

Carbon Fibres: Production, Properties and Potential Use

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ABSTRACT

Carbon fiber is composed of carbon atoms bonded together to form a long chain. The fibers are extremely stiff, strong, and light, and are used in many processes to create excellent building materials. Carbon fiber material comes in a variety of "raw" building-blocks, including yarns, uni-directional, weaves, braids, and several others, which are in turn used to create composite parts. The properties of a carbon fiber part are close to that of steel and the weight is close to that of plastic. Thus the strength to weight ratio (as well as stiffness to weight ratio) of a carbon fiber part is much higher than either steel or plastic. Carbon fiber is extremely strong. It is typical in engineering to measure the benefit of a material in terms of strength to weight ratio and stiffness to weight ratio, particularly in structural design, where added weight may translate into increased lifecycle costs or unsatisfactory performance.

Keywords: Carbon fiber, textile, yarn, fabric.

INTRODUCTION

Carbon fibers or carbon fibres are fibers about 5–10 micrometres in diameter and composed mostly of carbon atoms. Carbon fibers have several advantages including high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. These properties have made carbon fiber very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports. However, they are relatively expensive when compared with similar fibers, such as glass fibers or plastic fibers.

Classification and types

Based on modulus, strength, and final heat treatment temperature, carbon fibers can be classified into the following categories:

Based on carbon fiber properties, carbon fibers can be grouped into:

- Ultra-high-modulus, type UHM (modulus >450Gpa)
- High-modulus, type HM (modulus between 350-450Gpa)
- Intermediate-modulus, type IM (modulus between 200-350Gpa)
- Low modulus and high-tensile, type HT (modulus < 100Gpa, tensile strength > 3.0Gpa)
- Super high-tensile, type SHT (tensile strength > 4.5Gpa)

Based on precursor fiber materials, carbon fibers are classified into:

- PAN-based carbon fibers
- Pitch-based carbon fibers
- Mesophase pitch-based carbon fibers
- Isotropic pitch-based carbon fibers
- Rayon-based carbon fibers
- Gas-phase-grown carbon fibers

Based on final heat treatment temperature, carbon fibers are classified into:

- Type-I, high-heat-treatment carbon fibers (HTT), where final heat treatment temperature should be above 2000°C and can be associated with high-modulus type fiber.
- Type-II, intermediate-heat-treatment carbon fibers (IHT), where final heat treatment temperature should be around or above 1500°C and can be associated with high-strength type fiber.
- Type-III, low-heat-treatment carbon fibers, where final heat treatment temperatures not greater than 1000°C. These are low modulus and low strength materials.

Manufacturing Process

Carbon fibers from polyacrylonitrile (PAN):

Raw Materials

The raw material used to make carbon fiber is called the precursor. About 90% of the carbon fibers produced are made from polyacrylonitrile. The remaining 10% are made from rayon or petroleum pitch. All of these materials are organic polymers, characterized by long strings of molecules bound together by carbon atoms. The exact composition of each precursor varies from one company to another and is generally considered a trade secret. During the manufacturing process, a variety of gases and liquids are used. Some of these materials are designed to react with the fiber to achieve a specific effect. Other materials are designed not to react or to prevent certain reactions with the fiber. As with the precursors, the exact compositions of many of these process materials are considered trade secrets.

The Manufacturing Process PAN

Spinning

- Acrylonitrile plastic powder is mixed with another plastic, like methyl acrylate or methyl methacrylate, and is reacted with a catalyst in a conventional suspension or solution polymerization process to form a polyacrylonitrile plastic.
- The plastic is then spun into fibers using one of several different methods. In some methods, the plastic is mixed with certain chemicals and pumped through tiny jets into a chemical bath or quench chamber where the plastic coagulates and solidifies into fibers. This is similar to the

process used to form polyacrylic textile fibers. In other methods, the plastic mixture is heated and pumped through tiny jets into a chamber where the solvents evaporate, leaving a solid fiber. The spinning step is important because the internal atomic structure of the fiber is formed during this process.

