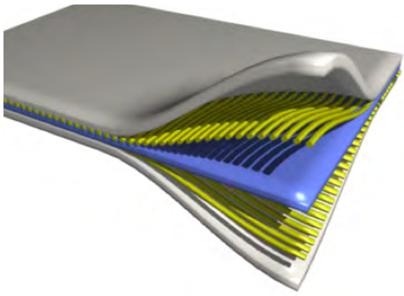
Composite materials are generally used for buildings, bridges, and structures such as boat hulls, swimming pool panels, race car bodies, shower stalls, bathtubs, storage tanks, imitation granite and cultured marble sinks and countertops. The most advanced examples perform routinely on spacecraft and aircraft in demanding environments.

https://en.wikipedia.org/wiki/Composite_material

Why do we make composite materials?

Consider the similarity between these two pictures.

http://www.grotecompany.com/applications/sandwich-production/



https://en.wikipedia.org/wiki/Composite_material

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

Your challenge…

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.

Demonstration of the effectiveness of sandwich structures:

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

Draw and label the equipment and what happened

TASK 1

Re-do the demonstration with your group. You will need to work out a way of measuring the rigidity or how much bending there is for each individual weight added. Talk with your partner to decide how you will measure the amount of bending and record the data in the table below. Your support structures need to be 21cm apart.

Mass (gms)	Amount of bending for Polystyrene (cm)	Amount of bending for Sandwich Structure (cm)

Graph the data to show the difference between the polystyrene and the composite material.

Can you represent why you think the sandwich structure works to alter the strength and rigidity?

What is the role of the tape and what properties make it work well?

Would one piece of tape above or below the polystyrene be as effective?

TASK 2 - Challenge

Your job as a Scientist is to create a stronger composite material using the least amount of material (polystyrene and tape) to reduce cost.

Work with your group to design to strongest sandwich structure composite material using the least tape. Test each design for strength and rigidity to decide the best design.

Decide how you will collect your data for each trial and produce a report that describes the design that works best. Include evidence (data) and an explanation as to why (using diagrams and words).

Teacher Notes

Composite Materials

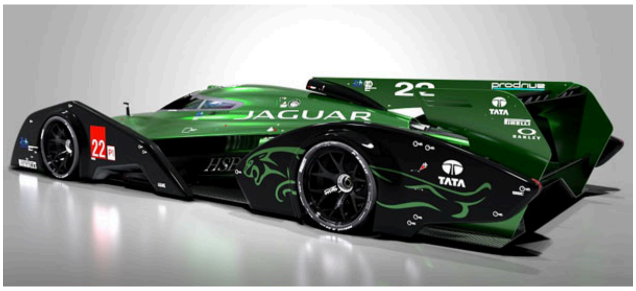
Deakin University hosts the **Institute of Frontier Materials** http://www.deakin.edu.au/research/ifm/? This Laboratory addresses some of the principles that are currently being investigated through research and design at the Institute. See at the end for details on materials.

This Laboratory

Initial questions are designed to tune-in students. The focus here is on what the materials used to make racing cars and surfboards. 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.

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

Racing car



http://www.tuvie.com/jaguar-xjr-19-lmp1-concept-race-car-for-the-year-of-2020/

Surfing

https://en.wikipedia.org/wiki/Surfing

Hint: focus on the how each is made (manufactured).

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 resulting a light product.

Today's Laboratory unpacks how composite materials can respond differently to unbalanced forces.

Change to an object's motion is caused by unbalanced forces, including Earth's gravitational attraction, acting on the object (ACSSU117)

The conceptual focus is on the unbalanced forces that result in this structure.

A composite material is made from two or more materials with different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components.
The individual components remain separate and distinct within the finished structure.
The new material may be preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials. More recently, researchers have also begun to actively include sensing, actuation, computation and communication into composites, which are known as Robotic Materials.
Typical engineered composite materials include:

- Composite building materials, such as cements, concrete
- Reinforced plastics, such as fiber-reinforced polymer
- Metal composites
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Composite materials are generally used for buildings, bridges, and structures such as boat hulls, swimming pool panels, race car bodies, shower stalls, bathtubs, storage tanks, imitation granite and cultured marble sinks and countertops. The most advanced examples perform routinely on spacecraft and aircraft in demanding environments.

