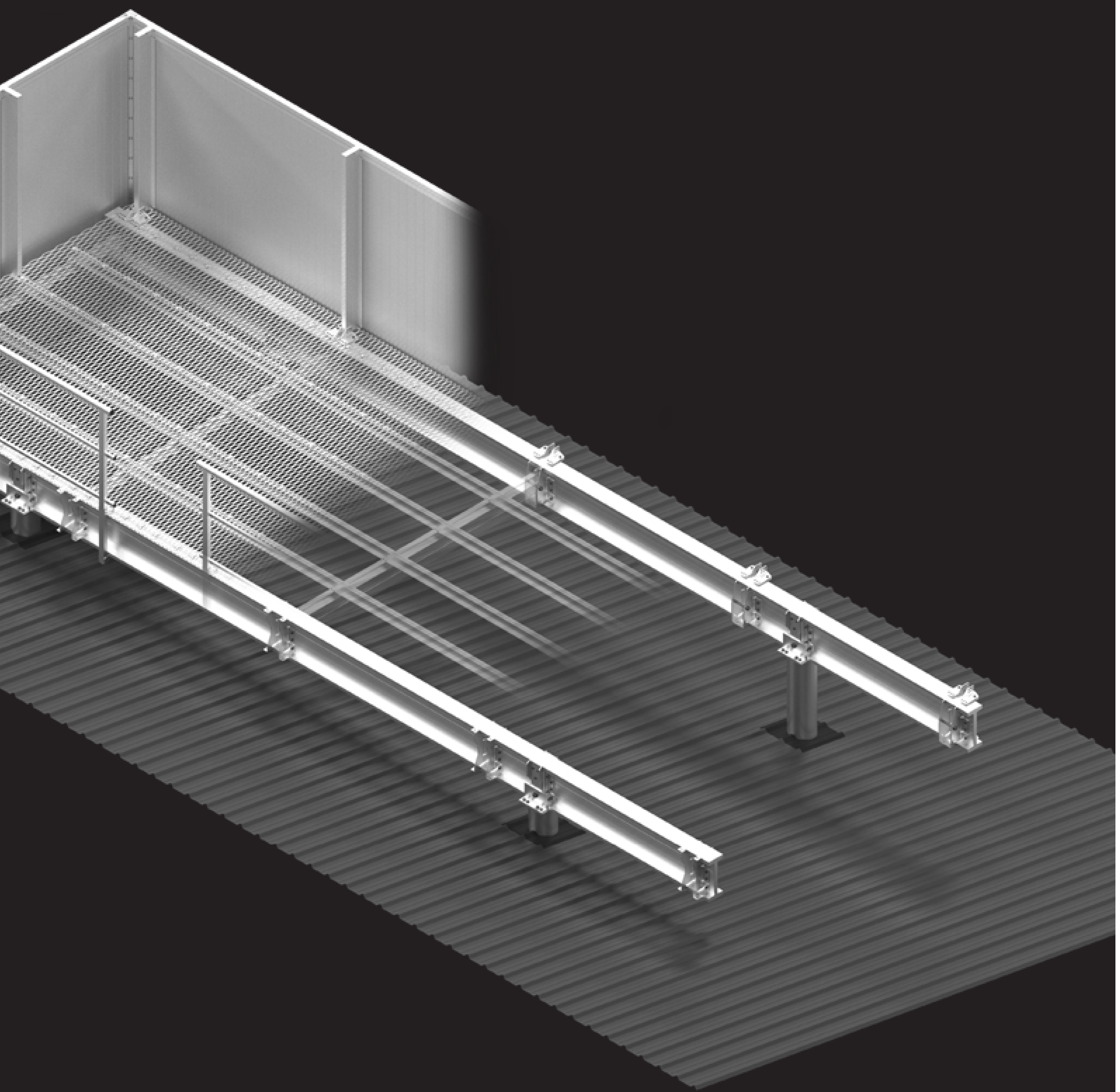
MONKEYTOE EBOOK 5

BIGGER, TALLER, STRONGER: REALISING THE POTENTIAL OF CARBON FIBRE

Monkeytoe

EVERYTHING BETTER



Monkeytoe roof platform using carbon fibre reinforced aluminium **XBeam**

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A NOTE FROM OUR DIRECTOR

Since reinforced materials like fibreglass first appeared in the 1930s, we've experienced leaps and bounds forwards in terms of what is possible in the world of manufacturing. More so than ever, it's possible for materials to allow us to design beyond what we first thought possible.

