PERFORMANCE COMPOSITES Inc.

1418 S. Alameda St. Compton, CA 90221
: 310-328-6661 : 310-782-3578
: www.performancecomposites.com

Graphite Composite Material Design Guide

For light weight, high performance products

The purpose of this design guide is to provide general information on graphite (carbon fiber) composite materials and some guidelines for designing lightweight high performance products with graphite composites. If you have more specific questions, please contact our engineers at Performance Composites, and they will gladly assist you.

Graphite (Carbon Fiber) Composite Materials (Definition and History)

Composite materials are made by combining reinforcement (fiber) with matrix (resin), and this combination of the fiber and matrix provide characteristics superior to either of the materials alone. In a composite material, the fibers carry majority of the loads, and are the major factor in the material properties. The resin helps to transfer load between fibers, prevents the fibers from buckling, and binds the materials together.

Graphite composites have exceptional mechanical properties which are unequaled by other materials. The material is strong, stiff, and lightweight. Graphite composite is the material of choice for applications where lightweight & superior performance is paramount, such as components for spacecrafts, fighter aircrafts, and racecars.

Graphite fibers (sometimes called carbon fibers) are made from organic polymer such as polyacrylonitrile. The material is drawn into fibers and kept under tension while it is heated under high temperature (> 1000C). 2 dimensional carbon-carbon crystals (graphite) are formed when the hydrogen is driven out. The carbon-carbon chain has extremely strong molecular bonds (diamond is a 3 dimensional carbon-carbon crystal), and that is what gives the fibers its superior mechanical properties.

Historically, graphite composites have been very expensive, which limited its use to only special applications. However, over the past fifteen years, as the volume of graphite fiber consumption has increased and the manufacturing processes have improved, the price of graphite composites has steadily declined. Today graphite composites are economically viable in many applications such as sporting goods, performance boats, performance vehicles, and high performance industrial machinery.

Applications of Graphite Composite Materials

Composite materials are extremely versatile. The engineer can choose from a wide variety of fibers and resins to obtain the desired material properties. Also the material thickness and fiber orientations can be optimized for each application.

The three greatest advantages of graphite composites are:

1. High specific stiffness (stiffness divided by density)
2. High specific strength (strength divided by density)
3. Extremely low coefficient of thermal expansion (CTE)

Please see table 1 for a comparison of costs and mechanical properties of graphite composite, fiberglass composite, aluminum, and steel. Due to the wide variety of graphite fibers and resins available, and the numerous combinations of the materials, the properties are listed in ranges.

TABLE 1

	Graphite Composite (aerospace grade)	**Graphite Composite (commercial grade)**	**Fiberglass Composite**	**Aluminum 6061 T-6**	**Steel, Mild**
Cost $/LB	$20-$250+	$5-$20	$1.50-$3.00	$3	$.30
Strength (psi)	90,000–200,000	50,000–90,000	20,000-35,000	35,000	60,000
Stiffness (psi)	10×10^6 - 50×10^6	8×10^6 - 10×10^6	1×10^6 - 1.5×10^6	10×10^6	30×10^6
Density (lb/in^3)	.050	.050	.055	.10	.30
Specific Strength	1.8×10^6 - 4×10^6	1×10^6 - 1.8×10^6	363,640-636,360	350,000	200,000
Specific Stiffness	200×10^6-$1{,}000 \times 10^6$	160×10^6-200×10^6	18×10^6-27×10^6	100×10^6	100×10^6
CTE (in/in-F)	-1×10^{-6} – 1×10^{-6}	1×10^{-6} – 2×10^{-6}	6×10^{-6} – 8×10^{-6}	13×10^{-6}	7×10^{-6}

Applications for High Specific Stiffness

Graphite composites are ideally suited for applications where high stiffness and low weight is required. Most metals used for structural applications have very similar specific stiffness, which is around 100 x 106. If an application demands high stiffness and lightweight, graphite composites are the only material of choice.

Examples are:

- Spacecraft structure
- Aircraft structure
- Drive shaft for trucks and high performance vehicles
- Machinery rollers
- Sail boat mast and boom
- Bicycle frame
- Machinery components that experience high acceleration & require stiffness & precision

Applications for High Specific Strengths
Graphite composites are widely used for lightweight structures that need to carry extremely high loads.

Examples are:
- Motorcycle components (skid plates, rock guards)
- Fishing pole
- Golf club shaft
- Aircraft structure
- Satellite antenna structures
- Racecar chassis

Applications for Low CTE
Graphite fiber has a negative coefficient of thermal expansion, which means when it is heated it will shrink. When the graphite fibers are put into a resin matrix (positive CTE), the composite can be tailored to have almost zero CTE. Graphite composites are used for high precision and thermally stable applications.

Examples are:
- High precision antennas
- Scanning & imaging machines
- Precision optical devices
- Metrology equipment

Manufacturing Process
Graphite composite components are manufactured utilizing a molding process. The graphite fibers can be woven into cloth, braided into tubes, or made into unidirectional tapes. The fibers are next coated with resin. This fiber & resin mix can be partially cured then frozen to create a pre-preg, or the fiber & resin mix can be used wet. The graphite fiber & resin mix is then placed into a mold in layers. The number of layers and the orientation of the layers will depend on the mechanical properties desired. The layers of graphite is then compacted and consolidated in the mold by pressure from a press or from a vacuum bag. Depending on the resin system, the part can be cured at room temperature or elevated temperature. Once the part is cured, the part is removed from the mold, and it is ready for finishing operations such as trimming and drilling.

Design Information

Graphite composites are considered designer's material, because the parts can be tailored to have strength and or stiffness in the directions and locations that are necessary by strategically placing materials and orienting fiber direction. Also the design and manufacturing flexibility that graphite composites offers provide opportunities to consolidate parts and to incorporate many features into the part to further reduce the total part price. Some general design guidelines are listed below:

Material Thickness	Typically range from .040" to ½". Can use sandwich construction to achieve lighter and stiffer parts.
Corner Radius	Recommend 1/8" or larger
Shape	Will duplicate the shape of the mold. Can be heavily contoured.
Dimensional Tolerance	+.010"
Surface Finish	Tool side can be class A Can be gel coated painted, or use any other surface coating
Shrinkage	.0005 in/in
Electrical Properties	Electrical conductive
Fire Retarding	Resins available in fire retardant applications meeting various ASTM classes & smoke generation requirements
Corrosion	Resins available for corrosion applications, especially for hot brine, most acids, caustics, & chlorine gases

Tooling

Molds are used to define the shape of the fiberglass parts. The graphite composite part will pick up all shapes and features of the molds; therefore the quality of the part is heavily influenced by the quality of the mold. The molds can be either male or female. The female molds are the most common and they will produce a part with a smooth exterior surface while a male mold will produce a smooth interior surface. A matched mold (male and female) is required if the part is consolidated using a press. The molds can be made with composite materials, metal filled epoxy, or machined from aluminum or steel. The type of mold and materials used depends on the type of part and the production quantity.

For more information e-mail: sales@performancecomposites.com