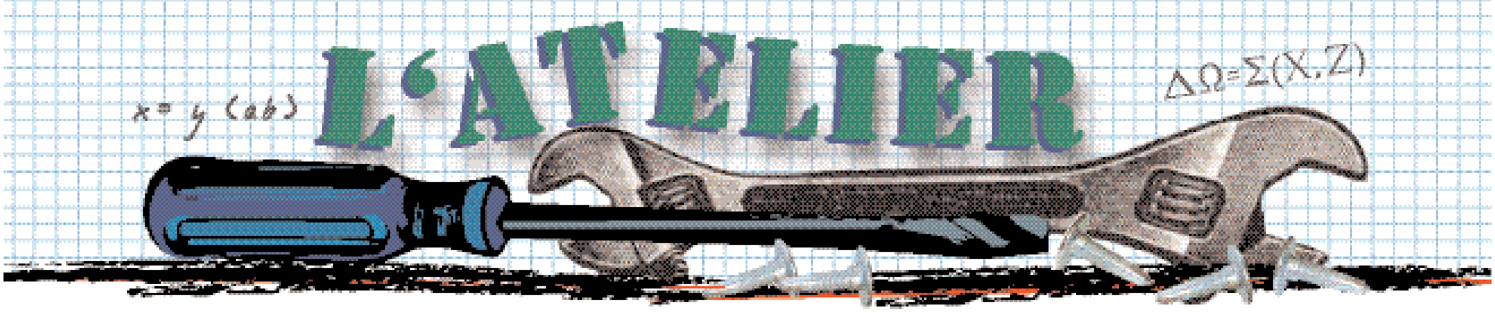


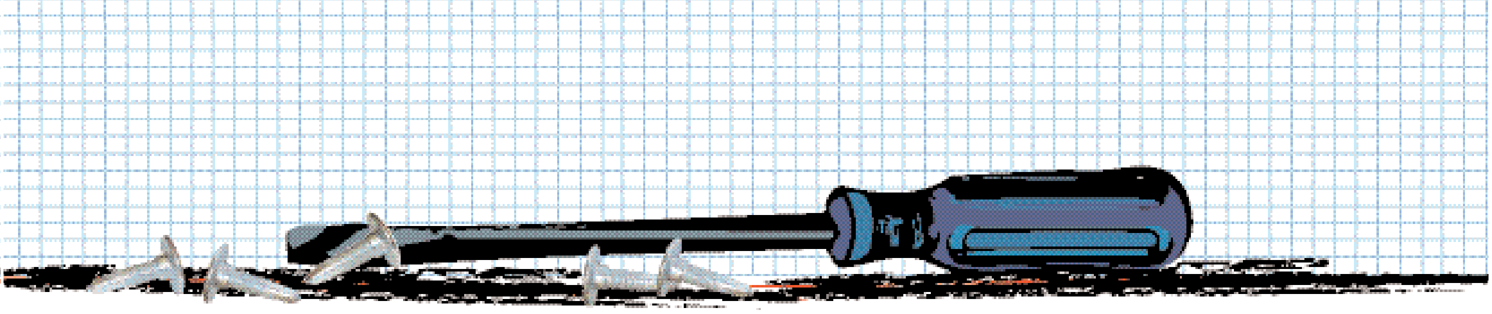
Carbon fibre : Ma

Carbon fibre, the expression alone conjures up visions of exotic technology, of Formula 1 cars and stealth fighter jets. Of course, in recent years, this mysterious material has gone somewhat mainstream and is no longer the exclusive playground of big budget undertakings, as evidenced by its appearance in high-end bicycles, and various lightweight aftermarket components for motorcycles and other high-performance applications. At this point some readers may be thinking aloud ”great, but this is a snowmobile magazine so why are we talking about a product used on mountain bikes?”. The answer to that question can be summarised in just two words: weight reduction. Many of you may remember a short time ago, say ten years or so, when titanium was the exclusive reserve of factory racing vehicles and the like yet here we are in 2007 and we now have production sleds that have a multitude of components made from this lightweight and resistant metal. The same is true for magnesium. Given the tremendous effort being expended by manufacturers in recent times to build lighter and more rigid sleds (for obvious reasons such as better performance, handling and fuel economy), expect their sights to turn to new avenues in their quest. In other words, it is not unreasonable to expect to see carbon fibre components to show up on your dealer floor in the not-too-distant future. In this month's column then we intend to de-mystify this material and answer the numerous questions you surely have. So, without further ado...