At Monkeytoe, we like to keep our eyes open to new possibilities in bringing together materials and technologies to deliver exceptional benefits to our colleagues and friends in the construction and design world. That's one reason we're so passionate about aluminium as a metal, for instance. In a previous white paper, we let aluminium's benefits truly shine. It's an abundant metal with incredible performance against corrosion; it's lightweight, so easier to install; it's endlessly renewable and it lasts a lifetime. Where steel had once dominated the building industry, aluminium can offer great new solutions.

Like aluminium, carbon fibre reinforced polymers (CFRPs, or 'carbon fibre' as its commonly known) has a huge range of applications both on its own and in conjunction with existing technologies.

Carbon fibre is made from a network of threaded carbon filaments in a matrix of a polymer or thermoset plastic. Each gives strength to the other: the polymer binds together the tough carbon fibres, making for a material that's stronger than either of them separately. A composite, in other words, is greater than the sum of its parts.

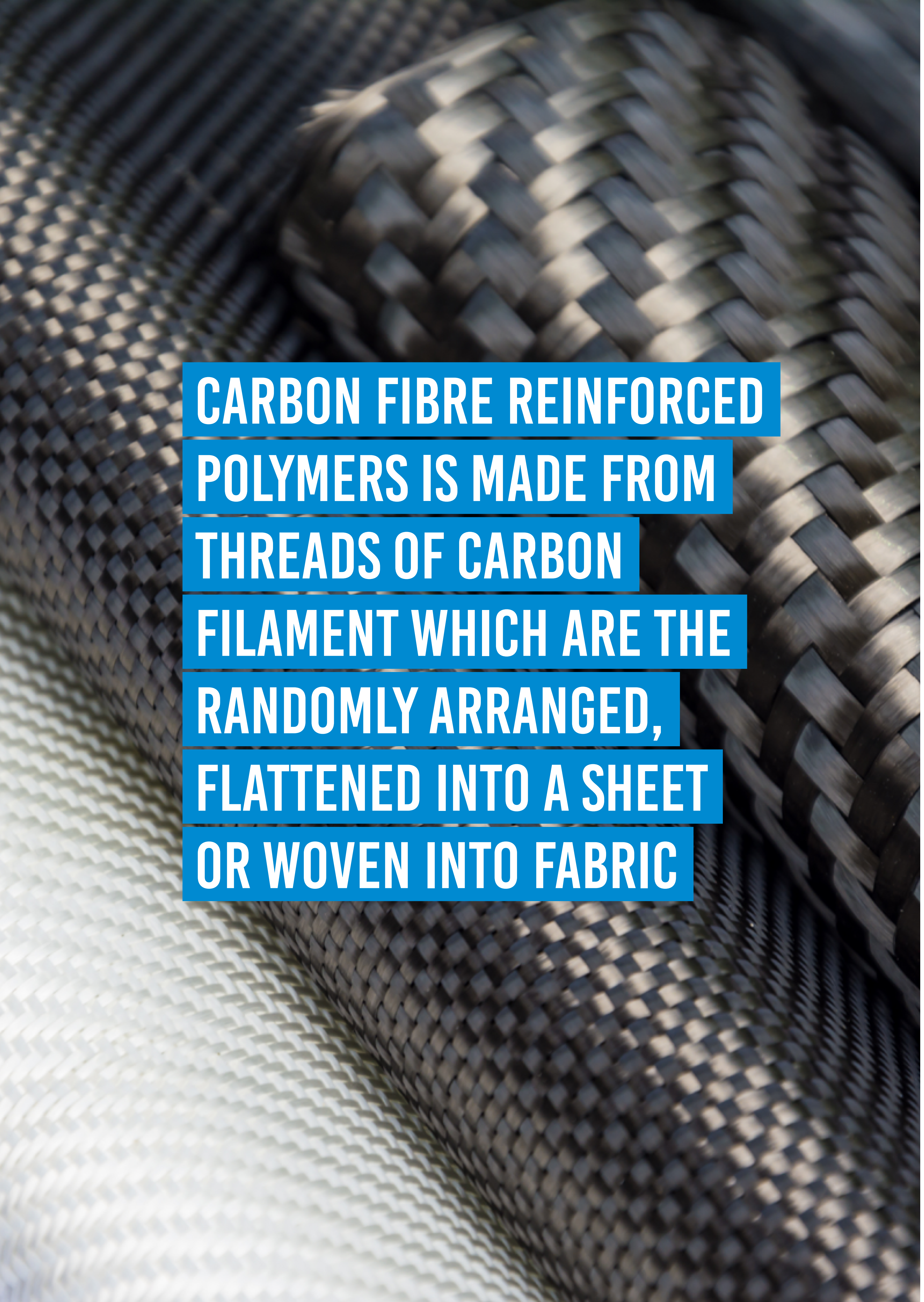
We believe that combining technologies means a better overall product, which is why we're keen on understanding the benefits of the parts and how they can come together to make a stronger whole. At Monkeytoe, we've raised the bar for design possibilities by utilising the strength, versatility and durability of aluminium. As we push towards bigger spaces and greater loads in construction and architecture, we're developing exciting new solutions that bring together the benefits of diverse, cutting-edge materials. Read on to discover how carbon fibre is helping us raise the bar even further in architecture, design and construction.