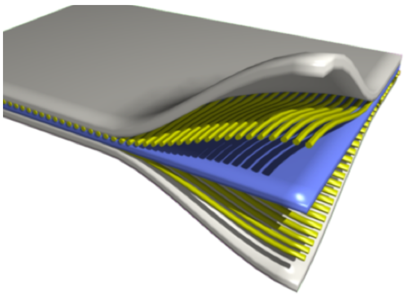
https://en.wikipedia.org/wiki/Composite_material

Why do we make composite materials?

These structures are stronger and lighter

Consider the similarity between these two pictures.

http://www.grotecompany.com/applications/sandwich-production/



https://en.wikipedia.org/wiki/Composite_material

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

Layers of materials are "glued" together.

Your challenge…

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.

Demonstration of the effectiveness of sandwich structures:

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

Draw and label the equipment and what happened

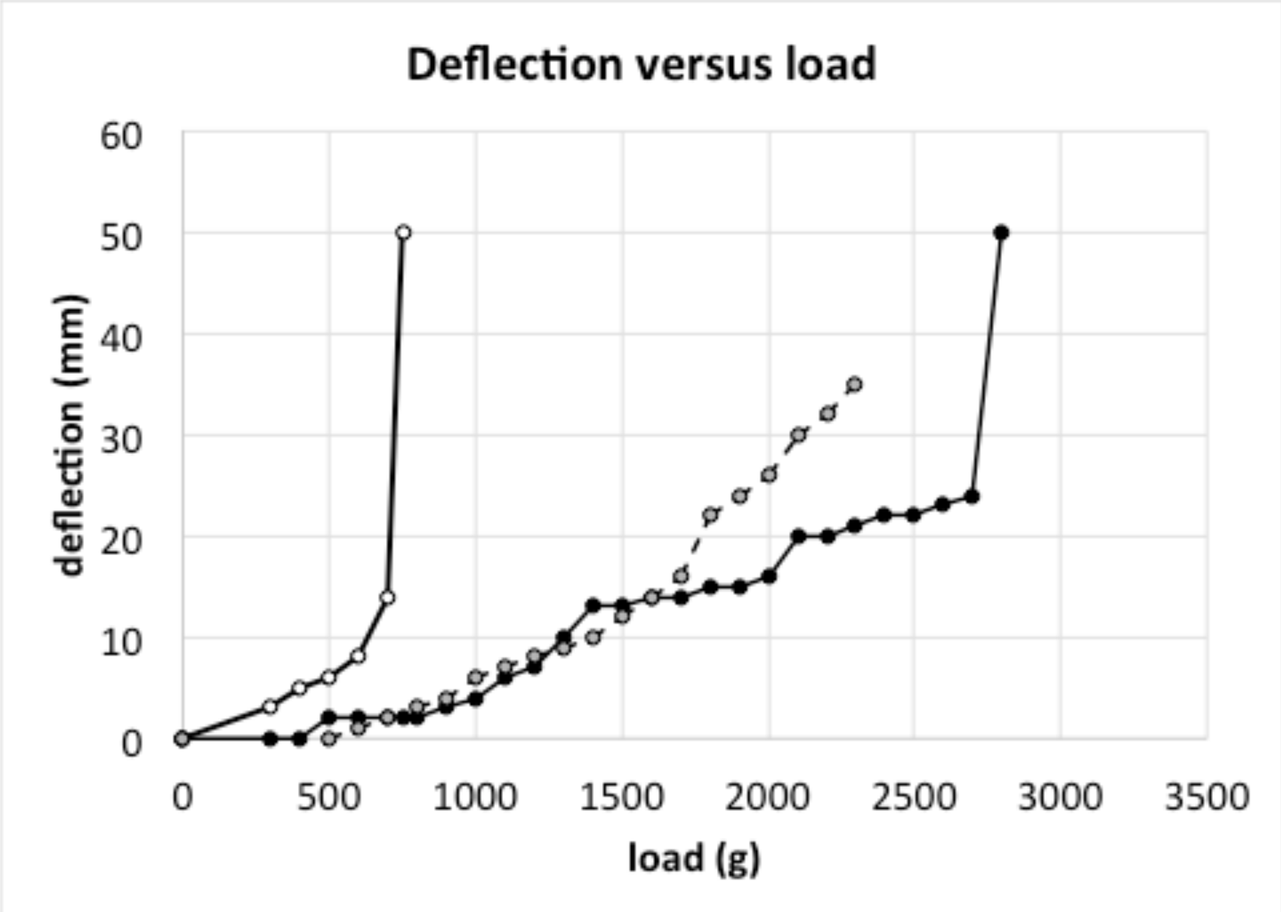
TASK 1

Re-do the demonstration with your group. You will need to work out a way of measuring the rigidity or how much bending there is for each individual weight added. Talk with your partner to decide how you will measure the amount of bending and record the data in the table below. Your support structures need to be 21cm apart.

