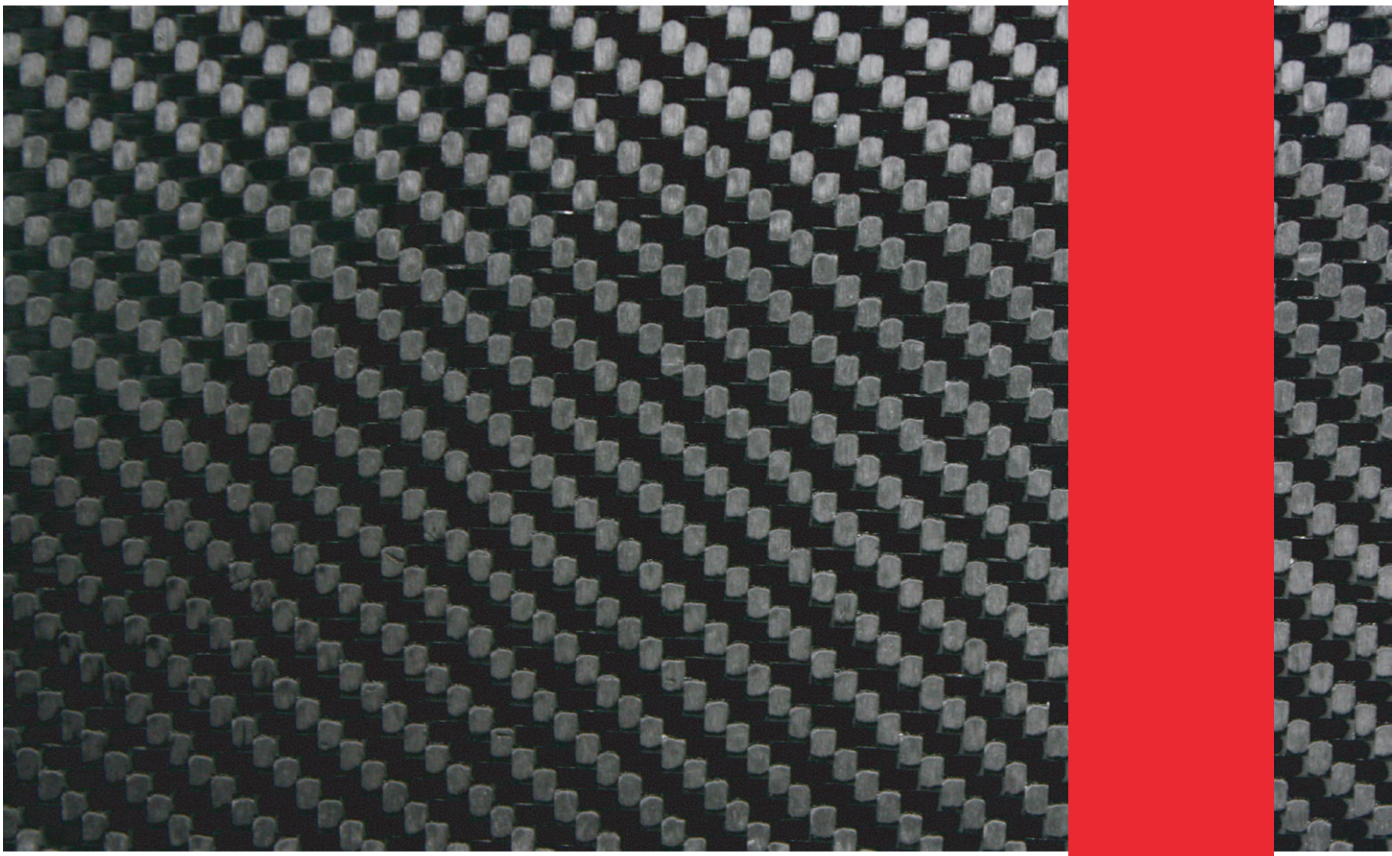
Element COMPOSITES



Ultimate Guide to Carbon Fiber Design and Application

www.element6composites.com

Element 6 Composites specializes in carbon fiber design, analysis, prototyping, and manufacturing. We are experts in carbon fiber composites and other high-performance materials. This guide will walk you through everything you need about carbon fiber design and application.