Tim Prestidge
DIRECTOR OF MONKEYTOE

INTRODUCTION

In recent years, carbon fibre-reinforced polymers (CFRPs, or simply 'carbon fibre') have become the material of choice where high strength-to-weight ratios and rigidity are demanded. While the technology has been around for a century across the automotive and boat building industries, it's only recently that carbon fibre has changed the way we think about materials in sports equipment, aerospace, satellites, civil engineering, and increasingly in luxury personal items. This comes thanks to carbon fibre's superior tensile strength and thermal strength, and its ability to maintain its shape over time.

Lighter, more durable, longer lasting and with a higher stiffness-to-weight ratio, it's easy to see why carbon fibre is making its way into the construction industry, where taller, bigger projects put higher demands on traditional building materials like steel, concrete and timber.



> CARBON FIBRE REINFORCED POLYMERS IS MADE FROM THREADS OF CARBON FILAMENT WHICH ARE THE RANDOMLY ARRANGED, FLATTENED INTO A SHEET OR WOVEN INTO FABRIC

MAKING FIBRE-REINFORCED POLYMERS (FRPS) 01

It's a bit like baking a cake

FRPs are composite materials, and composite materials have two parts: a matrix and a reinforcement, bonded together.
The reinforcement is the fibres, which link across each other and interlace to provide strength, support and flexibility. The matrix is what sits between them; it's the bond that holds the fibres in place.

Think of it a bit like baking a cake. If you threw flour, sugar, butter and baking powder in the oven, it might rise but it wouldn't hold together when it came out. That's a matrix without reinforcement; it's fibres without adhesive. Add an egg, and when that cooks, it holds the other ingredients in place. Now, cut off a slice and say that you're studying thermoset composites. Guilt-free!

Composites mean you get the best of both worlds, with virtually no drawbacks.
Resins and fibres on their own tend to be brittle, and don't have much structural strength to speak of in their raw form. Combine them, however, and they make each other stronger. As Tim says earlier, a composite truly is greater than the sum of its parts.

Carbon fibre reinforced polymers is made from threads of carbon filament which are then randomly arranged, flattened into a sheet or woven into a fabric, depending on the demand. Once the fibres have been woven or formed, they can be mixed with resins (especially for random-set) or brushed (for sheets) and shaped into whatever mould or form is needed. The resin sets or 'cures' into the hard plastic-like compound. From there it may be cut or shaped as needed, but it can't be un-cured; once it's set, it's fixed in place.

Because FRPs have two distinct elements, the properties of each FRP depend on what makes up the matrix and the reinforcement, which is why they should be chosen according to the demands of the situation.

An example of a typical spool of carbon fibre reinforcement fabric used in the process.

Carbon fibres are like chicken mesh

The structure of carbon in fibre depends on the manufacturing process, but the common theme is the hexagonal mesh of carbon atoms. At an atomic level, it looks like chicken mesh. Because the binding strength between carbon atoms is exceptionally high, carbon lattices are an order of magnitude stronger than metals or glasses. However, they're generally produced in small lengths (1/100 of a mm, though half a metre has been achieved), so they're woven together in a similar way that cotton fibres get spun into cotton thread, with each strand providing support to its neighbours. In that way, long, strong fibres are made, which can then be woven into tough sheets.

