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CARBON PROCESSING: HOW, WHERE, AND WHY?

While over 99.9% of the US bicycle imports in the 2003-2007 period originated from China and Taiwan (Reference: http://www.vitess.com/pdf/Bicycleretailer_07_stats.pdf; source: Bicycle Retailer & Industry News April 2008), this ratio is probably even closer to 100% in the context of today's carbon fibre processing for bicycle frames. Taiwanese companies are the undisputed carbon processing industry leaders. In this white paper, we will try to provide some meaningful insights into the carbon processing industry and why "Made in Taiwan" and "Made in China" are the overwhelming attributes of the vast majority of carbon fibre components today.

Carbon fibre – some basics

A carbon fibre is a long, thin strand of material about 0.0002-0.0004 in (0.005-0.01mm) in diameter and composed mostly of carbon atoms. The carbon atoms are bonded together in microscopic crystals that are more or less aligned parallel to the long axis of the fibre. The crystal alignment makes the fibre incredibly strong for its size. Ultrahigh Modulus carbon has a tensile modulus of 72.5-145 million psi; as a comparison, steel has a tensile modulus of about 29 million psi, making carbon fibre up to 5 times stronger than steel.

Carbon fibre was developed in 1958 in the labs of Union Carbide at their Parma Technical Center in the US. The most important application at the time was to reinforce high-temperature moulded plastic components for missiles. The process was initially based on heating strands of rayon until they carbonized. This process proved to be quite inefficient and was improved in the early 60's with the use of polyacrylonitrite (PAN) as a raw material.

About 90% of the carbon fibres produced today is still made from PAN and it accounts for almost all aerospace and high end carbon fibre applications. The manufacturing process to make carbon fibre is part chemical and part mechanical (see here for more info: http://pslc.ws/macrog/carfsyn.htm). The exact composition of the raw material varies from one fibre manufacturer to another and is generally considered a trade secret.

The industry has consolidated, with the 4 largest producers accounting for 87.2% of the worldwide PAN-based carbon production in 2007. The 3 largest producers are all based in Japan: Toray (36% market share), Mitsubishi (21.7%) and Toho (21.4%). The 4th is a Taiwanese company, Formosa Plastics Corporation with 8.1% market share – source Formosa Plastics Corporation.

Some bicycle brands refer to the type of carbon used to process their frames in the actual artwork. Traditionally, T700 from Toray (modulus of 23.5 t / mm2, or 33.4Msi) has been the go-to carbon fibre as it provides some good characteristics in terms of easiness of processing, product mechanical attributes and cost. Premium brands have looked to differentiate their offering and have slowly started to use more exotic fibres, with much higher mechanical characteristics but also significantly harder to process and leading to a more complex analysis of the balance between strength, lightness, compliance and reliability.

Carbon weave pattern is also a much discussed attribute of many frame-sets. The most prevalent standard in the industry are UD, 12k, 3k and 1k. UD stands for "unidirectional" and means that there is no weave pattern to the carbon fibre. 12k means that 12,000 strands of carbon fibre are used for each little square pattern; the same rationale applies to 3k and 1k. In other words, a 1k weave pattern will be 3 times as narrow as a 3k weave pattern. The angle of the weaving can vary from 15deg to 60 deg, and it will result in different torsion and flexion resistance characteristics. Though most weaving pattern used is at 45 deg.

In most cases, the question of weave pattern is purely a cosmetic one: only the last layer of carbon is weaved, with all other layers been laid-up with UD carbon. So when one promotes the use of a very high-modulus carbon with a 1k weave pattern, a sensible question might be: what is the carbon used for all layers other than the last one? In the case of Vitess, we also use 3k weaved carbon fibre in critical inner areas of the frame because of its very good characteristics in regards to crack prevention.

Carbon processing: turning carbon fibres into a product

Carbon fibre filament yarns are used in several processing techniques: prepregging, filament winding, weaving, braiding etc.

Prepregging is the dominant process used for producing bicycle frames. It entails the dipping of carbon fibre into an epoxy and the creation of sheets of carbon fibre. In some cases, the epoxy used incorporates very fine particles that some manufacturers refer to as "nano-technology". Some lab testing has shown that the use of this type epoxy may enhance the characteristics of the cured polymer in terms of impact resistance. Many players in the bicycle industry still refute this idea because of lack of conclusive lab testing results.

The sheets are then cut in unique elements of various shapes and used in the lay-up process. "Laying up" simply means that each unique element is set and adjusted on an inner reference, which is usually made of either a foam core-base material or an expendable air bag made of plastic or rubber. The way in which the elements are laid up in relation to the forces the component experiences is critical to its strength and physical properties.

The laid-up assembly is placed in a mould, where the inner shapes of the mould become the outer shape of the carbon-fibre part being made. Gas pressure is being applied to the air bag, leading to the compaction of all the different layers of carbon fibre elements to the inner surfaces of the mould. Heat is applied to the mould, which in turns hardens the epoxy and creates the "hard"-to-the-touch carbon fibre component that everybody is familiar with. In the case of foam-core, no gas pressure is applied, but the foam reacts to the heat and expands, which results in the same compaction of the carbon fibre in the mould.

In terms of the complete bicycle frame, several carbon constructions exist and offer various advantages and disadvantages.