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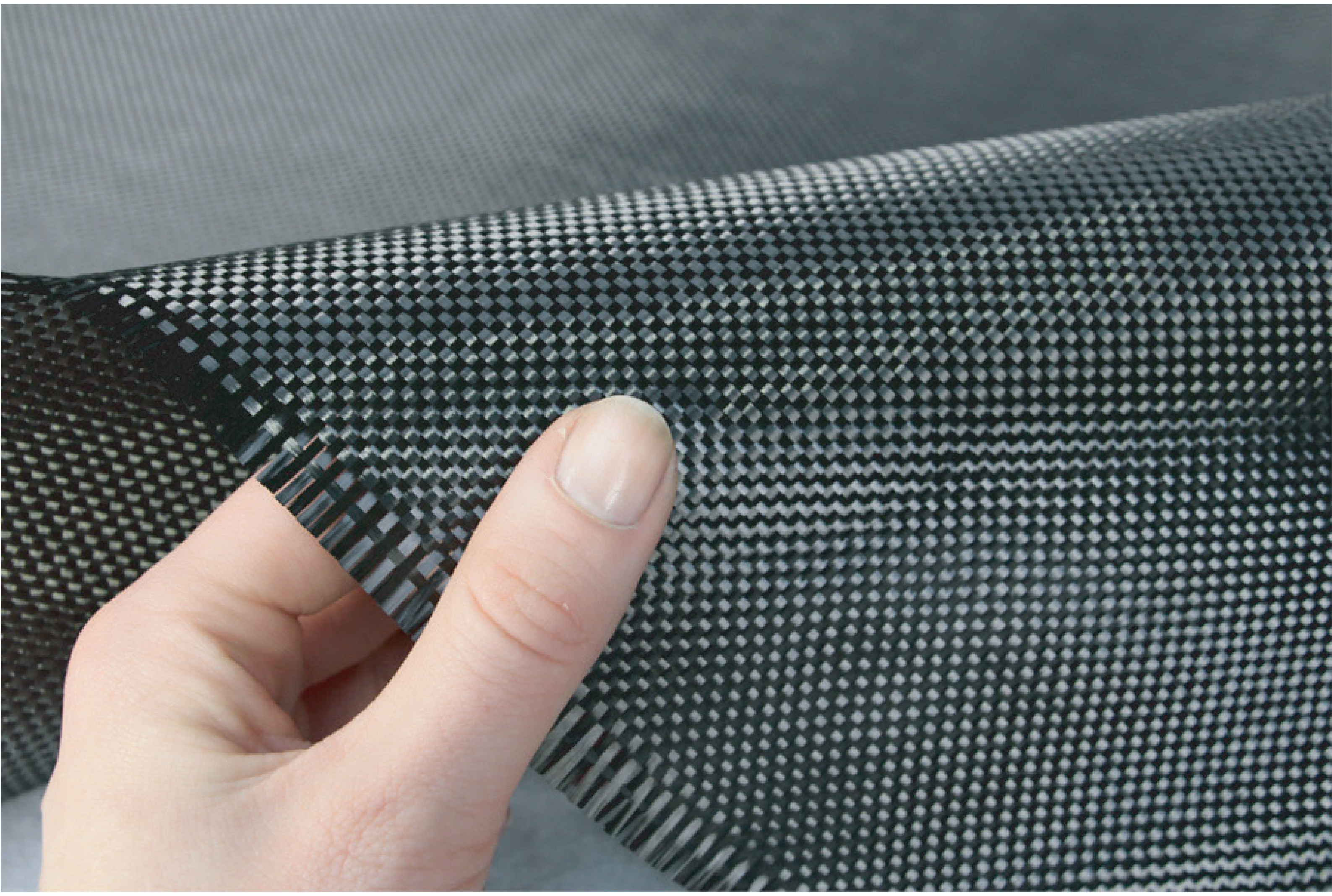
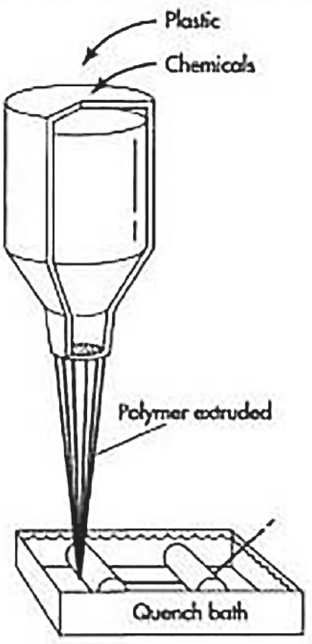
What is Carbon Fiber?



Carbon fiber is composed of strands of fibers 5 to 10 microns in diameter that consist of long, tightly interlocked chains of carbon atoms in a microscopic crystalline structure. These fibers are extremely stiff, strong, and light, and are used in many processes to create high-performance building materials. Carbon fiber reinforcements come in a variety of weaves, braids, and other formats such as tow, and uni-directional. These are combined with various resins to produce carbon fiber-reinforced composites in a wide range of shapes and fiber patterns.

How is Carbon Fiber Made?

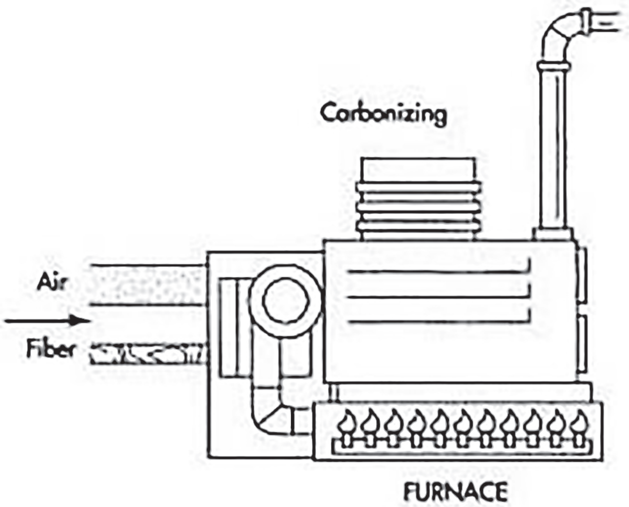
Step 1: Precursor



To produce carbon fiber, an organic polymer precursor is needed. This raw material is processed with heat and chemical agents to convert it to carbon fiber. The first high-performance carbon fiber materials were made from a rayon precursor.