Nomenclature and origins

Carbon fibre is part of a family of materials known as composites. These are engineered materials made from two or more constituent materials that remain separate and distinct on a macroscopic level while forming a single component. In other words, the products do not undergo a chemical reaction but remain two separate chemical entities. The most primitive composite materials comprised straw and mud in the form of bricks for building construction. Fibreglass is another more modern example of this type of material. Getting back to the constituent materials, these can be classified into two categories: reinforcement and the matrix. The reinforcement is a strong fibre (such as fiberglass, Kevlar, or carbon fibre) that gives the material its tensile strength. The matrix, on the other hand, generally a polymer or epoxy, acts like an adhesive to bind the fibres together. It also helps the composite to resist degradation and protects the fibres from the environment. The synergism produced from combining these elements yields material properties unavailable from naturally occurring materials.

Now, in light of the above, and for the sake of accuracy, what we commonly refer to as carbon fibre should really be referred to as carbon fibre reinforced plastic (CFRP). In the true sense of the words then, carbon fibre (sometimes known as graphite or graphite fibre) usually refers to the fabric made of yarns spun from extremely fine strands of carbon. This material's history dates back to the end of the 19th century when Thomas Edison and Joseph Swan invented a light bulb using carbon fibre obtained by carbonizing cotton and bamboo. Things changed very little afterwards until 1957 when scientists learned how to make the fibres from cotton and Rayon. The next great leap occurred in 1961 when the fibres began being manufactured from polyacrylonitrile (PAN) in Osaka, Japan. This was the beginning of "high performance" carbon fibre materials as it was around this time that it was discovered that the fabric made from weaving carbon strands made a formidable building block for a super light and rigid composite (essentially what we have today). In 1971 small amounts of PAN carbon fibres began being produced for sale to industry and began popping up on fishing poles and golf club shafts as early as 1973. By the mid 1970's high performance carbon fibre yarns were being used in the aircraft and aerospace industries. The use of CFRP's really hit its stride in this industry as aerospace engineers quickly grew to realize the weight savings that could be had compared with traditional materials like metals. Still in the world of the



terial of the future

By Michel Garneau

unobtainable, the material made its debut in Formula 1 in 1981 with McLaren and has since become a staple of the auto racing world.

More recently, the tremendous drive to alternative power sources has resulted in a boom in demand as the 50 metre long blades used in wind turbines are made from CFRP's. The aerospace industry continues to expand its use of CFRP's and this is made abundantly clear when one considers that the latest flagship passenger aircraft, the Boeing 787 and the Airbus A380, are comprised of 60 and 50 percent CFRB's respectively!

The new Airbus A380!

In the automobile industry, CFRP's are finally creeping into the high-end performance car market. BMW's latest M6 has CFRP front and rear bumpers, roof, beams and internal structures. Closer to home, General Motors has also begun to use the material in its top-line Corvette model.

Price has for a long time been the Achilles heel associated with CFRP and limited its spread. Growing demand, the result of increasing applications in the sporting goods area and more general engineering industries, has fortunately coincided with a steady decline in price over the years. As a result, we now find in a multitude of uses ranging from bicycles to helmets, boats to motorcycles, and this is but the beginning. While the aerospace industry currently consumes about 41 percent of the CFRP made, this is expected to drop as more industries jump on board and adopt CFRP's.

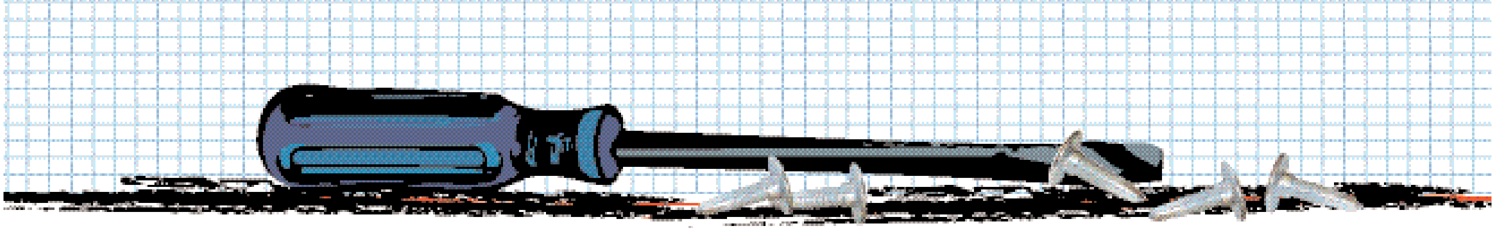
The impressive M6 from BMW.

