Description

Image

Caption

1. Close-up of the material. © Chris Lefteri 2. CFRP bike frame weighing only 1.08 kg. ©

The material

Carbon fiber reinforced composites (CFRPs) offer greater stiffness and strength than any other type, but they are considerably more expensive than GFRP (see record). Continuous fibers in a polyester or epoxy matrix give the highest performance. The fibers carry the mechanical loads, while the matrix material transmits loads to the fibers and provides ductility and toughness as well as protecting the fibers from damage caused by handling or the environment. It is the matrix material that limits the service temperature and processing conditions.

Compositional summary

Epoxy + continuous HS carbon fiber reinforcement (0, +-45, 90), quasi-isotropic layup.

General properties

Density		93.6	-	99.9	lb/ft^3
Price	*	17	-	18.9	USD/lb
Date first used		1963			

Mechanical properties

Young's modulus		10	-	21.8	10^6 psi
Shear modulus		4.06	-	8.7	10^6 psi
Bulk modulus		6.24	-	11.6	10^6 psi
Poisson's ratio	*	0.305	-	0.307	
Yield strength (elastic limit)		79.8	-	152	ksi
Tensile strength		79.8	-	152	ksi
Compressive strength		63.8	-	122	ksi
Elongation	*	0.32	-	0.35	% strain
Hardness - Vickers	*	10.8	-	21.5	HV
Fatigue strength at 10^7 cycles	*	21.8	-	43.5	ksi
Fracture toughness	*	5.57	-	18.2	ksi.in^0.5

Mechanical loss coefficient (tan delta)	* 0.0014	-	0.0033	

Thermal properties

Glass temperature	212	-	356	°F
Maximum service temperature	* 284	-	428	°F
Minimum service temperature	* -190	-	-99.7	°F
Thermal conductor or insulator?	Poor insulator			
Thermal conductivity	* 0.74	-	1.5	BTU.ft/h.ft^2.F
Specific heat capacity	* 0.215	-	0.248	BTU/lb.°F
Thermal expansion coefficient	* 0.556	-	2.22	µstrain/°F

Electrical properties

Electrical conductor or insulator?	Poor conductor			
Electrical resistivity	* 1.65e5	-	9.46e5	µohm.cm

Optical properties

Transparency	Opaque

Processability

Moldability	4	-	5
Machinability	1	-	3

Durability: water and aqueous solutions

Water (fresh)	Excellent
Water (salt)	Excellent
Soils, acidic (peat)	Limited use
Soils, alkaline (clay)	Limited use
Wine	Limited use

Durability: acids

Acetic acid (10%)	Limited use
Acetic acid (glacial)	Unacceptable
Citric acid (10%)	Excellent
Hydrochloric acid (10%)	Excellent
Hydrochloric acid (36%)	Limited use
Hydrofluoric acid (40%)	Unacceptable
Nitric acid (10%)	Limited use
Nitric acid (70%)	Unacceptable
Phosphoric acid (10%)	Excellent
Phosphoric acid (85%)	Acceptable
Sulfuric acid (10%)	Excellent

Sulfuric acid (70%)	Limited use

Durability: alkalis

Sodium hydroxide (10%)	Excellent
Sodium hydroxide (60%)	Limited use

Durability: fuels, oils and solvents

Amyl acetate	Acceptable
Benzene	Acceptable
Carbon tetrachloride	Excellent
Chloroform	Unacceptable
Crude oil	Acceptable
Diesel oil	Excellent
Lubricating oil	Excellent
Paraffin oil (kerosene)	Excellent
Petrol (gasoline)	Excellent
Silicone fluids	Excellent
Toluene	Acceptable
Turpentine	Acceptable
Vegetable oils (general)	Excellent
White spirit	Excellent

Durability: alcohols, aldehydes, ketones

Acetaldehyde	Limited use
Acetone	Limited use
Ethyl alcohol (ethanol)	Limited use
Ethylene glycol	Acceptable
Formaldehyde (40%)	Excellent
Glycerol	Excellent
Methyl alcohol (methanol)	Limited use

Durability: halogens and gases

Chlorine gas (dry)	Limited use
Fluorine (gas)	Unacceptable
O2 (oxygen gas)	Unacceptable
Sulfur dioxide (gas)	Excellent

Durability: built environments

Industrial atmosphere	Excellent
Rural atmosphere	Excellent
Marine atmosphere	Excellent