Currently, approx 90% of carbon fiber is made from polyacrylonitrile, while the other 10% or so is made from rayon or petroleum pitch.

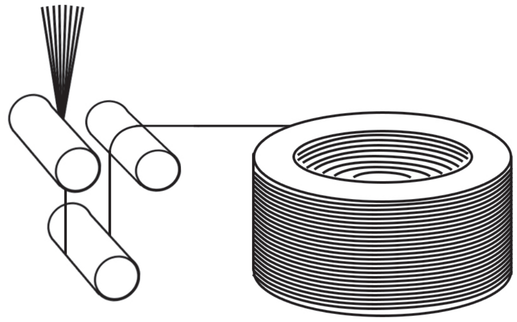
Step 2: Manufacturing



The carbon fiber manufacturing process begins with carbonization. To achieve high-quality carbon fiber, the precursor polymer needs to contain a high percentage of carbon atoms. The majority of the non-carbon atoms within the structure will be removed in the process.

First, the precursor is pulled into long fibers. These fibers are then heated to very high temperatures in an anaerobic gas mixture (without the presence of oxygen) to ensure the material doesn't burn. The heat energizes the atomic structure of the fibers and drives off most of the non-carbon atoms from the material.

Step 3:



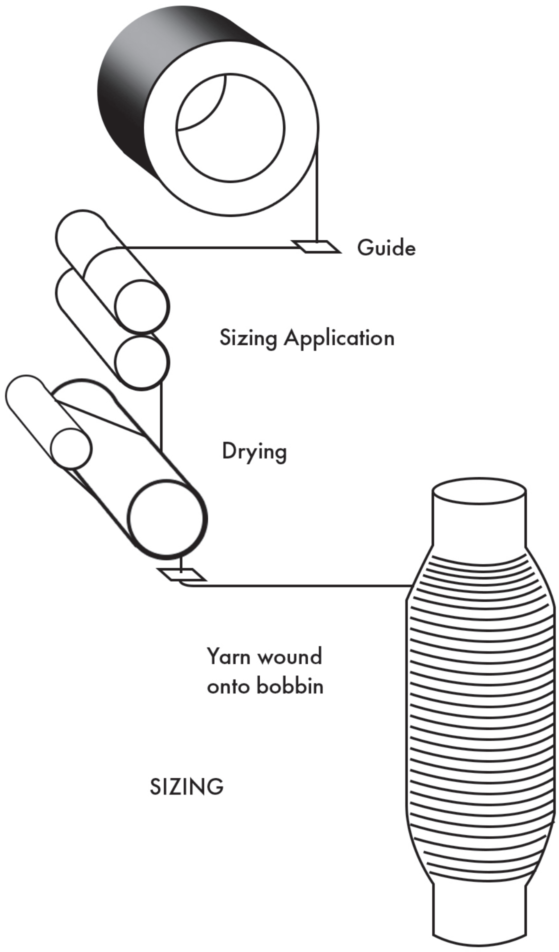
OXIDATION

Following carbonization, the surface of the carbon fibers must be treated to improve bondability with epoxies or other resins. Careful oxidation of the surface of the carbon fibers improves chemical bonding properties, while simultaneous roughening of the surface provides improved mechanical bonding.

This oxidation can be accomplished in a number of different ways. The carbon fiber can be exposed to various gases such as carbon dioxide or ozone, or liquids such as nitric acid, or even processed electrolytically.

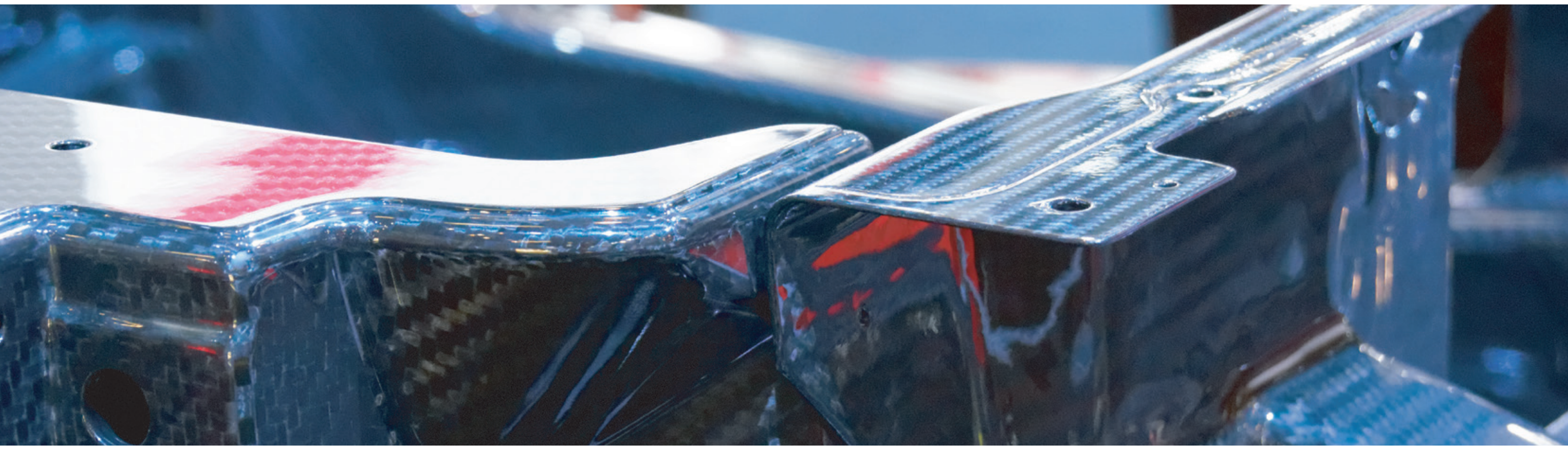
Step 4:

Prior to weaving, the carbon fibers must be sized, or coated, with a polymer to protect them during the weaving process. The sizing is selected for compatibility with the laminating resin to be used. The fibers are then wound onto bobbins, spun, and processed into various weaves and other formats



SIZING

Why Would You Use Carbon Fiber as Opposed to Another Material?



Reason 1: Strength

The primary reason why one would consider the use of carbon fiber is its high stiffness to weight ratio. Carbon fiber is very strong, very stiff, and relatively light.

The stiffness of a material is measured by its **modulus of elasticity**. The modulus of carbon fiber is typically 34 MSI (234 Gpa). The ultimate tensile strength of Carbon Fiber is typically 600-700 KSI (4-4.8 Gpa). Compare this with 2024-T3 Aluminum, which has a modulus of only 10 MSI and ultimate tensile strength of 65 KSI, or with 4130 Steel, which has a modulus of 30 MSI and ultimate tensile strength of 125 KSI.

High and Ultra-High Modulus carbon fiber or High Strength carbon fiber are also available due to refinements in the materials and processing. A composite carbon fiber part is a combination of carbon fiber and resin, which is typically epoxy. The strength and stiffness of a carbon fiber composite part will be the result of the combined strengths and stiffnesses of both the fiber and the resin. The magnitude and direction of local strength and stiffness of a composite part are controlled by the local fiber density and orientation in the laminate.

It is typical in engineering to quantify the benefit of structural material in terms of its strength to weight ratio (**Specific Strength**) and its stiffness to weight ratio (**Specific Stiffness**), particularly where reduced weight relates to improved performance or reduced life cycle cost.

A carbon fiber plate fabricated from standard modulus plain weave carbon fiber in a balanced and symmetric 0/90 layup has an elastic bending modulus of approx. 10 MSI. It has a volumetric density of about .050 lb/in3. Thus the stiffness to weight ratio or Specific Stiffness for this material is 200 MSI The Strength of this plate is approx. 90 KSI, so the Specific Strength for this material is 1800 KSI.

By comparison, the bending modulus of 6061 aluminum is 10 MSI, the Strength is 35 KSI, and the volumetric of density is 0.10 lb/in3. This yields a Specific Stiffness of 100 MSI and a Specific Strength of 350 KSI. 4130 steel has a stiffness of 30 MSI, a strength of 125 KSI and a density of .3 lb/in3. This yields a Specific Stiffness of 100 MSI and a Specific Strength of 417 KSI. This is shown in the table below.

Material	Specific Stiffness	Specific Strength
Carbon Fiber	200 MSI	1800 KSI
6061 Aluminum	100 MSI	350 KSI
4130 Steel	100 MSI	417 KSI

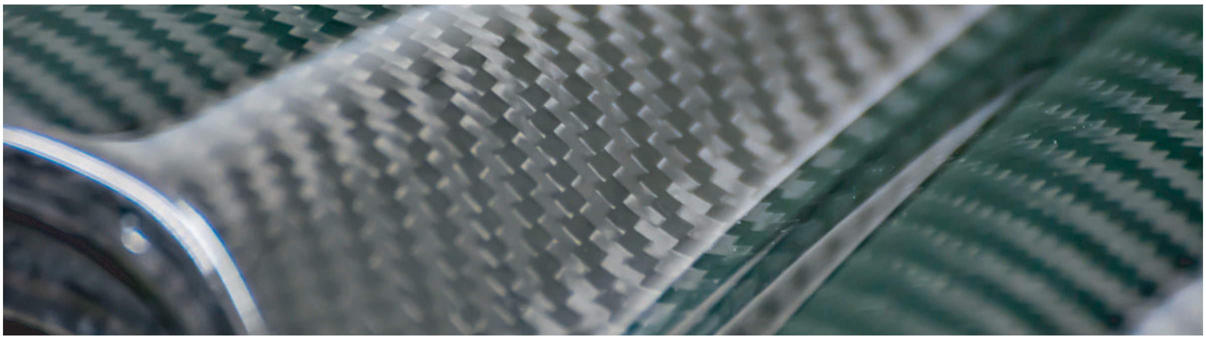
Hence, even a basic plain-weave carbon fiber panel has a specific stiffness 2x greater than aluminum or steel. It has a specific strength 5x that of aluminum and over 4x that of steel.