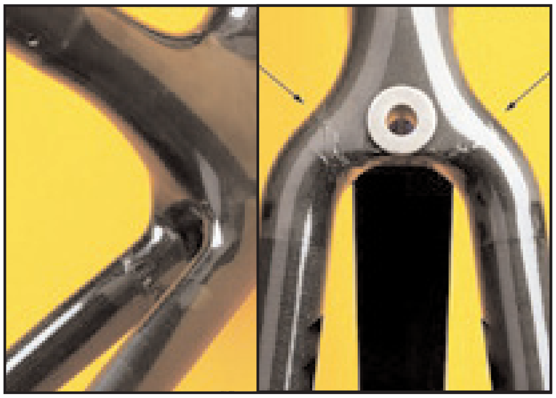
Properties

So what is it about CRFP's that make it so attractive to engineers? Well, it is generally regarded as strongest material known to man with an unsurpassed strength to weight ratio. The strength emanates from the carbon fibres (each carbon filament is made out of long, thin sheets of carbon similar to graphite) which have about 10 times the tensile strength of steel: one square inch of carbon fibre can take a 500,000-pound pull! When all is said and done, then, CRFP structures can be up to 75% lighter than steel and 10 times as strong. Longevity is also a bonus as it will not stretch, creep, fatigue, bend, weaken or corrode over time. Also, CFRP can be wound, braided, wrapped, layered or uniquely tailored to provide exacting safety and performance characteristics. In addition, carbon fibre conducts electricity, unlike most reinforcing fibres. Finally, they do not expand or contract when temperature changes. This is important in airplanes that may sit on a tropical runway one minute, and fly in the subzero stratosphere 10 minutes later.

At this time you could be forgiven for thinking that this is the perfect material but there are cons as well, the main one being its poor impact resistance (when compared to other fibre reinforced plastics). In fact, once the fibres start coming apart they can fail catastrophically. Formula 1 fans will surely recall incidents of yellow flag or safety car use following a collision, the result of the track being littered with sharp CRFP fragments. To overcome this problem, engineers often use other materials to give the CFRP's more flexibility. Kayak manufacturers, for example, often mix it with other materials like Kevlar or fibreglass. These can be mixed in a single fabric by weaving alternate yarns of carbon fibre and, say, Kevlar or by alternating layers of carbon fibre with layers of, say, Kevlar.

A related issue is that of the difficulty in detecting failure as CFRP can take an impact, and look good, but have failed inside. Evidence of this is extremely difficult to detect. In essence, the science of finding flaws in composites remains rather primitive. One can peer closely with a bright light, looking for delamination in some cases but this is not fool-proof. A higher-tech approach uses ultra-sound to listen for duplicate echoes signifying delamination. Ultrasound is rather straightforward on a flat surface but at joints, usually the critical areas, the confusing layers of fibre give, logically enough, confusing echoes. Engineers may compare new ultrasound scans to previous ones, looking for changes in the echo that signal delamination. Even if



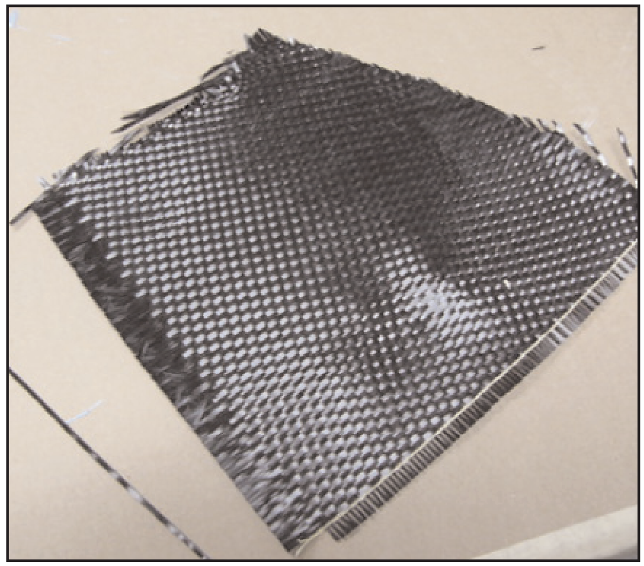


Fractures in this bicycle frame illustrate how challenging it can be to identify delamination in CFRP's.

evidence of damage is found, however, composites are tough to repair because drilling cuts the fibres that give strength in the first place. For this very reason, components are generally glued, not screwed, into place. Finally, due to their carbon composition, CFRP's are susceptible to exposure to flames.

