Carbon Composites in the Bike Industry.

By Raoul Luescher April 2004

Part 1.

Introduction.

Carbon fibre is being used more and more in cycling these days, just look at the pro peleton and almost everyone is using carbon frames, wheels and components. Check out the trade shows and see how many bikes and parts are made from composite materials, over the last few years it really has become the “must have” material for not only bikes but most sporting applications. So what is this magic material, how is it used in bikes and bike parts and what are its limitations.

Carbon fibre or more correctly carbon fibre composite, is an advanced composite material. This means it is a bit more high tech than other more common composite materials such as reinforced concrete or fibreglass septic tanks. I am sure you wouldn’t want a bike made of either of these materials! Composite materials are a blend of two or more materials in such a combination that its properties are superior to its individual components taken separately. Carbon composite as you know it, is a blend of carbon fibres with a polymer matrix. The fibre gives very high tensile strength and most importantly stiffness, the polymer matrix holds the fibres rigid so each fibre can transfer load to the next fibre. The matrix also gives the composite good vibration damping, a property carbon composite frames and forks are very well known for. With composite materials an engineer can design specific mechanical properties to handle a particular problem. Want a bike that is torsionally stiff for good power transfer but vertically compliant for a plush ride? Carbon composite can do it, and do it at a very light weight.

So why use these materials in the first place?

Material	Tensile Strength (GPa)	Tensile Modulus (GPa)	Density (g/ccm)	Specific Tensile Strength (Gpa/g/ccm)
Std Grade Carbon Fibre	3.5	230	1.75	2.00
High Tensile Steel	1.3	210	7.87	0.17

Table 1.

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The figure in red highlights the specific tensile strength of typical carbon fibre, note how it is more than ten times higher than steel. However by the time a composite part is made, this value is reduced a bit because the matrix also plays a part. It is still pretty impressive though.

Fibre Types.

There are many different types of raw Carbon Fibre as well as other fibres such as Kevlar©, Spectra©, Vectran©, ceramics and of course glass fibres. Basically without too much engineering jargon the most commonly used grades of carbon used in cycling are known as T300, AS4 and T700 , some companies are also using "High Modulus" fibres of various grades.
What is modulus you ask? Modulus refers to the stiffness value of a material, so high modulus fibres have a higher stiffness than standard or intermediate modulus fibre. This can be good because in many cases a bike frame is limited by its stiffness, so by using high modulus fibre less is needed to meet the design load requirements, thus a lighter bike is the result. However high modulus fibres have less elongation making them less damage tolerant than standard modulus T300 or AS4, it is also very expensive, these factors can limit its use. T700 fibre is a standard modulus fibre with a higher tensile strength and higher elongation, this is really good for bike frames because it has better damage tolerance. Sometimes a blend of different modulus fibres are used at various locations on a frame, this starts to get complex so the engineer really has to know what is going on with each layer and how it interacts with other parts of the frame for this to be successful.

Fabric Types.

There is a lot of talk about "unidirectional" and "multidirectional" fibre, so here is a very basic explanation. Wherever you see the famous carbon "weave" you are looking at a multidirectional (bi-directional actually) fabric. This is made by weaving bundles of carbon filaments called tows, in a similar process to the shirt you wear. These tows are commonly made up of either 3000, 6000 or 12000 individual carbon fibres, each filament is very fine. There are also many different styles of weave to give different properties

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and looks. I reckon a twill weave with 6000 tow fibres looks pretty good. Unidirectionals have the fibres running in one direction only and don't have the same weave look. There are advantages and disadvantages of each type as below;

Woven versus Unidirectional.

Advantages.

Easier to lay up in complex shapes.
More damage tolerant.
Looks good.

Disadvantages.
Slightly lower mechanical properties.
More expensive.
Heavier due to higher resin content.

Often an outer layer of woven is used with unidirectional material under this layer. This blends the better protection and look of a woven fabric with the better weight, strength and price of unidirectional.

<u>Basic Composite Engineering.</u>

Why talk about the direction of the fibre, what does this mean? Individual filaments are only strong along their length. This means a unidirectional material is only strong in one direction, hence the name. Woven bi-directional material is strong in two directions and triaxial fabric is strong in ….. you guessed it three directions. Sometimes a fabric with randomly orientated fibres is used to try and get strength in all directions, this approach has limitations however.
This is where the black magic comes in, by placing layers at different angles along a tube, an engineer can dial up the properties required. This is the main reason carbon frames and forks can be stiff and comfortable at the same time. This is the major difference between composites and metals. Metals have the same strength in all directions, the only things metal tube makers can change is wall thickness and the diameter of the tube.
So the direction that fibre is placed in a structure is very important to the final outcome and must be controlled during manufacture.

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Unidirectional material gives the designer very good control of what each layer of fibre is doing to optimise the part.

Resin Types.

If you thought that was complex, it can get just as confusing with the matrix, more commonly called the resin. The matrix resin is used to encapsulate the fibres and bond each fibre to the fibres around it. This allows each fibre to transfer load to the next fibre and thus create a rigid product. Remember it is the fibre that has the high tensile strength and stiffness, the resin acts as a transfer medium so each fibre can do its job.

What are the resin choices? In most cases various types of epoxy resins are used for bike parts. Again like all the different types of fibres there is a big selection of epoxy resins.