Directional strength

The sheets and weaves possible with carbon fibre also mean that it can be engineered to have a directional strength that's otherwise not possible with isotropic (i.e. the same in every direction) materials like traditional concrete or solid metal beams. It's the difference between designing in a solid metal bar and an I-beam: an I-beam has a superior bend and shear performance than a solid. Likewise, a 2014 study in Procedia Materials Science showed that carbon fibre has better tensile and flexural strength than fibreglass, making it a superior material for pull and twisting stresses.

In high-demand situations where you need a stiffer, lighter product, carbon fibre delivers better lifetime performance than fibreglass thanks to its structure.

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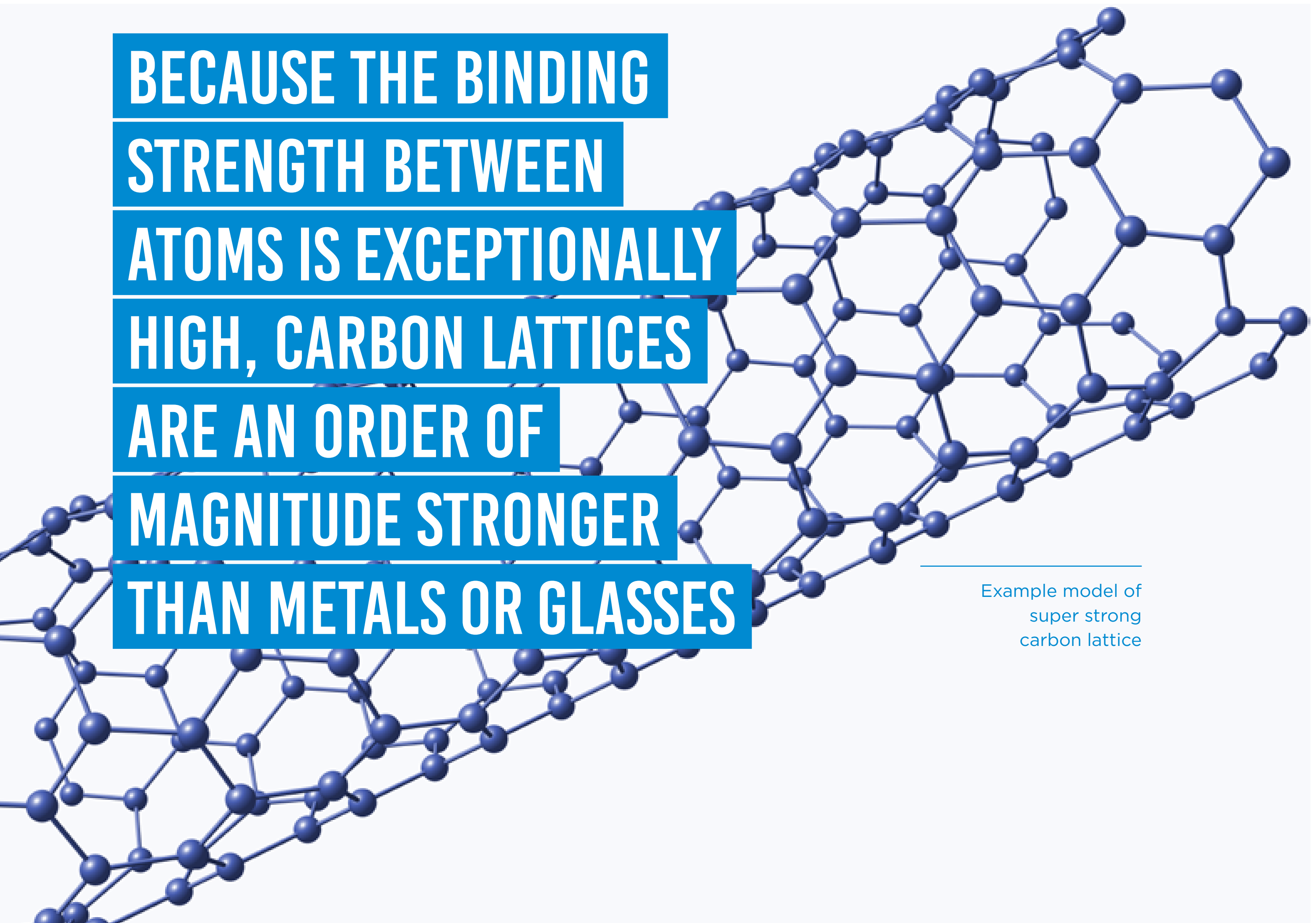