Production basics

Producing CFRP is a multi-step process that begins, unsurprisingly enough, with production of the actual raw materials. In the case of the carbon fibres themselves, one can begin with a substance composed of a long-chain polymer with carbon atoms forming the main "spine" of the molecule (such as polyacrylonitrile or PAN) then using heat or chemicals to remove anything from the molecule that isn't carbon while leaving the spine intact. These fibres are then woven to produce a "cloth" that will form the basis of the CFRP. During our visit with Christian Bourdages, owner of ExtremeGraphic Moto Design (see sidebar), we were told that there are presently only four sources for this fibre in the world and rapidly increasing demand (due in large part to the booming Chinese economy) is driving up price and making it more difficult to obtain.



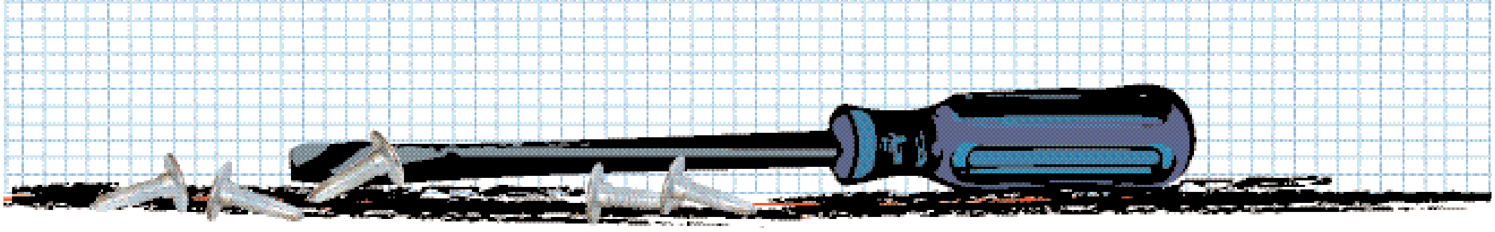
ExtremeGraphic Moto Design: One man's carbon dream

Christian Bourdages, owner of ExtremeGraphic Moto Design in Jonquière has had a life-long love affaire with snowmobiles. As his family was "snowmobile-less" when he was young, 12 year-old Christian decided to take matters into his own hands and build his own! His father quickly caught on to his son's passion and soon Christian was the proud owner of a Moto-Ski Zephyr. Since then, he has owned between 35 and 40 snowmobiles!

Over the years, his love of fabricating and working with his hands have led him to pursue a career which began with an automotive body shop and painting center, and eventually led him to open up his own motorcycle accessories business (ExtremeGraphic Moto Design). What began as a small enterprise making motorcycle undertails (passages de roues) out of fibreglass and generating sales of $59K in 1999 quickly grew to one that has developed a particular expertise in carbon fibre, expanded its product line, and generated in excess of $1M in sales in 2002!

His first exposure to carbon fibre came as the result of a chance meeting he had with a fighter jet mechanic stationed at the nearby Canadian Forces base in Bagotville. Not being one to shy away from a challenge, he quickly began working with this new product and made a few hand-made items on a table in his shop. His interest now peaked, he applied for and received a government research grant to refine a specialized RTM (resin transfer moulding) technique. His expertise quickly grew and in 2001 he secured a contract with Yamaha Canada to produce carbon fibre accessories for its FZ1 motorcycle. Over the years, despite increasing demands on his time, he has remained an active snowmobiler. In fact, his involvement in the sport has included participation in the inaugural Challenge Kanada (where he and his team finished a respectable 6th overall), as well as being active in drag racing, snowcross, even venturing so far as to try his hand at "snowmobile on water" competitions. Of course, his passion for the sleds soon worked its way back into his work and in 2005, his love of radar run competition soon had him working on aerodynamic improvement parts for his personal Mach Z, the result of his efforts being the Aero-Deflector kit featured in the November 2006 Quoi de Neuf section.

So what does the future hold for Christian and his team? Well, increasing competition in motorcycle components is causing him to steer his business in new directions, which will eventually include, among other things, a broad line of lightweight carbon fibre (and fibreglass) parts for snowmobiles. To learn more about ExtremeGraphic Moto Design, please visit their Web site at www.extremegraphicfsmd.com.



