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Analysis of Carbon Fiber

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A B S T R A C T

For many years, scientists worldwide have been looking for a wonder material that can fulfill all the needs of "raw" material needed in many industries, and all fingers after decades of research points towards Carbon Fiber. Carbon atoms bonded along the chain are the base material of Carbon fiber. They show various properties like being lightweight, robust, and a good conductor of electricity, and many more hence are used in many processes as basic building blocks. They come in various forms as the primary building material such as weaves, braids, yarns, and uni-directional, to name a few, which are used to create composite parts of various materials. With the weight that being of plastic and strength that being of steel, Carbon Fiber has proved itself to be the future raw material of various substances. Its high strength to weight ratio also makes it the most sought-after material in recent times.

Keywords: Carbon Fiber, Textile, Material, Yarn

1. Introduction

Carbon Fibers are made up of carbon atoms and are about 5-10mm in thickness. Although its efficient mass production is still a topic of ongoing research, making it a little bit more expensive than other types of fibers like glass and plastic, it still finds itself being used in multidimensional fields like aviation, automobile, telecommunication, and civil industries due to it being light, having high stiffness and high tensile strength along with high chemical resistance and temperature tolerance.

Figure 1: Threads of Carbon Fiber wrapped together

(Image Source: www.blendernation.com)

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2. Classification and Types

Carbon fibers can be classified on the basis of modulus, strength, and final heat treatment temperature:

2.1 On the basis of Carbon Fiber properties-

- Super high-tensile
- Ultra high modulus
- High modulus
- Intermediate modulus
- Low modulus and High tensile

2.2 On the basis of precursor fiber materials-

- PAN (Polyacrylonitrile) 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.

2.3 On the basis of final heat treatment temperature-

- High Heat Treatment carbon fibers (HTT), where final heat treatment temperature should be more than 2000°C and can be related with high-modulus type fiber.
- Intermediate Heat Treatment carbon fibers (IHT), where final heat treatment temperature should be around or more than 1500°C and can be related with high-strength type fiber.
- Low Heat Treatment carbon fibers (LHT), where final heat treatment temperatures is not more than 1000°C. These are low modulus and low strength materials.

3. Manufacturing Process of making Carbon Fibers from Polyacrylonitrile (PAN):

3.1 Raw Materials used-

Carbon Fiber is made up of raw material called precursor. The main component of Carbon Fiber of Polyacrylonitrile (around 90%) and the rest is made up of petroleum pitch or rayon. Carbon Fibers are organic molecules and are characterised by a long chain of molecules bound by carbon atoms. Various liquids and gases are used during the manufacturing process depending upon the properties desired in the final product**.**

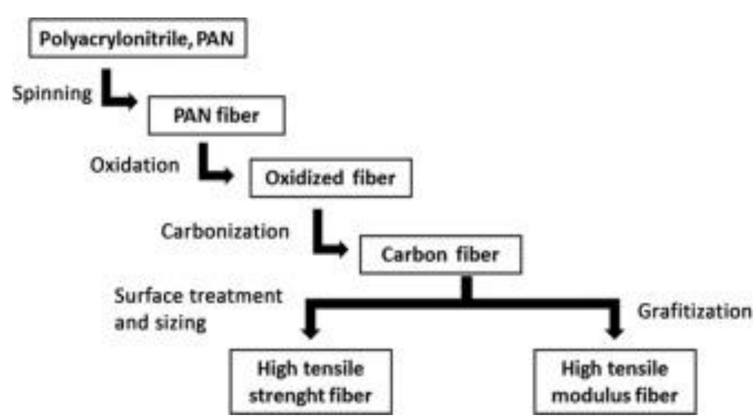

Figure 2: The Manufacturing Process PAN

Image Source: **www.sciencedirect.com**

3.2 Spinning

- Acrylonitrile plastic powder is blended with another plastic, like methyl acrylate or methyl methacrylate, and is reacted with a catalyst in a regular suspension or solution polymerization process to shape a polyacrylonitrile-plastic.
- In other techniques, the plastic mixture is warmed and pumped through tiny jets into a chamber where the solvents dissipate, leaving a solid fiber behind. This is an essential process as the internal atomic structure is formed during the process of spinning.
- After this, the fibers are washed and stretched to their desired width. This process helps in more substantial bond formation as the molecules get aligned within the fiber.

3.3 Stabilizing

Before the carbonization of Carbon Fibers, they are heated in air at around 200-300 C for about an hour so that the fiber can pick up oxygen molecules from the air and form a more thermally stable ladder bonding. This process is achieved with various tools and equipment like heated chambers and hot rollers, to name a few.

