Carbon and graphite demystified

Our cut-out-and-keep series to assist retailers with product knowledge.

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There appears to be much controversy over the differences and uses of carbon fibre composite in sports products like fishing rods, tennis rackets, golf club shafts and many others. Your customers might, for instance, insist on a high modulus graphite fishing rod for all occasions – but that is not necessarily in their best interest. Unfortunately, the right choice of material is not a simple one.

What are carbon and graphite?

Carbon: we all know carbon in its simplest form as charcoal in our barbecues. When charcoal burns the carbon is converted into carbon monoxide (CO) and carbon dioxide (CO^2) gases, leaving only a small amount of ash from impurities trapped in the charcoal. The largest sources of carbon are ancient forests that were buried, for example by lava flow, and through the action of heat and pressure converted to coal.

Graphite: Further heat and pressure convert it to graphite, and when further subjected to enormous pressure diamonds are produced. Both diamonds and graphite can be produced synthetically, for example, synthetic graphite is produced by simply heating petroleum residues to 2 800°C in an inert atmosphere.

To understand how a soft brittle material such as charcoal can be converted into a highly versatile engineering material with a multitude of highly advanced applications, an understanding of the unique properties of carbon is required:

- The element, C, carbon has the ability – more than any other chemical element – to form long chains that we call polymers. When other atoms and molecules are attached to this carbon chain, it gives us a variety of materials – e.g. most plastics – that may consist of backbone chains of several thousand carbon atoms in length. In its natural form the carbon atoms are arranged in hexagonal form as in figure 1, in graphite the carbon atoms are in superimposed honeycomb platelets as in figure 2.

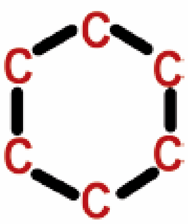

Fig 1: natural carbon

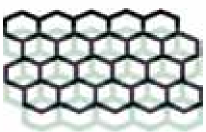

Fig 2: graphite

- **Composites**: When it comes to carbon fibres for use in composites, we once again make use of these properties to form chains. Graphite cannot be used for this because it is soft and brittle and the honeycomb structure cannot be broken down to form chains. The obvious starting point is something that is already a fibre, for example something that consists of a long chain of carbon atoms such as polyacrylonitrile (an acrylic resin fibre), rayon, or even coal tar pitch spun into fibres. Figure 3 shows a small section of the polyacrylonitrile molecule and demonstrates how the carbon atoms link into a long chain.

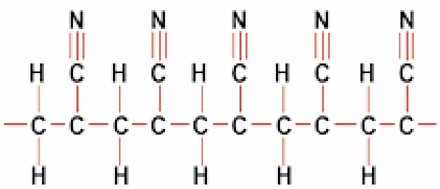

Fig 3: Poly(acrylonitrille)

Carbonization and graphitization

- **Carbonization**: the first step in the process is heating the fibre, under tension, to a temperature of approximately 300°C. This burns off all the hydrogen (H) and nitrogen (N) molecules leaving only the carbon chain. If it is heated further the carbon atoms will oxidize to CO and CO_2 as mentioned above. To prevent oxidation, the fibre is further heated in an inert gas atmosphere at temperatures ranging from 1 500°C to 2 000°C to form carbon fibre in the final stage. This last process is called carbonization.
- In **carbon fibres** the carbon atoms are arranged in long ribbons parallel to the length of the fibre and folded into each other. The orientation of the ribbons and folding gives carbon fibre its high tensile strength.
- **Graphitization**: if, in the final stage, the temperature is raised from 2 500°C to 3 000°C, the carbon forms into similar platelets as in figure 2. This process is called graphitization. However, the platelets are not superimposed as in graphite, but overlap each other along a line parallel to the length of the fibre. The orientation and overlap of the platelets result in high strength combined with stiffness.

Understanding modulus

The end properties (modulus) and cost of the fibre are determined by various factors:

- The type of fibre used to start the process, e.g. pitch, is used for the highest modulus;
- The temperature of the first stage of oxidation and the types of gas used;
- The temperature of the final carbonization or graphitization stage – the higher the temperature, the higher the modulus.

When the fibres emerge at the end, it is approximately as thick as the tenth of a human hair. Multiple strands are then spun together to form a yarn that may be used as such, or woven into a mat.

The end properties are usually expressed as a modulus, e.g. low modulus (LMG) for carbon fibre, intermediate modulus graphite (IMG), high modulus graphite (HMG) and ultra high modulus graphite (UHMG). Ultra high modulus graphite fibre is made from pitch at a very high final stage temperature of 3 000°C.