To group them there are two basic categories;

Two component

Resin component and hardener component are mixed prior to use and then begin to cure, usually at low to medium temperature. This is similar to the Araldite adhesive used around the home. Infact there are many different types of Araldite brand epoxies, the Lotus bike Chris Boardman used to win the Olympic pursuit in 1992 used an Araldite laminating resin.

Single component

“Prepreg” resin. Fabric comes supplied with resin pre-impregnated. This resin has to be stored in a freezer until ready to use. It is cured at an elevated temperature usually above 80 C up to about 180 C. No mixing of components is required. This is currently the aerospace standard due to its ease of handling and consistent properties.

Recently some thermoplastic matrices have also been used these have some advantages such as improved toughness and the ability to be recycled and the disadvantage of being more difficult to work with on complex shape parts. Research is being done with

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these systems, it may even be possible to weld carbon thermoplastic tubes one day.

How to put it all together.

So as you can imagine there are lots of choices for composite engineers to select the raw material properties they want in a frame, that can give you the ride you want in a bike. Now they have to decide the manufacturing process that puts it all together to make it real.

So what makes a good composite bike you ask?

There are many factors that all must be met to produce a good carbon bike.

Firstly the design must be done by people experienced with using composite materials. By this I mean engineers who know how these materials behave under load. Composites got a bad reputation in the Seventies because people basically replaced aluminium or steel with carbon composite without understanding its behaviour. This approach known as “black aluminium” had very limited success, and there were many frame failures. A well designed frame will be stiff, strong, light and have a long fatigue life.

Secondly selecting the most appropriate manufacturing method for the design is paramount. There are many different ways to make composite structures each method suited to certain types of components. This must be considered during the design stage.

Thirdly the materials used must be appropriate for the task. This means selecting the right fibre type and form, e.g. wovens, braid or unidirectional. The right resin system for the manufacturing process is also important along with its environmental properties. Does it get soft in the boot of your car on a summer’s day?

Last but by no means least is the quality control aspect of the process. Does each frame meet quality standards so it delivers what the manufacturer says it will? This is very important in composites, the military and aerospace industries spend a lot of money inspecting products so they deliver a consistent standard of performance. When you buy a Reynolds, Easton or Columbus

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metal tubeset to weld into a frame, you know what properties the tube has before you weld it, this is certified by the manufacturer. This is generally not the case with composites, the builder has to have their own quality control facility to ensure a safe product goes out the door.

Common methods of making cycling components.

Bladder molding.

Bladder molding is used a lot, think Trek and Giant to name two big bike manufacturers that use this technology. Bladder molding is where the fibre is pressed against a mold by a plastic or rubber bag inflated to high pressure inside the hollow carbon section. This is good for “monocoque” or one piece frames. Most often prepreg fabric is used, however dry fabric wet out with a two component resin can also be used. This method has the following advantages and disadvantages.

Advantages.

Can give high quality laminate.
Complex shapes can be made, sleek aero designs are possible.
Able to make a one piece frame, no joins to fail.

Disadvantages.

Expensive tooling required
Frame sizes are usually limited due to cost of making molds for a complete frame.
Can be difficult to control thickness of laminate.
Can be difficult to get consistent quality, can be operator dependant.

Resin Transfer molding.

Resin Transfer molding is used a bit too, such as the Hed 3 wheel. Here all the structural components are placed in a mold “dry” and then resin is injected under pressure to form the final part. This method is becoming quite popular in the aerospace industry due to

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the high degree of control in the process. Considered by some to be the way of the future.

Advantages.

Good control of surface finish, parts have a molded finish on all sides.
Controlled process, less chance for operator error.
High productivity and repeatability.

Disadvantages.

Expensive tooling required.
Limited to smaller parts unless you have lots of $$$$$.
High level of engineering expertise required.

Autoclave molding.

Autoclave molding is also used for some parts. This is basically a pressure cooker and is used extensively in aerospace.
Currently the majority of aircraft parts are made with this method using prepreg material. This is because of the high level of control of the process.

Advantages.

Good quality parts.
Currently the Gold Standard for aerospace parts.

Disadvantages.
Autoclave is expensive to operate and maintain.
High temperature rigid tooling is usually required.
Limited to certain shapes.
Small parts can be awkward.

Tape Laying / Filament winding.

Common method for making round objects, including tubes and pressure vessels such as LPG tanks. Fibre is wound around a removable tool called a mandrel. Once the composite has cured the mandrel is removed. This is the the best method to make a round tube because the fibre is wound on the mandrel under

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tension, so their aren't any kinks in the fibre. This allows the fibre to carry load at its best potential.

Advantages.

Very good quality tubes.
Inexpensive tooling.
Prepreg or wet systems can be used.
Good control and repeatability.

Disadvantages.

Poor external surface finish, needs further work to be acceptable for a bike frame tube.
Robots required to take full advantage of this technology.

Compression molding.

Used extensively in the automotive industry. This method involves placing fibre, usually a random orientation prepreg mat, into a closed mold or die then simultaneously heating and pressing it in a big press. Great for small parts where the load direction is unknown.

Advantages.

Quick cycle time, can produce many parts per day.
Used as a light weight replacement for small metal parts.

Disadvantages.

Press equipment and tooling can be expensive.
Limited to solid shapes.
Doesn't fully realise the advantages of composites.

Next Issue.

So now hopefully you will have a better understanding on what composites are and the basic methods of using them to create structural parts. The next article will delve a little deeper into how these methods and materials are used by different manufactures to give you the product you want.

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