When one considers the option of customizing carbon fiber panel stiffness through strategic fiber placement and includes the significant increase in stiffness possible with sandwich structures utilizing lightweight core materials, is it obvious the advantage that carbon fiber composites can make in a wide variety of applications. The specific numbers depend on the details of construction and the application. For instance, a foam-core sandwich has an extremely high strength to weight ratio in bending, but not necessarily in compression or crush. In addition, the loading and boundary conditions for any components are unique to the stiffness structure. Thus it is impossible to provide the thickness of a carbon fiber plate that would directly replace a steel plate in a given application without careful consideration of all design factors. This is accomplished through careful engineering analysis and experimental validation.

One example of design flexibility in carbon fiber is the custom design of beams with tailored stiffness along specific axes. Element 6 Composites has developed patent-pending methods for the fabrication of carbon-fiber tubes for optimum stiffness along each bending axis. Such tubes are similar to I-Beams in their resistance to bending, yet retain the high torsional stiffness found in a tube.

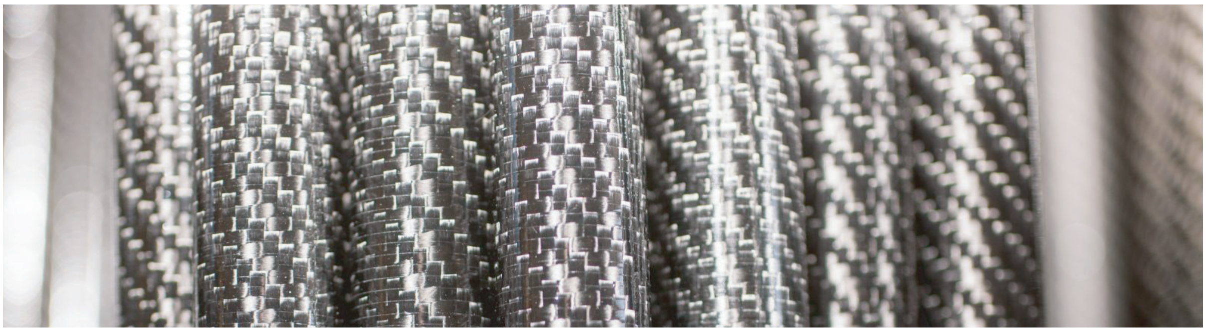
Reason 2: Low Thermal Expansion

One important benefit of choosing carbon fiber is its dimensional stability with changes in temperature. Carbon fiber has a coefficient of thermal expansion of less than one-millionth of an inch/inch per degree F, vs 7 millionths of an inch/inch per degree F for steel, or 13 millionths in/in for aluminum.



Reason 3: Anisotropic Properties

When designing composite parts, one cannot simply compare the properties of carbon fiber versus steel, aluminum, or plastic. These materials have homogeneous (properties are the same at all points), and isotropic (properties are the same along all axes). By comparison, carbon fiber parts are neither homogeneous nor isotropic. In a carbon fiber part, the strength resides along the axis of the fibers, and thus fiber density and orientation greatly impact mechanical properties. This provides the ability to taylor the mechanical properties of a part along any axis.



Carbon Fiber Design

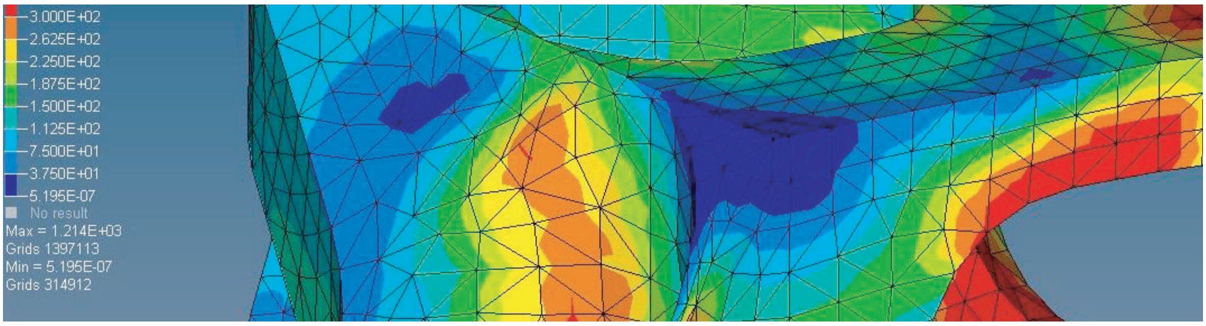
The carbon fiber design process begins with a thorough understanding of each customer's requirements, and the generation of a formal product specification. Product and process development are done simultaneously based on these technical requirements, as well as volume and cost considerations. In most cases, the carbon fiber design process involves a great deal of iteration between CAD design, analytical and computational analyses, and cost estimation. Different custom carbon fiber design projects require varying emphasis in these areas, depending on the client and application.

Our team of engineers, designers, and technicians have decades of experience in product development, research, and invention. Combining creativity with precision engineering, Element 6 Composites takes pride in helping customers develop practical and elegant solutions, whether for a single prototype or for a production run of thousands of parts.

Carbon Fiber Analysis

Our current computational tools include NeiNastran for Finite Element Stress analysis of composites. Our FEA experience ranges from advanced carbon fiber truss structures to prosthetics to wind turbines and unmanned aerial vehicles in a wide variety of applications.