Example model of super strong carbon lattice

Excellent strength and stiffness-to-weight ratios

Composites like carbon fibre are relatively light for their strength. The relative lightness means carbon fibre composites can be crafted into shapes that are inherently stiffer and stronger than steel or aluminium, while weighing a fraction of its metal counterparts. This is one reason why carbon fibres are used in conjunction with metals in high-performance aerospace and vehicle design.

COMPARISON TABLE

The density of steel is about	7,000 kg/m3
The density of aluminium is	2,700 kg/m3
The density of carbon fibre is around	2,000 kg/m3
The ultimate tensile strength of steel is between	0.2 and 2.1Gpa, depending on the type
The ultimate tensile strength of aluminium is around	0.69Gpa
The ultimate tensile strength of carbon fibre is	3.5Gpa

Carbon fibre's strength as a material comes down to the nature of the composite. The ability to tailor the direction of the carbon fibres means it can yield stiffness 20 times, and strength four times, greater than a metal baseline. That means carbon fibre structures can span further distances and support greater weights while also weighing less – opening doors for greater designs.

Complex shapes and part consolidation

Composites like carbon fibre can be made into highly complex shapes, making it possible to use a single piece made from composite to replace an entire assembly of metal parts. This is because composites are formed when the matrix (the resin) solidifies. Carbon fibre can be shaped into plane wings or watch parts before it cures, with no major milling or shaping after the fact, reducing manufacture time and creating a lighter product.

Rather than manufacture and fix together smaller parts, CFRPs make it possible to have a single continuous complex part manufactured from one composite material. While it's also possible to cast metals into complex shapes, carbon fibre can be shaped significantly below the melting points of steel or aluminium, and with less material. Now, a huge range of designs, textures and finishes are possible with CFRPs for any purpose.

1 https://www.sciencedirect.com/science/article/pii/S2211812814004854

2 http://www.compositesanalysis.com/benefits/

As we discussed in our 'Understanding Anti-Vibration and Isolating Vibration' white paper, isolating vibration is increasingly important where comfort matters and where sensitive equipment can be affected.

We've seen carbon fibre's potential as a vibration isolation material in road bikes. In conjunction with aluminium, carbon fibre not only makes the bike lighter, but it also acts as a vibration dampener, making for a more comfortable ride. There's potential to see this same principle in construction, with safer, quieter designs making their way into architecture.

WE'VE SEEN CARBON FIBRE'S POTENTIAL AS A VIBRATION ISOLATION MATERIAL IN ROAD BIKES, IN CONJUNCTION WITH ALUMINIUM, CARBON FIBRE NOT ONLY MAKES THE BIKE LIGHTER, BUT IT ALSO ACTS AS A VIBRATION DAMPENER MAKING FOR A MORE COMFORTABLE RIDE.

IT HAS THE POTENTIAL TO EASILY LAST THE LIFESPAN OF A BUILDING WITH REGULAR INSPECTIONS AND NO MAINTENANCE

Superior Performance

Carbon fibre is exceptionally tough and effectively resists harsh chemicals or water that would cause corrosion or rust. Externally, it has great durability potential and tolerance to UV damage if designed well; it's also non-magnetic and effectively blocks electromagnetic radiation. Carbon fibre is stable with changes in temperature and considered highly fire resistant. It really is the ultimate material.

If the above wasn't enough to impress, carbon fibre materials also have high impact strengths, making them durable against sudden impacts. Unlike wood, which is prone to rotting or termite infestation and sensitive to humidity changes, CFRPs are stable and pest resistant. Unlike steel, carbon fibre doesn't require re-painting or refinishing every couple of decades. Carbon fibre, like aluminium, resists salt spray corrosion, making it excellent for coastal applications throughout the world.

A lifetime of use

With the superior performance of carbon fibre in mind, it's easy to see why it's displacing and outlasting traditional materials in building construction, like steel. If a CFRP is designed with longevity in mind – like UV and moisture resistance – then it has the potential to easily last the lifespan of a building with regular inspections and no maintenance.