When it comes to the actual manufacturing of the CFRP, there are different techniques suited to one-off and medium or high volume applications. Low volume production generally involves moulds and RTM (resin transfer moulding) technology while at the other extreme, high volume parts can be stamped using thermoplastic composite materials. By coupling this with injection moulding, hundreds of parts per hour can be readily achieved.

Regardless of the technique used, it is critical to orient the fibres very specifically in the direction that carries the load. Like the plies in plywood, the strands in each layer of fibre are strong in one direction but weak in another so it is important to take this in consideration when placing the fibres. Finally, every effort must be made to keep voids to a bare minimum as these are the main source of trouble and failure in CFRP's.

While the choice of fibres is essentially limited to different weave patterns and strand dimensions, the same is not true for the matrix options. In fact, there are various resins available and used for making CFRP's, each with its own particular properties, advantages and disadvantages. Epoxy is the hardest and most resilient. On the downside, it is the most expensive option and has a tendency to tarnish (turn yellow) when exposed to UV light. The second choice is polyester, the same substance typically used for fibreglass. Polyester is readily available and provides exceptional strength and longevity. We were told by Christian that this is the resin he uses most often. Finally, there is ester, the weakest of the recommended resins. It should be noted that any and all of these resins can and are used in fibreglass also. However, the key element in providing CFRP's their exceptional strength remains the actual carbon fibres themselves. This is also the reason that CFRP's generally have a fibre content of 40 percent to 60 percent by volume.

There exists one other option in so far as carbon fibre and resin combinations are concerned and this is what is known as "pre-impregnated carbon fibre". As the name implies, the resin is pre-impregnated into the fibres in this case. This form of CFRP must be baked in an oven at 195 deg F for the resin to become activated and uniform. In addition to being expensive, it must also be stored in a cool environment (fridge) at all times prior to being used. Despite this, its use is becoming increasingly widespread.

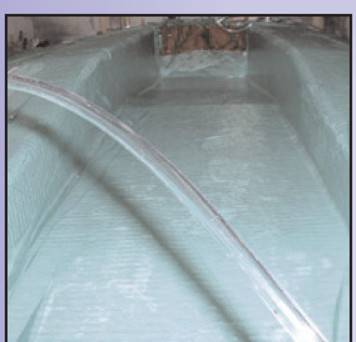
Production: hands on

Having had the privilege of visiting the ExtremeGraphic Moto shop in Jonquières, we were able to witness first-hand the production process involved in making CFRP components. Christian's firm has developed an acknowledged expertise in the moulding of CFRP and fibreglass components in recent years. Of course, as both products share the same basic fabrication process, not to mention a common use of moulds, this is a logical mating.

The (RTM) process begins with the placing of the carbon fibre cloth in between the two moulds. It is worth noting that the 2 moulds are sealed together by the use of rubber lips that ensure an air-tight fit. Once this is done, a line is attached to an air bleed fitting on one of the moulds. This line will be used to draw air out of the mould at a pressure of -14 psi (or one atmosphere). Another line (on

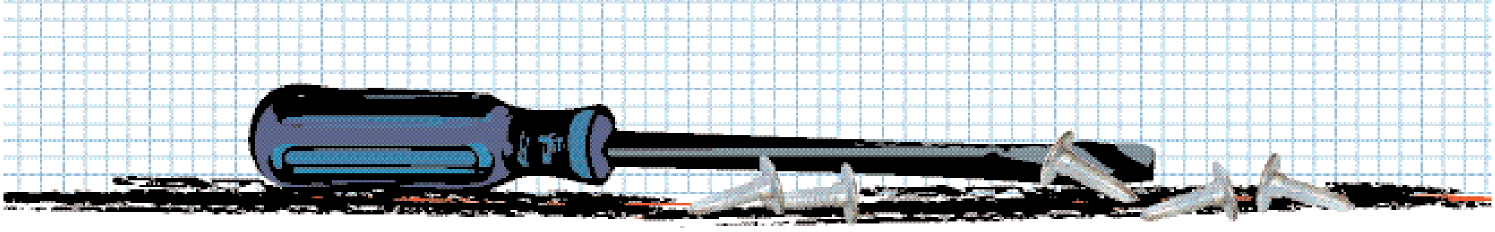
High fibre content

Christain Bourdages is not one to leave well enough alone. Early in 2005, his ingenuity and carbon fibre fabrication skills had him pondering the possibility of building a snowmobile tunnel out of carbon fibre. Being a man of action, Christian soon began work on transforming his beloved 2003 Polaris 440 snowcross racer into a veritable test-bed for his ideas. He quickly set off on building a one-off custom 159" tunnel made out of carbon fibre (that was to be mated to the stock bulkhead). Moulds were made and 4 layers of carbon fibre (and one of Kevlar, the latter to prevent ruptures and reduce brittleness) later, the new tunnel came into being. The final product's weight is identical to the stock aluminium 121" version, in addition to being much more rigid.