3.4 Carbonizing

After the stabilization process, the intermediate is heated at around 100-300 C in the absence of oxygen, and the pressure inside the chamber is kept higher than that of outside. The absence of oxygen prevents the fibers from burning at such high temperatures. As the temperature is increased and the fibers start to heat, they lose the non-carbon atoms in the form of various gases like H20, CO2, and CO. As the non-carbon atoms are lost along with some carbon atoms, the remaining carbon atoms align themselves in tightly formed carbon crystals which is more or less parallel to the axis of the fiber.

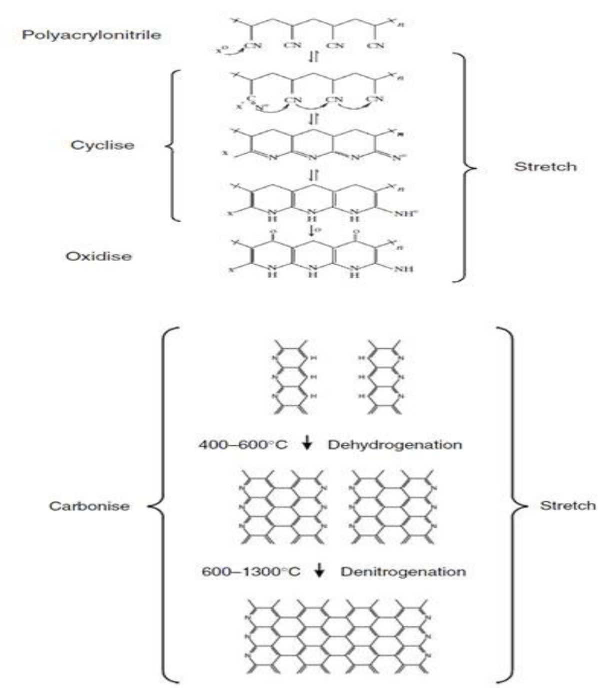

Figure 3: Chemical Reaction that happen during the process

Image Source: www.materialsciencejournal.org

3.5 Treating the surface

The intermediate formed after the previous process does not surfaces that are smooth enough to bond well with the epoxies and other materials used during the utilization of Carbon Fiber. To give it some better bonding properties, they are oxidized a little bit with oxygen. This can be achieved by either immersing the intermediate in gases like air, ozone or by dipping it in liquids such as nitric acid. Surface Coating through electrolysis is also a method that can be used but with great precautions.

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3.6 Sizing

- In the process of Sizing, Carbon Fibers are coated with coating materials like epoxy and polyester, which are compatible with the adhesive used in the process of forming composites.
- "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."[9]

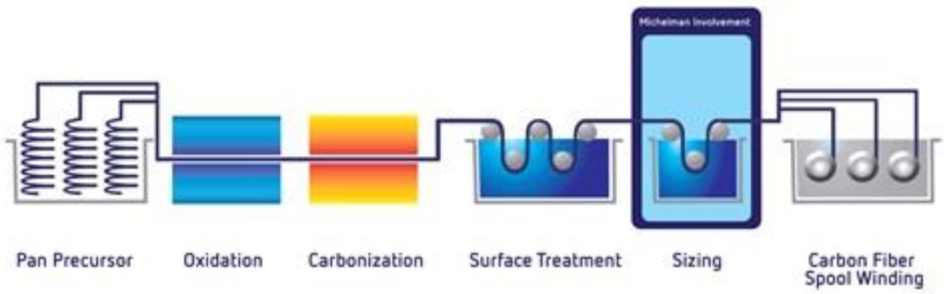

Figure 4: Complete Cycle used for the formation of Carbon Fiber
Image Source: www.azom.com

4. Properties

4.1 Carbon Fiber has High Specific Strength

Carbon Fibers have a good STRENGTH/WEIGHT ratio, making them capable of carrying a large load despite being not heavy without the fiber reaching its breaking point. Other materials that have good strength are Aluminium, High strength steel alloys, Titanium to name a few.

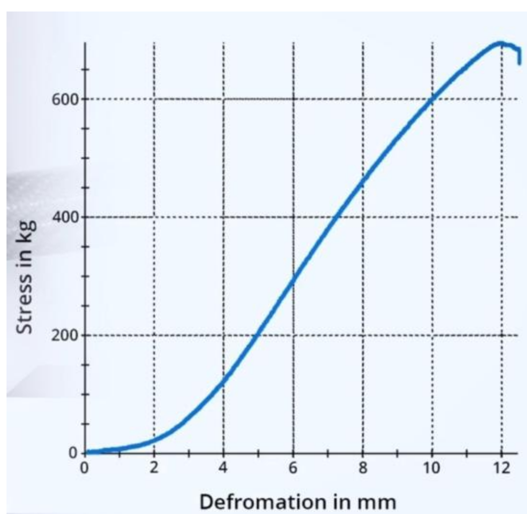

Figure 5: Curve showing the high stress capacity of Carbon Fiber
Image Source: www.easycomposites.uk

4.2 Carbon Fiber is very Rigid

Carbon Fibers have excellent stiffness or Rigidity, which means that they don't reflect much under high stress, which in turn is measured by Young's Modulus. Carbon fiber reinforced plastic is stiffer than Glass-reinforced plastic, pine, and aluminium.