- The fibers are then washed and stretched to the desired fiber diameter. The stretching helps align the molecules within the fiber and provide the basis for the formation of the tightly bonded carbon crystals after carbonization.

Stabilizing

Before the fibers are carbonized, they need to be chemically altered to convert their linear atomic bonding to a more thermally stable ladder bonding. This is accomplished by heating the fibers in air to about 390-590° F (200-300° C) for 30-120 minutes. This causes the fibers to pick up oxygen molecules from the air and rearrange their atomic bonding pattern. The stabilizing chemical reactions are complex and involve several steps, some of which occur simultaneously. They also generate their own heat, which must be controlled to avoid overheating the fibers. Commercially, the stabilization process uses a variety of equipment and techniques. In some processes, the fibers are drawn through a series of heated chambers. In others, the fibers pass over hot rollers and through beds of loose materials held in suspension by a flow of hot air. Some processes use heated air mixed with certain gases that chemically accelerate the stabilization.

Carbonizing

Once the fibers are stabilized, they are heated to a temperature of about 1,830-5,500° F (1,000-3,000° C) for several minutes in a furnace filled with a gas mixture that does not contain oxygen. The lack of oxygen prevents the fibers from burning in the very high temperatures. The gas pressure inside the furnace is kept higher than the outside air pressure and the points where the fibers enter and exit the furnace are sealed to keep oxygen from entering. As the fibers are heated, they begin to lose their non-carbon atoms, plus a few carbon atoms, in the form of various gases including water vapor, ammonia, carbon monoxide, carbon dioxide, hydrogen, nitrogen, and others. As the non-carbon atoms are expelled, the remaining carbon atoms

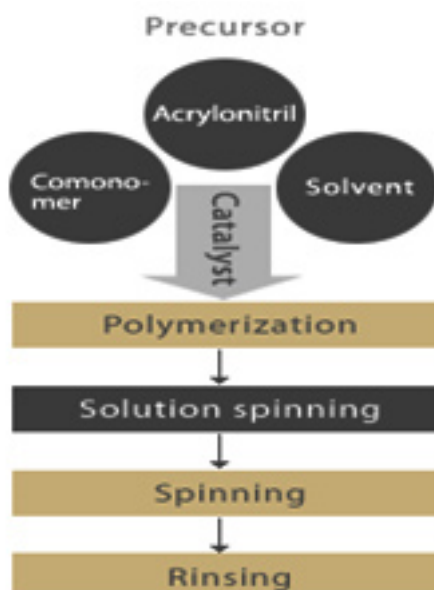
form tightly bonded carbon crystals that are aligned more or less parallel to the long axis of the fiber. In some processes, two furnaces operating at two different temperatures are used to better control the rate of heating during carbonization.

Treating the surface

After carbonizing, the fibers have a surface that does not bond well with the epoxies and other materials used in composite materials. To give the fibers better bonding properties, their surface is slightly oxidized. The addition of oxygen atoms to the surface provides better chemical bonding properties and also etches and roughens the surface for better mechanical bonding properties. Oxidation can be achieved by immersing the fibers in various gases such as air, carbon dioxide, or ozone; or in various liquids such as sodium hypochlorite or nitric acid. The fibers can also be coated electrolytically by making the fibers the positive terminal in a bath filled with various electrically conductive materials. The surface treatment process must be carefully controlled to avoid forming tiny surface defects, such as pits, which could cause fiber failure.

Sizing

- After the surface treatment, the fibers are coated to protect them from damage during winding or weaving. This process is called sizing. Coating materials are chosen to be compatible with the adhesive used to form composite materials.



Typical coating materials include epoxy, polyester, nylon, urethane, and others.

- 8 The coated fibers are wound onto cylinders called bobbins. The bobbins are loaded into a spinning machine and the fibers are twisted into yarns of various sizes.

Properties

Carbon Fiber has High Strength to Weight Ratio (also known as specific strength) Strength of a material is the force per unit area at failure, divided by its density. Any material that is strong AND light has a favourable Strength/weight ratio. Materials such as Aluminium, titanium, magnesium, Carbon and glass fiber, high strength steel alloys all have good strength to weight ratios.

