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Application of Carbon Fibers in Construction

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Abstract

Carbon fibers (also known as graphite fibers) are high-performance fibers, about five to ten micrometers in diameter, composed mainly of carbon, with high tensile strength. Plus, they are extremely strong with respect to their size. They have high elastic modulus in comparison with glass fiber. According to the working period, carbon fiber-reinforced polymers possess more potential than those with glass fiber. However, they are relatively expensive as compared to similar fibers, such as glass fiber, basalt fiber, or plastic fiber. Its high quality, light weight, and imperviousness to erosion, make it a perfect strengthening material. Carbon fiber-reinforced composite materials are used to make aircraft parts, golf club shafts, bike outlines, angling bars, car springs, sailboat masts, and several different segments which need to have less weight and high quality.

Keywords

Carbon fibers, polymers, construction, FRC

1. Introduction

Carbon fiber has a high 'strength to weight' ratio. Any material that is solid and light has a good strength/weight proportion. Materials like carbon and glass fiber, aluminum, titanium, magnesium, high quality steel combinations, all have a great quality to weight proportions.

a. Carbon fiber is extremely inflexible. Carbon fiber fortified plastic is more than four times stiffer than glass strengthened plastic, just about 20 times more than pine.

b. Carbon fiber is corrosion proof and chemically stable. Regardless of the way that carbon fiber themselves don't deteriorate, epoxy is fragile to light and ought to be secured.
c. Carbon fiber is electrically conductive. This element can be valuable and be an aggravation. Carbon fiber conductivity can encourage galvanic corrosion in fittings. The watchful establishment can decrease this issue.
d. Resistant to fire, depending on the gathering procedure and forerunner material, carbon fiber can be made into or often merged into defensive attire for firefighting.

2. Brief History

a. Carbon fiber was first produced by Joseph Swan in 1860 to be used in a light bulb.
b. In the early 1960s, carbon fibers were used in aircraft to make them withstand high temperatures in the atmosphere.
c. Between the 1960s and 1980s, they were mainly produced for defense purposes, and were used in NASCAR and formula 1 cars to make them lighter and more efficient.
d. In the early 21st century, due to increased demand, production expanded in various industries. Production capacities expanded in Asia, Europe, and the United States.
e. Despite the recession in 2007-2008, worldwide demand increased to nearly 40,000 metric tons in 2010.
f. The American Chemical Society named the advancement of high-performance carbon fibers a National Historic Chemical Landmark in September 2003
g. The National Academy of Engineering voted carbon fibers one of the top 20 engineering achievements of the 20th century.

3. Carbon Fiber Composites

Carbon fiber is usually combined with other materials to make a composite. It comprises very thin filaments of carbon fibers bounded with plastic polymer like resin, using heat or pressure. The resulting material has both strength and light weight. Carbon fibers are generally woven, which determines their strength. The composite will be more durable if the weave is more complex. The overall strength of composite is governed by the angle of weaves and resin used with the fiber. The resin used can be epoxy, thermoplastic, vinyl ester, or polyurethane. Since it can be formed at different densities, in unlimited shapes and sizes, it has a wide range of applications. It can be made into tubes, fabrics, or can be customized into composite parts.

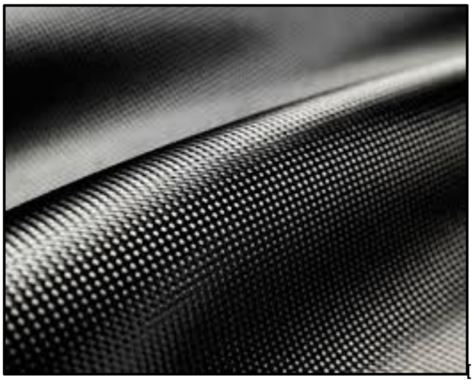

Figure 1. Carbon Fiber composite

4. Carbon Fiber Manufacturing Processes

The basic processes of carbon fiber manufacturing are:

4.1. Precursor

The manufacturing begins with a precursor in the form of fibers, typically PAN (polyacrylonitrile). These fibers are heated and carbonized to create carbon fiber. After the carbonization process, the fibers are wound onto coils, then further processed for use in industrial applications such as:

- aerospace materials
- sports equipment
- medical devices
- parts for electric vehicles
- robotic components

4.2. Carbonization

This process involves heating the carbon fibers, assembled into strands called “tows,” in an inert atmosphere, at a temperature of 1000-3000 degrees Celsius to convert them to graphite. Non-carbon elements such as hydrogen and oxygen are driven from the fibers through heating, and a portion of the remaining carbon content is converted into graphite. This stage takes several hours to complete and is very expensive.

4.3. Weaving and Braiding

At the end of carbonization process, the carbon fiber tow is wound on bobbins. These bobbins are then processed into multiple formats, which include:

- Cloth is woven in multiple weaves and densities
- Braided tubes and sheets
- Unidirectional ribbons
- Prepreg - all the above pre-wetted with epoxy, partially cured, then frozen

4.4. Moulding

The final step in the process involves moulding the carbon fiber into different structures such as: sheets, tubes, rods, angles, or complex carbon fiber parts. This is typically accomplished by placing the fiber wetted with epoxy, or a pre-wet prepreg, in a tool and curing it with heat. After the cure cycle, the moulded part is removed from the tool and trimmed to its final shape.

5. Carbon Fiber Composite Manufacturing Processes

There are several different manufacturing processes for carbon composites including filament winding, pultrusion, wet lay-up, vacuum bagging, resin transfer, and matched tooling. The process chosen depends on the application of the composite.

5.1. Filament Winding

In this, the fibers are wound around a rotating spindle. This process is perfect for making structural components with smooth curved surfaces like racing car bodies and kayaks. It also permits engineers to easily control where the reinforcement is placed in the finished product.

5.2. Pultrusion Processes

These processes create carbon fiber composites by pulling a resin-impregnated roving through a bath of heated resin to create specific sizes and shapes. How carbon fiber composites manufactured with this method are made is largely dependent on the desired product's properties and use.

5.3. Wet Layup / Vacuum Bagging / Resin Transfer

In these processes, carbon fiber cloth or unidirectional material, wetted with epoxy, is placed on a tool shaped as the desired part. With wet layup, the excess resin is mechanically removed, typically with a flexible scraper or sponge. With vacuum bagging, a bag or film is positioned over the part and the excess resin is removed by vacuum. With resin transfer, the resin is transferred by vacuum into the part after the carbon fiber cloth and bag are assembled on the tool.

6. Advantages and Disadvantages

6.1. Advantages

- Low weight of carbon fiber composites leads to energy savings.
- Due to low thermal expansion, they are used in optics and for military purposes.
- They do not block X-rays and are widely used for production of X-ray scanning systems.
- With unique appearance, they are used in the automotive industry and for design purposes.

6.2. Disadvantages

- The process of production of carbon fiber composites takes time and generates high costs.
- They offer poor/uncertain resistance to impacts.
- Carbon fiber composite parts are often beyond repair or repair is difficult and costly.
- They may catch fire if exposed to fire for a period.

7. Applications of Carbon Fiber

7.1. Civil Engineering

Some auxiliary building applications use carbon fiber strengthened polymer on account of its potential development advantages and adequate cost. The standard applications include fortifying structures made with steel, timber, brick work, or cast iron; retrofitting or expanding the heap limit of old structures to upgrade shear quality and flexure in fortified solid structures.

7.2. Medical Industry

Because it is biologically inert and permeable to x-rays, carbon fiber composites are ideal for use in prosthetics, implants, and surgical equipment. Medical imaging tables made from the fiber maintain critical dimensions even after high doses of x-ray and gamma radiation. Also, its composites have very low coefficients of thermal expansion, prompting their application in products such as telescopes, optical benches, and precision measurement tools.