Mass (gms)	Amount of bending for Polystyrene (cm)	Amount of bending for Sandwich Structure (cm)

As the mass increases the amount of bending will also increase. The polystyrene will eventually fail (break).

Graph the data to show the difference between the polystyrene and the composite material.



The graph shows the deflection of the polystyrene (vertical axis) as load (weights, horizontal axis) are applied to the centre of the polystyrene.

The left-hand-most data (open data points) are for polystyrene with no tape. The last data point is at 750 g. The polystyrene broke with a load of 800 g.

The midde set of data (gray data points) are for polystyrene with tape on the bottom and half of the top. The last data point is at 2300 g. The polystyrene broke with a load of 2350 g.

The right-hand-most data (black data points) are for polystyrene with full-width tape on the bottom and top. The last data point is at 2800 g. The polystyrene broke with a load of 2850 g.

Can you represent why you think the sandwich structure works to alter the strength and rigidity?

This question is worth engaging in class discussion – unpack the ideas around sandwich structures and how they can increase strength and rigidity (and what are these qualities useful for?).
This is a good representation construction activity.

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.

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. The bottom layer could be reduced to an optimal amount (of strength for cost).

TASK 2 - Challenge

Your job as a Scientist is to create a stronger composite material using the least amount of material (polystyrene and tape) to reduce cost.

Work with your group to design to strongest sandwich structure composite material using the least tape. Test each design for strength and rigidity to decide the best design.

Decide how you will collect your data for each trial and produce a report that describes the design that works best. Include evidence (data) and an explanation as to why (using diagrams and words).

Extensions to the experiment

These ideas will be developed in time.

Background materials

Modern materials

Since pre-historic times humans have used naturally found materials such a wood, stone and bone as both tools and construction materials, and natural plant and animal fibres have been used for the production of clothes and other textiles. We refer to the historical period that lasted for more than three million years up until about 5,000 years ago as the Stone Age, as during that period the predominant material used by humans and our predecessors for making tools was stone. The periods following the Stone Age are generally referred to as the Bronze Age and Iron Age, with the start of each 'age' being signified by the appearance in the historical record of evidence of the production and use of these particular metals in a region of the world.

Stone is a natural material and comes in a wide range of forms, ranging from the very soft (such as Talc that is used in powder and cosmetics) to very hard (such as Granite used in building and road construction). A key difference between stone and metals such as bronze and iron is that bronze and iron are hardly ever found naturally occurring. Iron is normally found naturally as an 'ore', that is, as a chemical compound of iron and other elements. The oldest iron probably came from that found in meteorites, some of which are composed of relatively pure iron, which can be softened by heating to a high temperature and shaped into tools (wrought iron). Mixing iron ore and carbon in a high temperate furnace (smelting) produces a relatively pure form of iron that can be melted in moulds to produce shaped objects (cast iron).

Pure iron is relatively soft, and while cast iron is hard, it is also brittle and can fracture. Smelted iron can be further processed in a furnace to remove more impurities, and with the addition of small quantities of other specific elements, an iron alloy (mixture) called steel can be made. Alloying different types and amounts of additives to iron results in many possible steels with a wide range of desirable properties, including corrosion resistance and high strength. Bronze is another metal alloy, a mixture of copper (a relatively abundant but soft metal) with tin, and sometimes other elements, to produce a durable material that can be cast into shapes.

Stone is a natural material, while steel and bronze are artificial metal alloys. While stone and timber are still commonly used materials, 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.

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. The search for, and application of, new materials is a joint scientific and engineering endeavour that leads to the new and improved products that we have.

Natural fibres such as wool, cotton and silk, and metal alloys such as steel are materials that have been used for thousands of years. Never-the-less, scientific research is still going on today to refine the properties of these materials and to find new applications for them. For steel, there is an on-going quest to produce lighter, stronger steels to make cars weigh less and use less fuel without compromising passenger safety, and to reduce the time and energy required in production so that steels can be cheaper and have less environmental impacts. The processing of natural fibres uses large amounts of water and energy, and creates large volumes of waste water, and there is a desire to lower the environmental impact and cost of using natural fibres. Fabrics made from natural fibres have a range of desirable features, including being light weight, thermally insulating and in some cases water resistant. Research continues into how mimic these desirable properties in fabrics made from synthetic materials.