Carbon Fiber is very Rigid

Rigidity or stiffness of a material is **measured by its Young Modulus** and measures how much a material deflects under stress. Carbon fiber reinforced plastic is over 4 times stiffer than Glass reinforced plastic, almost 20 times more than pine, 2.5 times greater than aluminium.

Carbon fiber is Corrosion Resistant and Chemically Stable

Although carbon fiber themselves do not deteriorate, Epoxy is sensitive to sunlight and needs to be protected. Other matrices (whatever the carbon fiber is imbedded in) might also be reactive.

Carbon fiber is Electrically Conductive

This feature can be useful and be a nuisance. In Boat building It has to be taken into account just as Aluminium conductivity comes into play. Carbon fiber conductivity can facilitate Galvanic Corrosion in fittings. Careful installation can reduce this problem.

Fatigue Resistance is good

Resistance to Fatigue in Carbon Fiber Composites is good. However **when carbon fiber fails it usually fails catastrophically** without much to announce its imminent break. Damage in tensile fatigue is seen as reduction in stiffness with larger numbers of stress cycles, (unless the temperature is high) Test have shown that failure is unlikely to be a problem when cyclic stresses coincide with the

fiber orientation. Carbon fiber is superior to E glass in fatigue and static strength as well as stiffness.

Carbon Fiber has good Tensile Strength

Tensile strength or ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before necking, or failing. Necking is when the sample cross-section starts to significantly contract. If you take a strip of plastic bag, it will stretch and at one point will start getting narrow. This is necking. It is measured in Force per Unit area. Brittle materials such as carbon fiber does not always fail at the same stress level because of internal flaws. They fail at small strains.

Testing involves taking a sample with a fixed cross-section area, and then pulling it gradually increasing the force until the sample changes shape or breaks. Fibers, such as carbon fibers, being only 2/10,000th of an inch in diameter, are made into composites of appropriate shapes in order to test.

Fire Resistance/Non Flammable

Depending upon the manufacturing process and the precursor material, carbon fiber can be quite soft and can be made into or more often integrated into protective clothing for firefighting. Nickel coated

fiber is an example. Because carbon fiber is also chemically very inert, it can be used where there is fire combined with corrosive agents. Carbon Fiber Fire Blanket excuse the typos.