Lower whole-life costs

The upfront cost of utilising carbon fibre in building design is greater than the equivalent in steel or aluminium, but the whole life savings quickly show. Because it's lighter and stronger than traditional metal or timber designs, carbon fibre puts less stress on underlying structures, meaning less structural support is needed to achieve the overall design you want. The corollary is that you can also put a greater payload on an existing design without needing to worry about performance or having to spend on a larger or more complex structure to handle the weight.

There's also reduced maintenance required over the lifespan of a building. Steel is often chosen in building design because it's cheap and readily available but, as mentioned, there's also the need to repaint every couple of decades to mitigate corrosion – and that costs money, and time in lost productivity if a building needs to be closed. Since well-designed carbon fibre requires no ongoing maintenance (just regular inspections), there's further savings to be had in the long-term life of a building or design.

CARBON FIBRE COMPOSITES IN DESIGN

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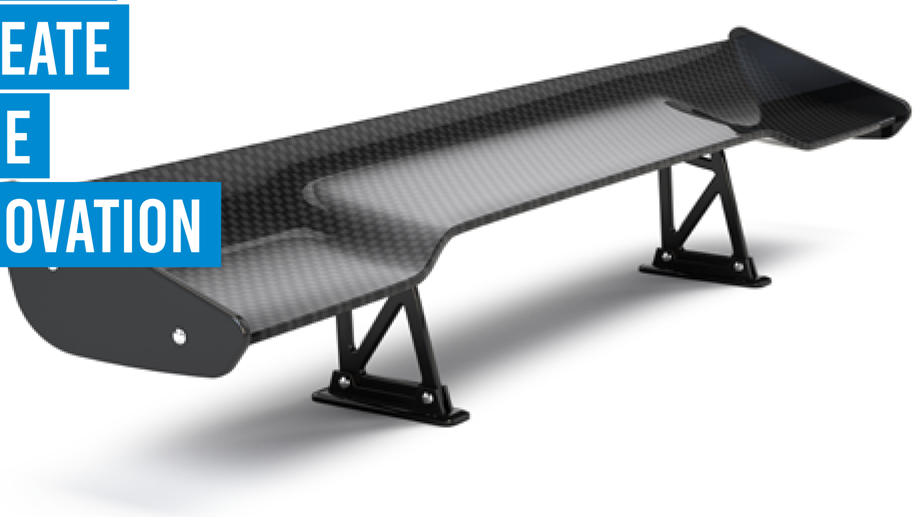
Creating a greater lifetime saving

Carbon fibre is a relatively expensive technology, compared with traditional building materials like steel, aluminium or timber. However, its flexural strength, lightness and performance mean that it's worth investigating the material's strategic use.

Take, for example, a sports car. Yes, you could build everything from the springs up out of carbon fibre, and while it would be a light and durable car, it wouldn't be a comfortable ride. Metal is used overwhelmingly for the suspension springs themselves, for instance, because steel's flexibility makes it a better candidate for this role. Better to make the panels and interior out of stiff, light carbon fibre and get the full advantage from carbon there. Together they create an overall lighter, stronger and more comfortable car.

WHAT DESIGNERS ARE STARTING TO REALISE IS THAT INTRODUCING CARBON FIBRE ELEMENTS INTO DESIGN HAS THE POTENTIAL TO CREATE GREATER LIFETIME SAVINGS AND INNOVATION



What designers are starting to realise is that introducing carbon fibre elements into design has the potential to create greater lifetime savings and innovation possibilities that quickly offset the higher cost of CFRPs. That lighter, stronger sports car now uses less fuel, has a faster 0-100 and a higher top speed. It's performing in ways that are only possible with smart design and the right application of advanced materials.

Just in the same way that FRPs themselves take advantage of multiple materials' properties to create a better whole, strategically combining FRPs with other materials means it's possible to change up the construction and design industries, realising new opportunities from lighter and taller office blocks to more durable, longer-lasting roads.

The biggest limit to design capability is your materials. When the first steel bridges were being built, engineers designed them with the same shape as older wooden bridges, since they didn't yet fully understand steel's superior performance over timber. In the same way, there is huge potential for new carbon fibre composites to change not just how tall, wide and long we can build, but how we come to

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