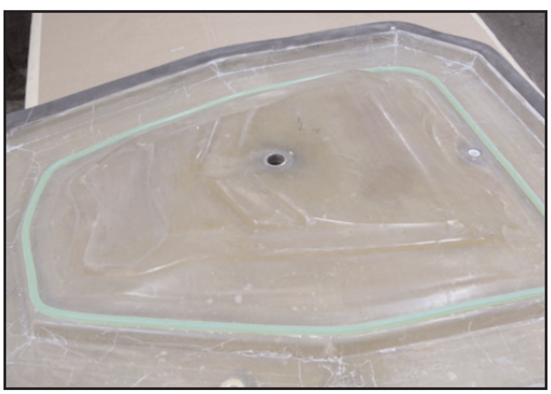


The stock rear suspension was maintained and modified with the addition of rail extensions. A custom 159" version of Camoplast's Ripsaw track was added to complete the package. The end result, according to Christian, is a light, versatile and rugged sled that never ceases to impress. What about durability you ask? Well, after one year of thorough abuse, the only visible sign of wear is a slight crack in the gel coat at the rear of the tunnel, the result of a rock picked up at the end of the season!

Needless to say, the wheels are turning once again and you can be sure that this will not be the last carbon fibre tunnel to be wheeled out of the shop in Jonquières. Of course, Christian is already contemplating building an entire chassis out of carbon fibre. Ah yes, a pioneer's work is just never done!



the opposite mould) is then run into the resin container. The vacuum will cause the resin to enter the mould and fill the available cavity. In order to prevent micro-bubbles from forming in the resin, excess resin is drawn out at a pressure of -7 psi (or half an atmosphere). Resin is allowed to enter the mould until it is full at which time the line feeding the resin is pinched to stop the flow. In the case of the polyester resin used during our visit, the mould is then allowed to sit and dry for approximately 15 minutes at an ambient temperature of 74 degrees F. Since the resin is allowed to dry under vacuum, there is no discharge of odour. Once the drying period is over, a compressed air line is hooked into one of the air nipples and the air is used to separate the moulds from one another. The new part is then taken out, inspected, cut, drilled (for mounting holes), wet sanded, and readied for priming and painting. In most cases, a transparent gel coat is applied but some applications are painted in the desired colour.



Possible uses (snowmobile)

In essence, CFRP can be used virtually anywhere we currently use steel, aluminium or any other synthetic material. This includes the tunnel, chassis, suspension components, hood, airbox, guards, covers, and so on. The uses are practically limitless. The main limiting factor lies in the cost. Resistance to impact is also a factor, although this can be remedied to a significant degree by incorporating additional substances such as Kevlar into the mix.

Future

So what does the future hold for CFRP's? Well, for starters, we fully expect to see its use continue to expand. Perhaps even more significant is the potential for the discovery of new properties, and the development of new and unique uses for this remarkable material. For example, CFRP's ability to conduct electricity is laying the foundation for a new area of research called "structural electronics". This refers to the possibility of developing smart structures that could sense and behave intelligently, giving engineers a way to monitor the structures they build more closely. This could lead to aircraft components that are huge energy-storage devices or solar cars whose body panels can store energy. New kinds of electronics that are less costly to make and that save space could also be envisioned. Also, since carbon material is easier and less expensive to fabricate than silicon (which requires extremely clean factories), in addition to being stronger, we could see the introduction of computers without traditional silicon chips. And this is but the tip of the iceberg for this remarkable and promising material.

Conclusion

So given all of its highly desirable properties, how long before we see this heretofore exotic material on a production snowmobile? Well, no one knows for sure. We do expect that it will initially appear in one or more manufacturer's accessories catalogue. However, as options for weight reduction from more conventional sources (parts rationalisation and re-design, increased use of magnesium, titanium, and plastics,...) run out, carbon fibre will inevitably end up on consumer sleds and that will be fine with us.