Steel is strong and relatively cheap because iron is a dense and abundant element. However, magnesium is also a relatively abundant metal (making up 13% of the Earth's mass), and compared to iron it is lightweight, having a density less than a quarter of that of iron. Like pure iron, pure magnesium is soft and not very strong. However, also like iron, mixing magnesium with small amounts of other elements produces alloys that are both strong and lightweight. Compounds of magnesium have been used for thousands of years, but it wasn't until the 1800s that pure metallic magnesium was first produced. This comparatively modern material remains the active subject of much scientific research to enhance its strength and formability through alloying and processing, so that it can be used in new applications where we want its strength and other desirably metallic properties combined with its light weight.

Small amounts of elements are added to some pure metals to control the internal structure of the alloys created so that they have new and more desirable properties. Perhaps the ultimate goal of materials science and engineering is to be able manipulate individual atoms or molecules to construct a material or device 'from the bottom up'. Operating on materials at very small scales is known as nanotechnology – the name coming from the prefix 'nano' in the length nanometre. Nanotechnology refers to manipulating materials or objects in the size range one to 100 nanometres – one nanometre is one millionth of a millimetre in length. Developments in nanotechnology are driven in part by the desire for more powerful computers, which requires more and more electronic devices to be placed in computer chips, which in turn requires smaller and smaller electronic devices. This challenges both our engineering ability to make these devices, but also how to connect to them with tiny nanowires, so that they can be assembled into computer products.

The other driver of nanotechnology and nanomaterials research is that materials and objects constructed at the nanoscale often exhibit new and previously unexpected properties. A sheet of single carbon atoms connected in a hexagonal pattern in a sheet and rolled into a tube ('nanotube') is the strongest and stiffest material known. Many materials are used as catalysts, because they promote certain reactions to occur – for example, platinum is used in the catalytic converter in most modern cars, to convert the toxic exhaust fumes into carbon dioxide and water. The effectiveness of a catalyst depends on the surface area available for the conversion reaction to occur on. One cubic centimetre of platinum in a single cube has an outside surface area of six square centimetres. If this is chopped into smaller one millimetre sized cubes, the available surface area increased to 60 square centimetres. If the original cube is chopped into one nanometre sized cubes, for the same volume/amount of platinum the surface area for reaction is increased to 60 million square centimetres. On-going research into nanotechnology continues to reveal new properties of materials and new ways to engineer at very small scales.

High strength materials, like metals and concrete, are typically heavy. Historically this was less of a problem when materials and energy were relatively cheap – we could build heavy vehicles that were strong and safe, and we could have less concern about the amount of fuel used to move them around. As we move into a resource constrained world where we want to use less raw materials and energy, we look for lighter-weight materials that might replace 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. Composite materials are one approach to achieving the desirable lower weight and higher strength combination. A composite material is one that is 'composed' of two or more separate components. By carefully combining two or more materials that have some desirable characteristics, it can be possible to create a new 'composite material' that emphasises the desirable characteristics of the individual materials that make it up.

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 composites are light and strong, but the raw materials used are expensive and a lot of energy is required for their production, and the curing process to produce a carbon fibre product takes a long time compared to the manufacture of similar products made from metals. Carbon fibre composites are used in applications where weight is more critical than cost, such as aircraft. Scientific research continues to find cheaper and more sustainable raw materials from which to make carbon fibres, and engineering efforts are directed at minimising the energy needed to produce the fibres and the time required to curing of products made from carbon fibre composites.

Modern materials research and development

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. The search for, and application of, new materials is a joint scientific and engineering endeavour that leads to the new and improved products that we have. Materials research and development (R&D) draws on many scientific disciplines, including physics, chemistry and biology. Materials R&D can be viewed from a number of levels – the level of the materials themselves (i.e., metals, plastics, steels, nanomaterials); the level of industry sectors (i.e., chemicals, construction materials, forest products); or their wider applications (i.e., health, food, energy, construction, transport).

The ability to research, develop and design with new materials is central to the plans of many developed countries to sustain their prosperity and competitiveness, to the plans of some other countries as they transition from economies based on previously abundant raw materials and/or industries in decline, and to the plans of many developing countries to help boost their development. As with much scientific research, the long-term uses and value of newly discovered materials is difficult to accurately predict, other than to say that those who can participate in and lead the R&D of new materials will almost certainly reap substantial national benefit.