7.3. Musical Industry

The music industry is also finding applications of carbon fiber’s unusual properties. Along with its high dimensional stability and resistance to humidity, it exhibits low damping to vibration. This characteristic combined with high stiffness to weight can improve the resonance of an instrument. Musical instruments made using carbon fiber offer a full, rich sound, provide greater acoustic volume, and are unaffected by changes in ambient conditions.

7.4. Aerospace Industry

Carbon fiber is utilized broadly in spacecraft segments and structures, where its properties beat those of any metal. 30% of all carbon fiber is used as part of the aerospace business. From helicopters or warrior planes to lightweight planes, carbon fiber has its influence, expanding range and streamlining support.

7.5. Sports Industry

Applications of carbon fiber in sports merchandise has a wide range, from racing cars to bicycle frames, hardening of running shoes to ice hockey stick, tennis racquets and golf clubs to fishing rods, etc. It is used as part of crash caps as well, for climb-ers, horse riders and engine cyclists – in fact in any game where there is a peril of head harm.

(a)

(b)

(c)

(d)

(e)

(f)

Figure 2. Applications of carbon fiber

8. Applications in Construction

8.1. Carbon Fiber in Precast Concrete

Reinforced concrete is cement in which bars (rebars) or fibers have been incorporated to strengthen them, else they would be brittle. The most widely used form of enhancement is welded-wire fabric, a mesh of steel wires placed in cement. These reinforcing methods are incorporated into cement when it is made. But when existing structures crack or the initial construction did not account for additional strength needed for unpredictable situations, then rebar or other reinforcing materials can't be added to them. A carbon fiber grid is used in the panel faces to replace steel mesh reinforcement, and as a mechanical link to the outer and inner sections of a concrete wall. Replacing welded grid with carbon fiber grid allows less use of concrete, which reduces weight and the need of protection from chemicals.

8.2. Carbon Fiber - Reinforced Asphalt

Paving materials like hot-mix asphalt (HMA) provide cost efficient methods for surfacing roads, airfields, and improving world's transport infrastructure system. However, like other materials, HMA is also affected by distress mechanisms, which lead to corrosion and fail with respect to time. This is caused by factors which include the magnitude and type of load, interaction of material with other materials and climatic conditions. Major distresses include cracking, raveling, and permanent deformation. Including fibers in paving materials reinforces the material by adding tensile strength to it, which results from aggregate interconnections. It allows the material to bear more strain. Researchers have been experimenting with various types of fiber reinforcements which include carbon, glass, polyester, Kevlar, etc. Also, the fiber reinforcement of HMA has resulted in a blend of several fibers, made to achieve different characteristics.

8.3. Bridge Construction

Another field making use of carbon fiber is bridge construction. Since 1992, many footbridges were built mostly from fiber reinforced compounds. The main purpose for the application of carbon fiber-reinforced plastic was to provide weight reduction and economy of lifting equipment.

9. Conclusion

Carbon fiber technology continues to advance with the demand for higher performance. Carbon fiber composites are an excellent manufacturing material for many mechanisms because of their ability to provide unique physical properties, depending on where the carbon fibers are placed in finished products. How each component is manufactured depends upon how much rigidity or reinforcement it needs, and ultimately this process comes down to the desired product's use. While many industries have found applications for carbon fiber in their end products, it is also important to note that this material plays a significant role within the manufacturing process too. Tools made with carbon fiber composites can be 50% lighter than those made from conventional materials. Inspection tools and machine parts that were earlier moved with heavy equipment can be lit with carbon fiber, making them easier to handle and move. Industries using robotics and other automated systems are replacing metal-end effectors with carbon fiber composite ones, that allow the automation to move faster and more precisely, lift heavier parts, and reduce the motor load on the equipment. As more and more industries have found ways of manufacturing this unique material, its price is likely to decrease in the coming future. It is expected that the research, experiments, and developments will lead to the use of similar effective materials in the field of construction.

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