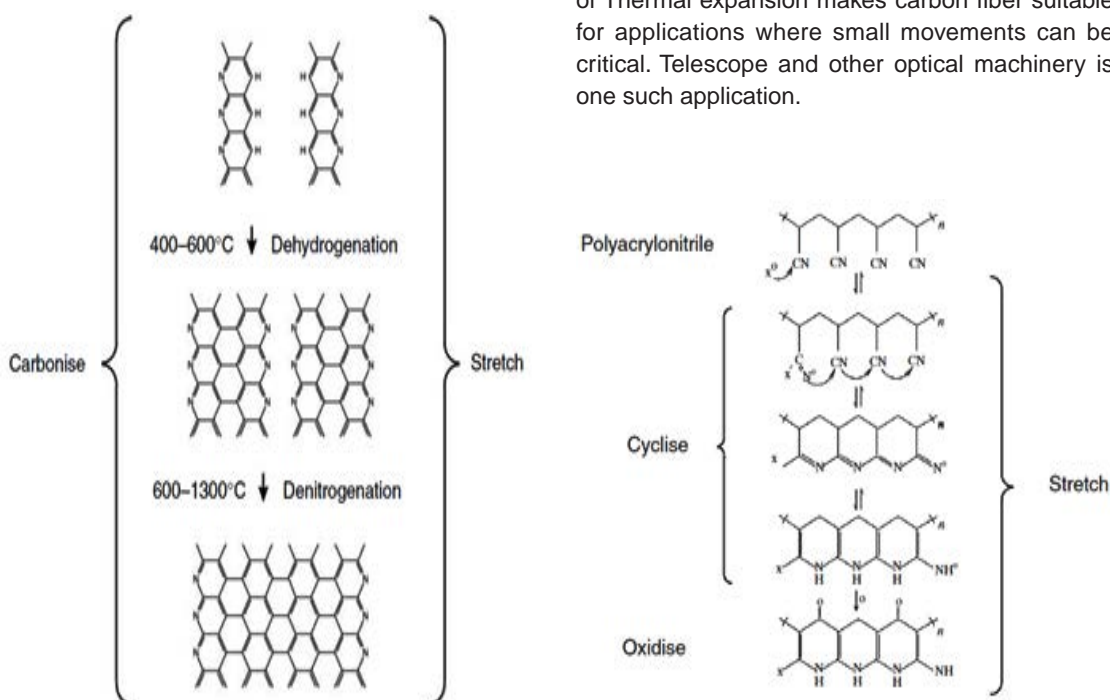
Thermal Conductivity of Carbon Fiber

Thermal conductivity is the quantity of heat transmitted through a unit thickness, in a direction normal to a surface of unit area, because of a unit temperature gradient, under steady conditions. In other words its a measure of how easily heat flows through a material.

Because there are many variations on the theme of carbon fiber it is not possible to pinpoint exactly the thermal conductivity. Special types of Carbon Fiber have been specifically designed for high or low thermal conductivity. There are also efforts to Enhance this feature.

Low Coefficient of Thermal Expansion

This is a measure of how much a material expands and contracts when the temperature goes up or down. Units are in Inch / inch degree F, as in other tables, the units are not so important as the comparison. In a high enough mast differences in Coefficients of thermal expansion of various materials can slightly modify the rig tensions. Low Coefficient of Thermal expansion makes carbon fiber suitable for applications where small movements can be critical. Telescope and other optical machinery is one such application.



1. Physical strength, specific toughness, light weight	Aerospace, road and marine transport, sporting goods
2. High dimensional stability, low coefficient of thermal expansion, and low abrasion (GHz) precision	Missiles, aircraft brakes, aerospace antenna and support structure, large telescopes, optical benches, waveguides for stable high-frequency
3. Good vibration damping, strength, and toughness	Audio equipment, loudspeakers for Hi-fi equipment, pickup arms, robot arms
4. Electrical conductivity	Automobile hoods, novel tooling, casings and bases for electronic equipments, EMI and RF shielding, brushes
5. Biological inertness and x-ray permeability	Medical applications in prostheses, surgery and x-ray equipment, implants, tendon/ligament repair
6. Fatigue resistance, self-lubrication, high damping	Textile machinery, general engineering
7. Chemical inertness, high corrosion resistance	Chemical industry; nuclear field; valves, seals, and pump components in process plants
8. Electromagnetic properties	Large generator retaining rings, radiological equipment

Non Poisonous, Biologically Inert, X-Ray Permeable

These qualities make Carbon fiber useful in Medical applications. Prosthesis use, implants and tendon repair, x-ray accessories surgical instruments, are all in development. Although not poisonous, the carbon fibers can be quite irritating and long term unprotected exposure needs to be limited. The matrix either epoxy or polyester, can however be toxic and proper care needs to be exercised.

Carbon Fiber is Relatively Expensive

Although it offers exceptional advantages of Strength, Rigidity and Weight reduction, cost is a deterrent. Unless the weight advantage is exceptionally important, such as in aeronautics applications or racing, it often is not worth the extra cost. The low maintenance requirement of carbon fiber is a further advantage.

It is difficult to quantify cool and fashionable. Carbon fiber has an aura and reputation which makes consumers willing to pay more for the cachet of having it. You might need less of it compared to fiberglass and this might be a saving.

Carbon Fibers are brittle

The layers in the fibers are formed by strong covalent bonds. The sheet-like aggregations readily allow the propagation of cracks. When the fibers bend they fail at very low strain.

Applications

Characteristics and Applications of Carbon Fibers

CONCLUSION

The latest development in carbon fiber technology is tiny carbon tubes called nanotubes. These hollow tubes, some as small as 0.00004 in

(0.001 mm) in diameter, have unique mechanical and electrical properties that may be useful in making new high-strength fibers, submicroscopic

test tubes, or possibly new semiconductor materials for integrated circuits.

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