Types of modulus

Modulus alone is meaningless. It must be further described such as elastic modulus, flexural modulus, ductile modulus and several others. The concept of modulus could probably best explained by looking at the graph on the next page:

- The **tensile strength**, or elasticity, is **To p70**

New recreational fishing permit fees a relief

	Fees 2009	Fees proposed April 2010	Fees October 2010	Short term permits*	Fishing vessel licenses
Diving in MPA's	R 79	R 85	R 85	R 42	5m or less: R 269
West Coast rock lobster	R 79	R 500	R 87		5-8m: R 375
East Coast rock lobster	R 79	R 500	R 87		8-12m: R 606
Mollusks	R 79	R 300	R 87	R 50	12-20m R 1 137
Mud crabs	R 79	R 300	R 87	R 50	More than 20m R 1 813
Marine aquarium fish	R 79	R 300	R 87	R 50	High seas fishing vessel R1 962
Fishing license (angling)	R 62	R 200	R 69	R 45	
Spearfishing	R 79	R 300	R 87	R 50	
Use of throw nets	R 79	R 300	R 87	R 50	
Cost per boat (skipper)	R 79	R 500	R 87	R 50	

Retailers selling fishing tackle can breathe a sigh of relief: the excorbitant hike in recreational fishing permit fees announced in the beginning of the year that resulted in many customers threatening to stop fishing, has been reversed.

The new permit fees that came into effect on on October 1 this year, is "a far cry from that which they initially proposed," says Cary Steele-Boe, chairman of the Recreational Fishing Services.

The fees published in the Government Gazette No.795 of 10 September 2010, are on average about 400% lower than the fees proposed in April (see table), and are on average only 10% higher than the permit fees in 2009.

The fees proposed by the Department of Environmental Affairs and Tourism (DEAT) caused an outcry, and stakeholders vehemenently objected at meetings held around the country.

Many recreational boat anglers who mainly fish during summer holidays at the coast, said that they would rather find other hobbies as it would become too expensive for a family to go fishing. This would have been a big blow to the fishing tackle trade.

The public meetings were followed by much calmer consultative meetings between represenatatives of fishing organisations – the tackle industry was represented by John Pledger, chairman of SAFTAD (SA Fishing Tackle Agents and Distributors) – and officials from the Department of Agriculture, Forestry and Fisheries.

Following the Cabinet shuffle in the beginning of the year, Marine and Coastal Management and the Marine Living Resources Act, which regulastes marine fishing and diving, was moved from DEAT to the Department of Agriculture, Forestry and Fisheries.

The proposed increases were subsequently withdrawn, and the new Ministry was given the task of determining new fees.

According to Pledger, the meetings between the angling bodies and Government showed how important it was for industries (like the sports and outdoor trade) to have represenhtative structures that can engage with Government and other stakeholders when problems arise. The sports industry is currently not represented by any organisation.

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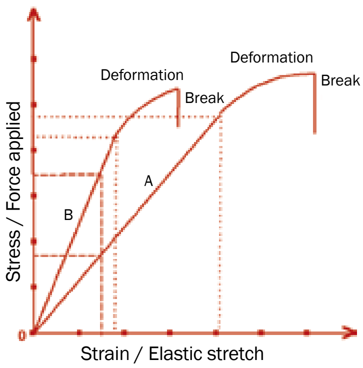

shown where the dotted lines meet, i.e. the force causing the maximum elastic stretch before the material is permanently deformed. Graph A has the higher tensile strength. This is usually expressed as kg/m^2, or pounds per square inch (PSI). A material with a higher tensile strength (like carbon) can therefore absorb a greater force before it deforms, or breaks.

- The **modulus of elasticity** is the steepness of the line or curve. Graph B has the higher modulus of elasticity. The broken lines show that more force is required to cause stretch. This is usually expressed in Pascal, or Giga Pascal (GPa) in the case of carbon fibres. A product made from a material with a higher modulus of elasticity (e.g. HMG rods) will therefore be stiffer, with less elasticity.
- The **flexural modulus** can be represented by a similar graph but, instead of extension, it is a measure of the bending the material undergoes.

Some typical values are shown in the table.

Fibre	Tensile strength	Modulus of elasticity
Carbon	1500 Mpa	135 GPa
High modulus graphite	1000 MPa	175 GPa

Therefore, carbon fibre with its higher tensile strength can take a greater force before it is deformed, whereas high modulus graphite with its higher modulus of elasticity, thus steeper line, require more force to cause extension, i.e. it is stiffer.

Use in products

- In the case of sea fishing rods carbon fibre may therefore be preferred. With its higher tensile strength a carbon rod may handle heavier loads, such as big fish, or heavy casting lures.
- With fly rods, better casting performance may be obtained with graphite fibre because it can be made thinner and lighter. Because of its thinner section, fly rods made from HMG must be handled with greater care – broken rods have been reported when, for example, a beaded fly strikes the rod in a poorly executed cast.

It should also be noted that the above values are for the fibres used on their own.

- The values for **composites**, consisting typically of 50/50 carbon fibre and epoxy resin, are higher than for either material by itself. Products like rackets or hockey sticks, which have to withstand high impact forces, are usually made of composite materials.

It must also be obvious by now that all the many properties of carbon fibre composites, must be considered to find the best material appropriate to the intended end-use.