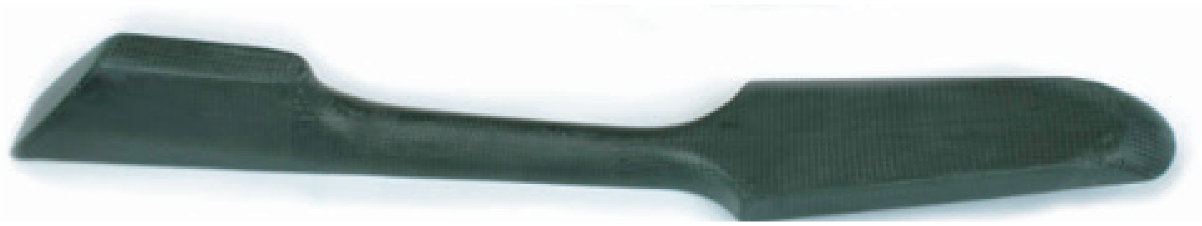
In addition to our internal expertise, we have relationships with experts available to support us with unusual or particularly challenging analyses. One example involved a NYSTAR grant we received, which allowed us the opportunity to work with Cornell University to test our carbon fiber materials. This provided excellent data for model refinements and internal design databases.



Carbon Fiber Prototyping

An integral part of the design process is prototyping. At Element 6 Composites, our carbon fiber prototype group is staffed by experienced engineers and seasoned craftsmen. Carbon fiber prototyping can range from simple test pieces to fully functional near production ready assemblies. Often individual components and sub-assemblies go through extensive testing to validate design calculations and assure the customer that the final product will meet all specifications.

In addition to their use in evaluating functionality, our high-quality carbon fiber prototypes are often used by customers as marketing tools. Our prototype team aims for production-level quality, in both form and function, even at the early stages of product development.

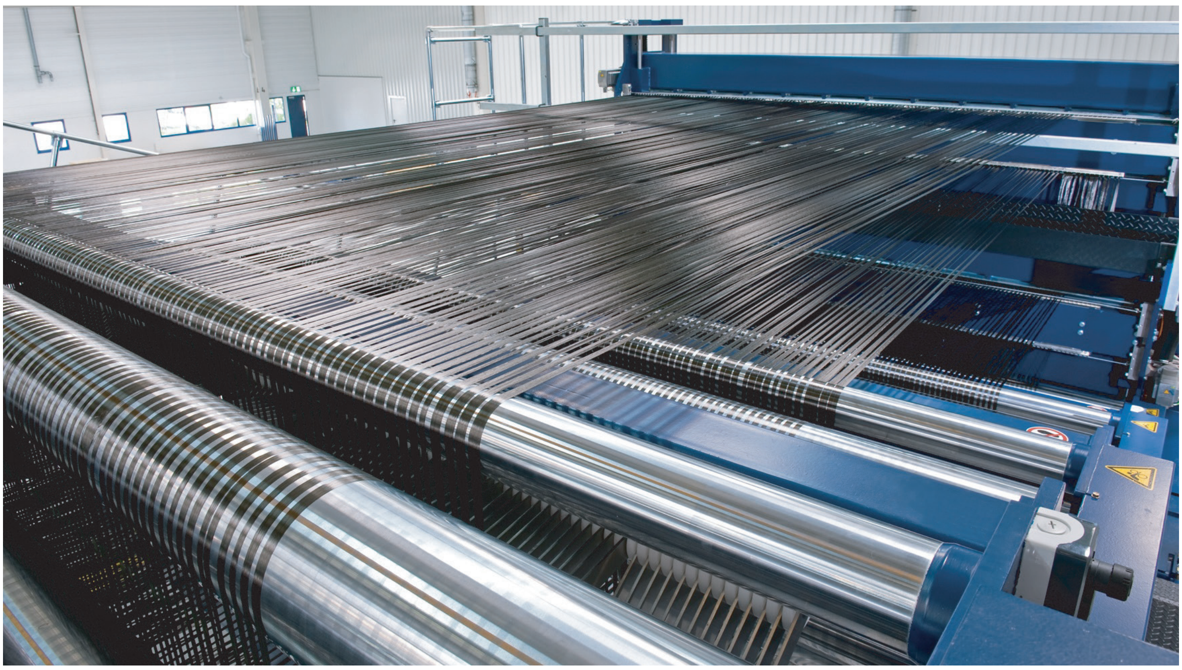


Carbon Fiber Manufacturing

The processes we utilize require an advanced level of manufacturing skill. Our highly trained and experienced craftsmen are knowledgeable in a wide range of carbon fiber materials, manufacturing processes, and techniques, to ensure unmatched quality. Our goal is always zero defects, and team members are highly motivated to meet this goal.

The Element 6 Composites staff are experts in multiple custom carbon fiber processes, including wet layup, vacuum bagging, matched tooling, vacuum-assisted resin transfer (VARTM), pultrusion, and other non-traditional proprietary methods. As a leading New York carbon fiber products manufacturer for a wide variety of applications, we also have years of experience with CNC machining carbon fiber, aramid, and other fiber-reinforced composites. Due to the conductivity, stiffness, and brittle behavior of carbon-fiber composites, machining these parts requires special tools and often non-traditional techniques.

