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Carbon Fibre as a Recent Material Use in Construction for Superior Strength

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Abstract

Over the ages as we have evolved, so has our engineering and researching skill sets. Even today, we are constantly innovating, researching and developing technology in pursuit of a sustainable future. Throughout this evolution, researches and engineers have found themselves in constant search for new and better materials to optimally manage the performance cost tradeoff in the construction sector. Many new raw materials have been discovered and many ground-breaking composite have been developed, of which not all but some have proved to be a phenomenal success. Carbon fiber is one of these materials, which is usually used in combination with other materials to form a composite. The properties of carbon fiber, such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion makes them one of the most popular material in civil engineering possessing strength up to five times that of steel and being one-third its weight, we might as well call it 'the superhero' of the material world.

Keywords: carbon fiber, ground-breaking, high stiffness, high tensile strength, low weight, high chemical resistance.

I. Introduction

The 20th century saw a roller coaster ride in the demand for carbon fiber. Threats to peace increased the demand for carbon fiber for defense purposes mid-century [1]. A downturn in defense needs result in a reduction in production of carbon fiber toward the close of the century. By the beginning of the 21st century, new applications and new markets sent the production of carbon fibers on an upswing. Despite a downturn in 2007-2008, worldwide demand increased to approximately 40,000 metric tons in 2010. Carbon fibers have revolutionized the technology of materials. It is no wonder that the National Academy of Engineering voted carbon fibers [2] one of the 20 top engineering achievements of the 20th century and the American Chemical Society named the development of high performance carbon fibers a National Historic Chemical Landmark in September 2003.

My bachelor's thesis is devoted to applying carbon fiber for construction [3], renovation and structure reinforcing purposes. Carbon fiber is not an absolutely new material, it is successfully applied in such fields as: aviation and aerospace industry, car industry, production of sport equipment, production of working clothes and military accoutrements, electronic industry, etc. Rather new is the idea of using carbon fiber in building structures. At the present time methods of strengthening of the structures with fibers are applying for different structures. Also very prospective directions of using carbon fiber is fiber-concrete and fiber-cement, reinforced with carbon fibers, using carbon fiber as post-tension or pretension reinforcing bars in new reinforced concrete structures, applying polymeric and metal composites for structures. The main reason that carbon fiber is considered as construction material so rarely, is its high price, but the general trend of increasing production of carbon fiber and reducing its cost can said might change this situation in the construction industry.

Carbon fibers are a type of high-performance fiber available for civil engineering application. It is also called graphite fiber or carbon graphite, carbon fiber consists of very thin strands of the element carbon [4]. Carbon fibers have high tensile strength and are very strong for their size. In fact, carbon fiber might be the strongest material. Carbon fibers have high elastic modulus and fatigue strength than those of glass fibers. Considering service life, studies suggests that carbon fiber reinforced polymers have more potential than agamid and glass fibers. They also are highly chemically resistant and have high temperature tolerance with low thermal expansion. and corrosion resistance.

Each fiber is 5-10 microns in diameter. To give a sense of how small that is, one micron (um) is 0.000039 inches. One strand of spider web silk is usually between 3-8 microns. Carbon fibers are twice as stiff as steel and five times as strong as steel, (per unit of weight). . The most important factors determining the physical properties of carbon fiber are degree of carbonization (carbon content, usually more than 92% by weight) and orientation of the layered carbon planes (the ribbons).

Carbon fiber-reinforced composite materials [5] are used to make aircraft and spacecraft parts, racing car bodies, golf club shafts, bicycle frames, fishing rods, automobile springs, sailboat masts, and many other components where light weight and high strength are needed. Carbon fiber's high strength, light weight and resistance to corrosion make it an ideal reinforcing material.

II. PROPERTIES OF CARBON FIBER

1) 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 favorable Strength/weight ratio. Materials such as Aluminum, titanium, magnesium, Carbon and glass fiber, high strength steel alloys all have good strength to weight ratios. It is not surprising that Balsa wood comes in with a high strength to weight ratio.The following figures are offered for comparison only and will vary depending on composition, alloy, type of spider, density of wood etc. The units are kN.m/kg [6-7].

Table 1- Carbon Fiber has High Strength to Weight Ratio (also known as specific strength)

Spectra fiber	3619
Kevlar	2514
Carbon Fiber	2457
Glass Fiber	1307
Spider Silk	1069
Carbon Epoxy Composite	785
Balsa axial load	521
Steel alloy	254
Aluminum alloy	222
Polypropylene	89
Oak	87
Nylon	69

Note that strength and rigidity are different properties, strength is resistance to breaking, and rigidity is resistance to bending or stretching.

2) 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 aluminum. For more information on stiffness and how it is measured, plus a comparison table of different materials see my Young Modulus page.

3) 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.

4) 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 Aluminum conductivity comes into play. Carbon fiber conductivity can facilitate Galvanic Corrosion in fittings. Careful installation can reduce this problem. Carbon Fiber dust can accumulate in a shop and cause sparks or short circuits in electrical appliances and equipment.

5) 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 has 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.