4.3 Carbon fiber is Chemically Stable

Carbon Fibers are Chemically inert and Corrosion resistant; hence do not deteriorate with time, although epoxy and other matrices in which carbon is embedded may be reactive and needs to be protected.

4.4 Carbon fiber is Electrically Conductive

Carbon Fibers are highly conductive, and heat loss during transmission is also comparatively less than other materials, which make it a suitable material to be used in chargers; however, this ability can also be a bane in boat building where like Aluminium, it can facilitate Galvanic corrosion in the fitting;

therefore it has to be taken into account before the installation.

4.5 Carbon Fiber has good Tensile Strength

Carbon Fibers can withstand a large amount of stress while it is being stretched or pulled before its starts necking or failing, i.e., the cross-section of the sample starts to reduce dramatically. It is usually tested by taking carbon Fiber of definite width and then stretching it gradually until the sample changes the shape or breaks. Due to its internal flaws, the carbon Fiber never breaks at constant value but instead fails at minor strains. This property makes them a desirable raw material for various industries.

4.6 Fire Resistance/Non Flammable

Due to their flexible nature, the Carbon Fibers can be pretty soft and can be integrated into the materials of protective clothing made for firefighters. Its property of being chemically inert also helps in using it when the fire is combined with some corrosive agents to protect from both fire and any hazardous chemical reaction. Nickel-coated Carbon Fiber is a famous example of it being used in firefighting equipment.

4.7 Thermal Conductivity of Carbon Fiber

Thermal Conductivity is a measure of how effectively can heat can flow through a material. Due to so many Carbon Fiber variations, different forms can be used to achieve both high and low thermal Conductivity depending upon the requirement.

4.8 Low Coefficient of Thermal Expansion

The coefficient of thermal expansion is a measure of much a material expands or contracts depending upon the temperature variation. Carbon Fibers have a low thermal expansion coefficient, making them suitable for parts where even a tiny movement can be critical, like in a telescope or any other optical type of machinery.

4.9 Non Poisonous, Biologically Inert, X-Ray Permeable

Due to the properties mentioned above, Carbon Fibres have a variety of uses in Medical appliances like implants, tendon repair, X-ray accessories, and various other surgical instruments. Although Carbon Fibers are non-toxic yet their exposure should be limited due to the presence of other polyesters and epoxy in it.

4.10 Fatigue Resistance is good

The resistance to Fatigue ratio in Carbon Fiber Composites is very good than compared to any other materials.

5. Characteristics and Applications of Carbon Fibers

CHARACTERISTICS	APPLICATIONS
Physical strength, light weight , specific toughness	They are used in Aerospace industry, road and marine transportation sector and for making sporting goods.
High dimensional stability, low abrasion, low coefficient of thermal expansion	They are used for the manufacturing of Missiles, aircraft brakes, large telescopes, aerospace antenna and support structure, optical benches.
Good vibration damping ability, strength, and toughness	Useful in Audio equipment, loudspeakers for Hi-fi equipment along with pickup and robot arms
Electrical conductivity	Automobile hoods, novel tooling, casings and bases for electronic equipments, EMI and RF shielding, brushes
Biological inertness and X-ray permeability	Medical applications in prostheses, surgery and x-ray equipment, implants, tendon/ligament repair
Fatigue resistance, self-lubrication, high damping	It is extremely useful in the Textile machinery.
High corrosion resistance , Chemical inertness	It finds various uses in Chemical industry; nuclear field along with valves, seals, and pump components for processing plants
Electromagnetic properties	Carbon Fiber is used in the making of Large generator retaining rings and various radiological equipment

6. Conclusion

For the most part of the century, scientists worldwide have been looking for the next breakthrough element, and Carbon Fiber has proved to be the front runner in that race. With the plethora of applications like in batteries, the aviation industry, and the automobile industry and advantages over the current element being used in these industries, Carbon Fiber is expected to overshadow all other compounds in the near future. Although in the current times, its scope of mass synthesis is limited due to which it is costly, but slowly and steadily, efforts are being made to work on the problems that are stopping Carbon Fiber from booming. In a nutshell, the authors can't emphasize strongly enough that the future is of Carbon Fiber.

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