One advantage of composites is the ability to manufacture parts optimized for strength, stiffness, and design simplicity. From simple to complex, we use advanced carbon fiber fabrication techniques to create superior results. To accomplish this we apply our three core strengths: Innovation, Technology, and Creativity.



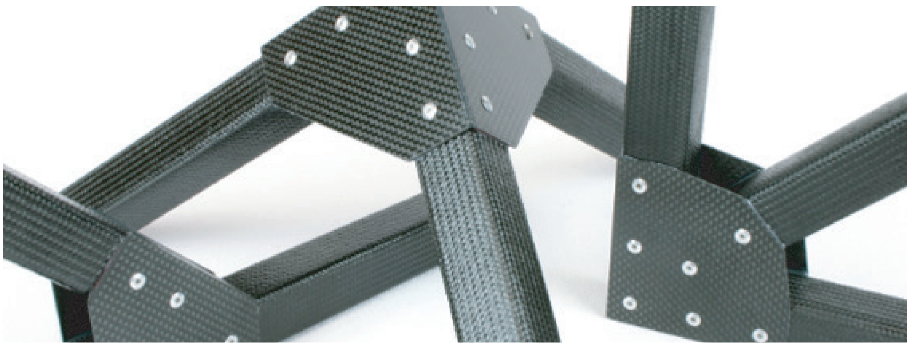
Carbon Fiber Uses and Applications

Carbon Fiber Trusses and Beams

Carbon fiber composites provide an alternative to conventional materials, such as steel or aluminum, for the construction of lightweight trusses and frame structures. Element 6 Composites has developed three systems for designing and fabricating carbon fiber tubular structures: two optimized for high strength, robustness, and customization, and one for reduced weight and lower cost.

1. Square Carbon Fiber Tubes and Gussets

The first high strength, robust construction system utilizes rectangular and square tubes, and gussets to connect them. The tubes range from as small as 3/4"x3/4" to 2"x4" and larger. In addition to overall dimensions, wall thicknesses, gusset geometries, and layup schedules can be customized to meet the needs of each application. For example, uni-direction carbon fiber can be added to individual members to increase bending/axial stiffness and strength. Likewise, gusset thickness and geometry can be adjusted to ensure proper load transfer through the joints. NeiNastran composite FEA calculations can be used to optimize structures for minimum weight while maintaining the specified strength and stiffness requirements.



2. Modular Connectors and Roll Wrapped Carbon Fiber Tubes

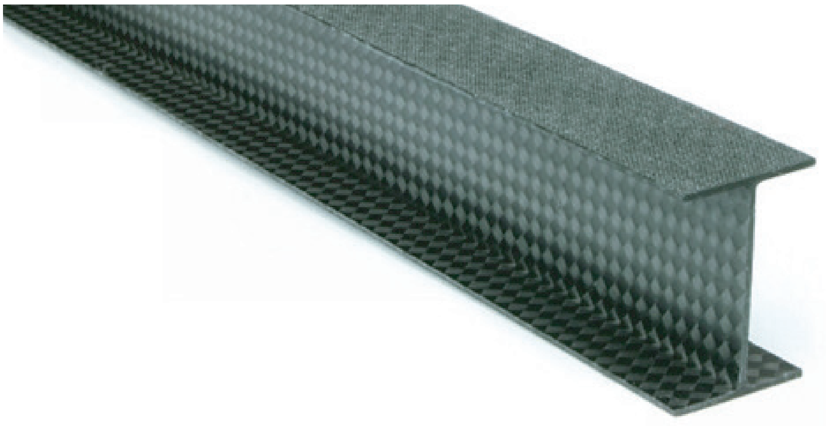
DragonPlate now offers a full line of patented Modular Carbon Fiber Tube Connectors that make it very easy to build strong, robust structures with roll wrapped carbon fiber tubes. The Modular connectors are typically bonded inside the end of tubes and connected to each other with bolts. Multiple tubes can be connected with a single bolt that can easily be removed for quick disassembly and reinstalled later. Simple pinned joints allow infinite choices in attachment angles. Tubes can be attached to plates or other mounting brackets. Modular connectors with end threads allow easy attachment of hardware, sensors, cameras, etc. The connector is easily bonded into the tube with a patented joint design that is exceptionally strong.

3. Pultruded Round Tubes and Connectors

An alternative lightweight, and cost-effective, carbon fiber construction method utilizes our patented connectors and pultruded carbon fiber tubes. This system provides a great deal of versatility to the structural designer, with infinite combinations of lengths and angles, and a wide array of attachment components. In addition, the skills necessary for the construction of this type of structure are very easy to master. Element 6 Composites specializes in both design and fabrication; however, many of our customers have the in-house capability to assemble the final carbon fiber truss structures once we have worked together through the design and prototyping phases of development.