In Australia, the federal government provides significant funding of R&D – about $9 billion in 2014. This money supports a range of research important to the federal government (biosecurity, defence, etc.), as well as supporting more general research that is likely to bring benefits to the wider society, and hence may not be undertaken by solely commercial organisations. Government R&D funding in Australia essentially goes to universities ($2.9B), to public sector research organisations (such as CSIRO – $1.8B) and to the private sector in the form of tax incentives to support R&D work ($2.1B). The remaining $1.8B goes to support research collaboration between these sectors, such as the Cooperative Research Centre program.

While commercially operated organisations carry out most of the processing of materials and the production of goods using those materials, the R&D activity associated with materials science and technology is shared between different types of organisations. Australia's universities undertake much of the basic research in materials, producing new knowledge that may be eventually used by commercial organisations to improve their production processed and/or develop new products. Australia's largest publicly funded research organisation is the Commonwealth Scientific and Industrial Research Organisation (CSIRO - http://www.csiro.au/). CSIRO seeks to undertake, support and commercialise research in national priority areas, including materials. Other publicly funded research organisation in Australia with a focus on materials include Forest and Wood Products Australia (http://www.fwpa.com.au/), the Cotton Research and Development Corporation (http://www.crdc.com.au/) and Australian Wool Innovation (http://www.wool.com/). Tax incentives to private industry to undertake R&D work mean that the Commonwealth government will reduce the tax bill of a private company by a dollar amount equal to a proportion (currently around 40%) of the spending that the company makes on certain types of R&D work.

The Cooperative Research Centre (CRC) program is an important way in which the Australian government supports and encourages research that has strong commercial potential. CRCs are only funded when there is a significant input of funds by commercial organisations as partners in the CRC, and when the planned research activity aims to solve problems that will make Australian industry more competitive. Currently fund materials-related CRCs include the Automotive Australia 2020 CRC (http://www.autocrc.com/), the CRC for Advanced Composite Structures (http://www.crc-acs.com.au/) and the CRC for Polymers (http://www.crcp.com.au/). A simple view of the Australian R&D support system would suggest that universities primarily undertake fundamental (so called 'blue sky') research that, while contributing new scientific knowledge, may not have any immediate commercial application. The actual situation is a lot more complex than that. Most research funding granted to universities requires at least the consideration of the practical outcomes of the research, and many funding schemes require the involvement of industry partners, including a funding contribution from industry.

Beyond research grants supplied by the government, most universities actively seek to build partnerships with industry to share expertise and resources to solve practical problems through R&D. Research capabilities, staff and equipment are often organised into 'Centres' that focus on a specific research theme – for example the Centre for Sustainable Materials Research and Technology at the University of New South Wales (SMaRT@UNSW - http://smart.unsw.edu.au/) seeks to bring together university researchers and industry to develop new sustainable materials and manufacturing processes. Another way to organise research expertise at universities is via a larger 'Institute' that might combine research capacity across a number of related areas – for example, the Institute for Frontier Materials (IFM – http://www.deakin.edu.au/research/ifm) at Deakin University. The IFM seeks to foster innovation in materials science and engineering research, including in the following areas: metals alloy design and processing, biomaterials, corrosion protection, electrochemistry and materials, modelling of materials and processes, nanotechnology, textiles, and composite materials.

Centres, Institutes are similar groups within a university are not the only what to organise R&D resources. In composite materials science and engineering, it is possible to simply list equipment, expertise and experience related to composites R&D, such as this example from the University of Rhode Island College of Engineering in the USA:
http://egr.uri.edu/research/composite-materials-research-development-capabilities/
Another example is the Carbon Nexus facility at Deakin University in Australia:
http://www.carbonnexus.com.au/
Carbon Nexus is a part of the IFM at Deakin University, and one element of the wider composite materials R&D undertaken at Deakin University. Specifically, Carbon Nexus focusses on carbon fibre composite materials R&D, with its research priorities listed as:

1. Low cost carbon fibre
2. High performance carbon fibre
3. Surface treatment of carbon fibre
4. Advanced composite manufacturing

The Carbon Nexus facility includes advanced equipment for the production and testing of carbon fibre composite materials, and also a team of materials scientists and engineers who specialise in carbon fibre composites R&D. Carbon Nexus undertakes R&D that is funded through all of the mechanisms noted above, with a focus on industry collaboration and industry funded R&D.