The vast majority of today's carbon frames follow a one-piece front triangle approach, which basically means that head-tube, down-tube, top-tube and seat-tube are in fact one continuous element. Seat-stays and chain-stays are then bonded to the front triangle. There are various interpretation of this principle with some manufacturers separating the front triangle into multiple elements – some of them include a one-piece "head-tube, top-tube, down-tube" element and a secondary bonded "seat-tube, bottom bracket" element. Traditionally, manufacturers have called this construction "monocoque".

Other manufacturers use a Tube-to-Tube technology. This can involve a lug-approach, which is basically as close to a non-carbon frame-making process as it gets. Lugs are made and bonded to shell-junctions. Different processes exit to produce the lugs; prepeg and filament winding being the prevalent ones. In some other cases, manufacturers use a tertiary process of carbon re-wrapping for each tube junction. The latter one is what we selected for Vitess frames. Our White Paper 6.0 will provide more details about the different carbon constructions and explain how the Vitess carbon frame is made and how it differs from most mass-market brands.

Carbon processing – the story of an industry ... a Taiwanese industry

Carbon fibre was originally a structural material used by the aerospace industry in the UK and the United States both in civil and especially in military applications. In the 70's, carbon fibre found its way to consumer markets. The sporting goods industry rapidly developed an interest for this innovative material. Tennis rackets made of carbon fibre debuted in 1978, based on the work of 2 California-based composite pioneers. But the level of industrial know-how as well as the manufacturing infrastructure would not allow for a true commercial application for mass-market prior to the early 80's. By that time, and following the leadership of a few very innovative firms, Taiwan was already the largest producer of carbon fibre rackets, with a worldwide market share of almost 90%. Carbon fibre fishing rods were introduced in 1982. By 1985, Taiwan was the largest worldwide manufacturing base for carbon fibre golf shafts.

This very fast growth of the Taiwanese carbon processing footprint of the 80's was followed by a period of strategic planning and production relocation in the 90's. The industrial powerhouse of China was slowly gaining ground, and this led to a massive re-structuring of the Taiwanese industry. Some firms chose a "red ocean" strategy and grew scale significantly in order to remain viable and heavily invested in China to build low-cost production capacity. Some firms chose a "blue ocean" strategy and ventured into new markets and new applications. Not being sure what to do, some firms tried to follow both approaches in parallel. The companies that decided against scaling up in markets that they had been involved with and for keeping a large footprint in Taiwan had to move to higher value-added and more technically-demanding products. The difference in labour cost between Taiwan and China made production in Taiwan only viable for more complex parts such as medical devices, automotive and aerospace parts, helmets, and safety-related bicycle components such as frames.

As the manufacturing expertise grew and systems were put in place to control quality, production was slowly relocated to China to lower costs and to allow firms to remain competitive in the global market and to respond to the cost-cutting requests from Western buyers and brand marketers. Most China-based manufacturing plants remain under ownership and operating control of Taiwanese companies.

Slowly, Taiwanese companies grew from being OEM (original equipment manufacturer), to ODM (original design manufacturers) to OBM (original brand manufacturer). This has been the case for the 2 largest bicycle manufacturers in the world: Giant and Merida. The 3rd largest one, Ideal, has not moved into the OBM space quite yet. All three companies are based in Taiwan.

Today, carbon processors are either pure-play companies dedicated to the bicycle industry, or they are multi-play firms with operations in other sporting goods industries (tennis rackets, hockey sticks…) and even playing in fields such as automotive, aerospace, medical… The number of different companies related to carbon processing in Taiwan is incredibly high, even though most mass-market bicycle brands use perhaps the largest dozen of them.

Industry challenges

As labour wages increase in China, many firms are looking at relocating to even lower-cost jurisdictions, but given the level of investment of the last decade in Mainland China, decisions are not easy to make. Bike Europe, a European web communication platform for industry professionals very recently reported that bikes imported in 2009 into Europe from the Philippines, Tunisia and from Bangladesh were significantly less costly than those from China.

Lead-times have also become a major issue for Western brand marketers and Asian carbon processors alike. A few major reasons for that:

- Labour shortages and labour disruption in the most populated country on earth have become a recurring theme as government central planning creates tremendous pressure on internal population migrations, which is compounded by the simple fact that workers are looking for higher wages,

- Carbon fibre supply has also become a major challenge as the airframe industry has slowly grown an affinity with this material. Both Boeing and Airbus are heavily involved in carbon-fibre related projects and given the man-engineering nature of this type of composite material; the need for raw material is bound to explode. As Eric Koh from Martec, a large Taiwanese carbon processor, acknowledged a few years back, "a single Airbus A380 superjumbo jet will use some 70,000 metric tons of carbon fiber, while the entire sporting goods industry consumes about 200,000 tons a year. We're talking about three Airbuses". "And they have 150 on order" he added. – source: http://www.allbusiness.com/retail-trade/miscellaneous-retail-miscellaneous/4147432-1.html. Today's actual numbers both in terms of carbon fibre consumption and A380 production forecast are obviously different, but the point of reference is still valid.

- Ocean and air freight transit from Asia to both Europe and North-America has become more lengthy and costly because of container shortages and limited air capacity.

Relocation of non-carbon bicycle manufacturing into other regions of the world has already begun to some degree. Over the last couple of years, large European bike manufacturers have announced major investment in Eastern Europe. But many factors specific to the carbon processing industry, such as expertise level and very high labour content, make such an industrial move much more complex to execute and a status-quo situation for the next few years is a very likely outcome. New investments in Mainland China do not show signs of slowing down; to the contrary non-Taiwanese investors are looking at carbon processing in Mainland China as a good space to be in.