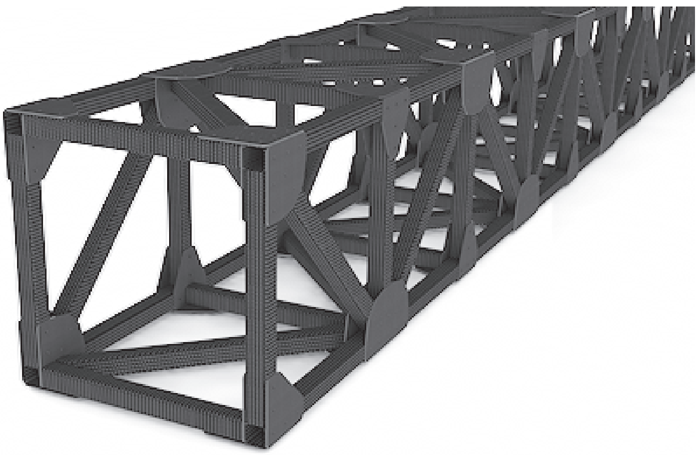
Carbon Fiber Structural Beams

Many applications from robots to load-bearing structures require customized carbon fiber structural beams. Element 6 Composites specializes in designing and fabricating custom carbon fiber structural beams for a wide array of industries and users. Although these beams are typically more expensive than a similar metal component, the substantial weight savings that can be achieved through advanced composites often outweighs this upfront investment.



Carbon Fiber Truss Applications

The applications for lightweight carbon fiber trusses and beams are endless. Some examples include robotic structures and end-effectors, replacements for cantilevered beams in high-speed or portable applications, scientific and metrology applications, and unmanned vehicle frames. If the application requires minimum weight, yet high stiffness and strength, carbon fiber trusses or beams may be a solution worth investigating.



Carbon Fiber Tactical Bridges and Ladders

Carbon fiber composites provide substantial advantages over conventional materials in the construction of advanced tactical carbon fiber ladders and bridges. Element 6 Composites has worked with both the military and law enforcement to develop a wide range of patented lightweight tactical carbon fiber ladders, platforms, and bridges, ranging from extremely lightweight ladders to heavy-duty segmented ladder/bridges.

Carbon Fiber in Musical Instruments

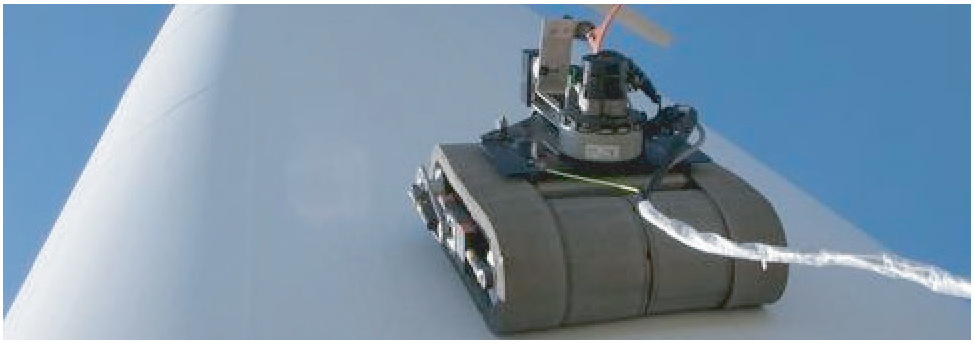
In addition to industrial and military applications, the people at Element 6 Composites also have a strong interest in the application of carbon fiber composites to the field of music and acoustic resonance. Element 6 has been privileged to work with some of the preeminent instrument builders and researchers, leading to the development of many unique applications for carbon fiber stringed instrument building.

Unmanned Vehicles

Element 6 Composites has worked with multiple companies to help develop and manufacture a variety of unmanned ground and air vehicles. Combining decades of experience in composites, structural design, and aerodynamics, Element 6 Composites supports customers in basic configuration design and analysis, component optimization, prototyping, and production manufacture. With a history of projects ranging from military ground robotics to lighter than air vehicles to rigid wing and vertical takeoff and landing carbon fiber UAVs, we have both the expertise and facilities to support your project. Below are a few examples of unmanned vehicles and components Element 6 Composites has helped design and/or produce.

Automation and Robotics

Facilities incorporating industrial automation into their manufacturing processes continually strive to improve efficiency through increased speed and greater precision. Often the most direct means to achieve these goals is reduced weight and increased stiffness of the robotics and in particular the robotic end effectors. Lightweight end effectors translate directly to increased speed on the production line, higher precision, reduced motor and actuator loads, and improved reliability.



Why is it Important to Have an Element 6 Engineer Help with Your Designs?

Occasionally potential customers call us and ask, "can you copy this steel part in carbon fiber?" The answer is typically, "that is probably not a good idea." In most cases, it doesn't really make sense to make a part designed for metal and just replace metal with carbon. You need to design it for carbon fiber for multiple reasons. The material properties of steel and carbon fiber are vastly different. They are processed and fabricated by vastly different processes. You need to design a part for carbon fiber to take advantage of its unique properties.

One reason, in particular, is that carbon fiber parts are typically thin-walled for shell structures because, with the high strength of carbon fiber, you do not need a thick wall. With metals, you can start with a block of stock and machine away material until all that is left is your part. With composites, you typically start with a tool, and apply selected fibers in the correct locations and orientations, until strength and stiffness requirements are met.

Composite parts typically require some thought and analysis by an engineer skilled in the trade. One needs to analyze where the forces are going to be applied to the part and to plan. One needs to plan where fiber should be located and in what direction. Typically, you design the part and the specific process to fabricate it at the same time.

Contact Element 6 Composites Today!

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for a quote or contact us
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