The orientation of the fibers and the different fiber layer orientation, have a great deal of influence on how a composite will resist fatigue (as it has on stiffness). The type of forces applied also result in different types of failures. Tension, Compression or Sheer forces all result in markedly different failure results. Paper on test of carbon fiber composites intended for automotive use. American Institute of Aeronautics and Astronautics, test for materials to be used in wind turbines blades.

6) 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 do not always fail at the same stress level because of internal flaws. They fail at small strains. (in other words there is not a lot of bending or stretching before catastrophic failure)

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.Units are MPa this table is offered as a comparison only since there are a great number of variables.

Table 2- Carbon Fiber has good Tensile Strength

Carbon steel 1090	3600
High density polyethylene (HDPE)	37
Polypropylene	19.7-80
High density polyethylene	37
Stainless steel AISI 302	860
Aluminum alloy 2014-T6	483
Aluminum alloy 6063-T6	248
E-Glass alone	3450
E-Glass in a laminate	1500
Carbon fiber alone	4127
Carbon fiber in a laminate	1600
Kevlar	2757
Pine wood (parallel to grain)	40

7) 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 Blanket used as welding protection.

8) 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. There are a number of systems of measures depending on metric or imperial units.

1 W/(m.K) = 1 W/(m.oC) = 0.85984 kcal/(hr.m.oC) = 0.5779 Btu/(ft.hr.oF)

This table is only for comparison. The units are W/(m.K)

Table 3- Thermal Conductivity of Carbon Fiber

Air	.024
Aluminum	250
Concrete	0.4 -0 .7
Carbon Steel	54
Mineral Wool insulation	.04
Plywood	.13
Quartz	3
Pyrex Glass	1
Pine	12
Carbon Fiber Reinforced Epoxy	24

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.

9) 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.

Table 4- Low Coefficient of Thermal Expansion

Steel	7
Aluminum	13
Kevlar	3 or lower
Carbon Fiber woven	2 or less
Carbon fiber unidirectional	minus 1 to +8
Fiberglass	7-8

Carbon fiber can have a broad range of CTE's, -1 to 8+, depending on the direction measured, the fabric weave, the precursor material, Pan based (high strength, higher CTE) or Pitch based (high modulus/stiffness, lower CTE).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.

III. APPLICATIONS

Several structural engineering applications utilize carbon fiber reinforced polymer because of its potential construction benefits and cost effectiveness. The usual applications include strengthening structures made with concrete, steel, timber, masonry, and cast iron; Retrofitting to increasing the load capacity of old structures like bridges; to enhance shear strength and for flexure in reinforced concrete structures. Other applications include replacement for steel, prestressing materials and strengthening cast-iron beams.

Carbon fiber has gone to the moon on spacecraft, but it is also used widely in aircraft components and structures, where its superior strength to weight ratio far exceeds that of any metal. 30% of all carbon fiber is used in the aerospace industry. From helicopters to gliders, fighter jets to micro lights, carbon fiber is playing its part, increasing range and simplifying maintenance.

Its application in sports goods ranges from the stiffening of running shoes to ice hockey stick, tennis racquets and golf clubs. 'Shells' (hulls for rowing) are built from it, and many lives have been saved on motor racing circuits by its strength and damage tolerance in body structures. It is used in crash helmets too, for rock climbers, horse riders and motor cyclists – in fact in any sport where there is a danger of head injury.

The applications in the military are very wide ranging – from planes and missiles to protective helmets, providing strengthening and weight reduction across all military equipment. It takes energy to move weight – whether it is a soldier's personal gear or a field hospital, and weight saved means more weight moved per gallon of gas.

A new military application is announced almost every day. Perhaps the latest and most exotic military application is for small flapping wings on miniaturized flying drones, used for surveillance missions. Of course, we don't know about all military applications – some carbon fiber uses will always remain part of 'black ops' – in more ways than one.

The uses of carbon fiber in the home are as broad as your imagination, whether it is style or practical application. For those who are style-conscious, it is often tagged as 'the new black'. If you want a shiny black bathtub built from carbon

fiber, or a coffee table then you can have just that, off the shelf. iPhone cases, pens and even bow ties – the look of carbon fiber is unique and sexy.
Carbon fiber offers several advantages over other materials in the medical field, including the fact that it is 'radiolucent' – transparent to X-rays and shows as black on X-ray images. It is used widely in imaging equipment structures to support limbs being X-rayed or treated with radiation.
The use of carbon fiber to strengthen of damaged cruciate ligaments in the knee is being researched, but probably the most well known medical use is that of prosthetics – artificial limbs. South African athlete Oscar Pistorius brought carbon fiber limbs to prominence when the International Association of Athletics Federations failed to ban him from competing in the Beijing Olympics. His controversial carbon fiber right leg was said to give him an unfair advantage, and there is still considerable debate about this.

As costs come down, carbon fiber is being more widely adopted in automobiles. Supercar bodies are built now, but its wider use is likely to be in internal components such as instrument housings and seat frames.

CONCLUSIONS

Carbon fibre plates are thin, strong and flexible, they can be designed and installed to provide a cost effective solution which does not detract visually from the original design of the structure. It has high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and one of the most popular material in civil engineering. It possess strength up to five times that of steel and being one-third it weight. It has more applications in civil engineering, military, sporting goods, in medical, in automobile industry, etc. so use of carbon fiber in construction is always effective and provide high strength to the structure.

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