BERTHA RESIDES on a quiet industrial estate in Bristol, in the west of Britain. The affectionate name has been given to what at first appears to be a giant loom from the Industrial Revolution. And in some ways it is. Bertha (pictured above) is an automated braiding machine. Like a horizontal maypole, ribbons of carbon fibre are drawn from 288 bobbins contained on a pair of huge rings, and passed over and under one another as they are wound tightly around a revolving mould. The final product could be a propeller for an aeroplane, a ship's hydrofoil or a set of wheels for a sports car. In fact, Bertha can knit just about any hollow component up to 800mm by ten metres, and do so quickly and accurately by depositing some 300kg of carbon fibre an hour.

Just as textile production began to be mechanised at the end of the 18th century, creating the modern factory, manufacturing is going through another revolution. This time it is driven by digital processes and new materials, such as carbon-fibre composites. Automated braiders are one of several new systems turning carbon-fibre production from a slow, labour-intensive craft into a mass-manufacturing process that will change many industries.

Carbon fibre is attractive because it is lightweight and exceptionally strong. The toughest fibres are up to ten times stronger than steel and eight times more so than aluminium, reckons Zoltek, an American carbon-fibre producer. Carbon fibre is also five times lighter than steel and half the weight, or less, of aluminium. Nor does it corrode. In transport industries, where "lightweighting" is most valuable, carbon fibre allows aircraft and cars to be made lighter and so travel farther on the same amount of fuel or a single charge of their batteries. This will help them meet tougher emissions targets.

And there are other advantages, too. One is that carbon fibre allows manufacturers to make much larger, more complex parts in one go, says Richard Oldfield, chief executive of the National Composites Centre (NCC), a research laboratory set up by the University of Bristol, and home to Bertha. Instead of making an aircraft's wing or car body by welding, riveting and bolting together hundreds of individual components, these bits can be consolidated into a single carbon-fibre structure. This saves time and materials and allows designers to come up with novel products.

Hot stuff

Engineers got interested in carbon fibre in the 1960s. The fibres consist of carbonised polymers, made up of long strings of molecules bound together by the powerful bonds between carbon atoms. The fibres are made by heating a precursor material to around 3,000°C in a protective atmosphere of inert gases. The most commonly used precursor is polyacrylonitrile (PAN), which is produced by the petrochemicals industry. Pitch, obtained from coal tar, is sometimes used instead. Once carbonised, the fibres are wound onto bobbins, spun into yarns or formed into tapes. Depending on the final application, they can also be woven into fabric sheets.

On their own, carbon fibres are brittle and can break easily. But their strength comes in tension (they resist being pulled apart). So, the fibres need to be aligned in such a way to impart their strength by distributing loads throughout a structure. This is done by placing the fibres, tapes or mats onto a mould in the required orientation, creating what is known as a preform. It is a slow process often done by hand. This is now being automated, aided by the fact that the optimal alignment of the fibres is often calculated using sophisticated computer-aided design systems, and the same data can program robots to lay-up the fibres or wind them on braiding machines such as Bertha.

The preforms then need to be made solid. This is done by impregnating the fibres with a chemically activated resin, which hardens when it is cured. The curing process is usually carried out inside a large oven called an autoclave, which applies heat and pressure to consolidate the structure and force out any air bubbles. It can take hours, sometimes with autoclaves left to run overnight. For a relatively low throughput this might not be a problem. But for higher volumes, especially in carmaking, faster cycle times are needed.

Various out-of-autoclave curing techniques are starting to be used. One is resin transfer moulding (RTM). This involves placing preforms inside a mould which is then closed. Resin is injected into the mould and heat and pressure applied. Depending on what is being produced, RTM can cut processing times by half or more.

Fast cars

McLaren has been making sports cars out of carbon fibre since the British company used the material for the world's first Formula 1 racing car in 1981. All F1 cars are now made from carbon fibre, and the protection it affords drivers has allowed many to walk away from spectacular crashes. To build its sports cars the company starts with a carbon-fibre "MonoCell", a giant tub which forms the main structure of the vehicle.

The company uses a specialist contractor to make MonoCells, although those for future car models will be produced at a new £50m ($65m) McLaren Composites Technology Centre in Sheffield, Britain. The first of the new cells has just been delivered. Impressively, the large and complicated structures are produced with RTM in one go—although McLaren is keeping the details secret. "I often look at the MonoCell and wonder myself how it is possible to make it," says Claudio Santoni, the centre's technical director.

McLaren says carbon fibre will be essential in keeping weight down in future hybrid and electric models. By 2025 it expects the centre to be making MonoCells for some 6,000 cars a year. As a high-end brand, it is not seeking large volumes. But other carmakers are. One is BMW, which uses a variant of RTM in Leipzig, Germany, to make bodies for more than 130 of its i3 electric cars every day. BMW plans to increase that number substantially.

Another speedy production process is "overmoulding". This combines sheets of carbon fibre with injection-moulded plastic. Injection moulding has long been used to produce plastic parts by extruding a molten polymer into a mould. It is quick and accurate. By combining the two processes, overmoulding allows plastic parts to be selectively reinforced with carbon fibre. Thus strengthened, such parts could be used as car doors, aircraft interiors and in many other products. The NCC reckons an overmoulding system it is working with in Bristol can churn out finished components in just 60 seconds.

Progress is also being made in reducing the cost of carbon fibre itself. Prices vary according to quality, but industrial-grade carbon fibre is roughly $20 a kilogram, although aerospace versions are more expensive. By comparison, steel used in carmaking is about $1 a kilogram. As carbon fibre is so much lighter and stronger than steel, less material is needed. And the additional cost is also compensated for by product-lifetime savings on fuel and emissions. Nevertheless, cheaper carbon fibre would find greater use in manufacturing.

Oak Ridge National Laboratory in Tennessee thinks it could cut the cost of industrial-grade carbon fibre by about half with more efficient production processes. According to some estimates, roughly 90% of the energy needed to make things with carbon composites is consumed in producing the fibre itself. Oak Ridge is looking at the use of cheaper alternatives to PAN and low-temperature carbonisation processes.

The lab also uses chopped-up carbon fibre in large-scale 3D printers to produce structures. It recently employed the system to print moulds for the precast concrete façade of the Domino tower, a new 42-storey building in Brooklyn, New York.

Chopped carbon fibres can be made from manufacturing offcuts or recycled material. Recycling will become even more important once a greater number of carbon-fibre cars, aircraft, ships, wind turbines and other products reach the end of their working lives. There will be mountains of the black stuff to deal with. Companies are coming up with ways to recover the fibres, usually with heat or chemicals. Sometimes the fibres can be re-spun, but if they are too short they can still be suitable for parts subject to less stress. A combination of lower-cost mass-production techniques and effective carbon-fibre recycling, will lead to a lot more Berthas knitting away furiously.