UV radiation (sunlight)	Good

Durability: flammability

Flammability	Slow-burning

Durability: thermal environments

Tolerance to cryogenic temperatures	Unacceptable
Tolerance up to 150 C (302 F)	Excellent
Tolerance up to 250 C (482 F)	Limited use
Tolerance up to 450 C (842 F)	Unacceptable
Tolerance up to 850 C (1562 F)	Unacceptable
Tolerance above 850 C (1562 F)	Unacceptable

Geo-economic data for principal component

Annual world production, principal component		2.76e4	-	2.8e4	ton/yr

Primary material production: energy, CO2 and water

Embodied energy, primary production	*	4.91e4	-	5.42e4	kcal/lb
CO2 footprint, primary production	*	32.9	-	36.4	lb/lb
Water usage	*	161	-	177	gal(US)/lb

Material processing: energy

Autoclave molding energy	*	2.26e3	-	2.49e3	kcal/lb
Compression molding energy	*	361	-	399	kcal/lb
Filament winding energy	*	278	-	308	kcal/lb
Resin spray-up energy	*	1.54e3	-	1.7e3	kcal/lb
Resin transfer molding (RTM) energy	*	1.32e3	-	1.46e3	kcal/lb

Material processing: CO2 footprint

Autoclave molding CO2	*	1.67	-	1.84	lb/lb
Compression molding CO2	*	0.266	-	0.294	lb/lb
Filament winding CO2	*	0.206	-	0.227	lb/lb
Resin spray-up CO2	*	1.14	-	1.25	lb/lb
Resin transfer molding (RTM) CO2	*	0.975	-	1.08	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle		✘			
Recycle fraction in current supply		0.5	-	1	%
Downcycle		✔			
Combust for energy recovery		✔			
Heat of combustion (net)	*	3.39e3	-	3.56e3	kcal/lb
Combustion CO2	*	3.17	-	3.33	lb/lb

Landfill	✔
Biodegrade	✘
Toxicity rating	Non-toxic
A renewable resource?	✘

Environmental notes

Fiber composites cannot be recycled.

Supporting information

Design guidelines

Polymer composites can be formed by closed or open mold methods. All the closed mold methods produce fiber orientation parallel to the mold surfaces (for extrusion, it is parallel to the inside surface of the orifice die). Of the open mold methods, all allow multidirectional fiber orientation parallel to the mold or mandrel, except pultrusion, where the fibers are oriented parallel to the laminate surface and the mold plates, and calendaring, where they are parallel to the sheet surface. Lay up methods allow complete control of fiber orientation; they are used for large one-off products that do not require a high fiber-resin ratio. Lamination and calendaring form sheets, pultrusion is used to make continuous shapes of constant cross section and filament winding produces large hollow items such as tubes, drums or other containers. Joints in long-fiber composite materials are sources of weakness because the fibers do not bridge the joint. Two or more laminates are usually joined using adhesives and, to ensure adequate bonding, an overlap length of 25mm for single- and double- lap joints or 40-50mm for strap, step and scarf joints is necessary. Holes in laminates dramatically reduce the failure strength making joining with fasteners difficult. Composite manufacture is labor intensive. It is difficult to predict the final strength and failure mode because defects are easy to create and hard to detect or repair.

Technical notes

The properties of long fiber composites are strongly influenced by the choice of fiber and matrix and the way in which these are combined: fiber-resin ratio, fiber length, fiber orientation, laminate thickness and the presence of fiber/resin coupling agents to improve bonding. Glass offers high strength at low cost; carbon has very high strength, stiffness and low density; Kevlar has high strength and low density, is flame retardant and transparent to radio waves (unlike carbon). Polyesters are the most widely used matrices as they offer reasonable properties at relatively low cost. The superior properties of epoxies and the temperature performance of polyimides can justify their use in certain applications, but they are expensive. The strength of a composite is increased by raising the fiber-resin ratio, and orienting the fibers parallel to the loading direction. The longer the fibers, the more efficient is the reinforcement at carrying the applied loads, but shorter fibers are easier to process and hence cheaper. Increased laminate thickness leads to reduced composite strength and modulus as there is an increased likelihood of entrapped voids. Coupling agents generally increase tensile strength. Environmental conditions affect the performance of composites: fatigue loading, moisture and heat all reduce allowable strength.

Typical uses

Lightweight structural members in aerospace, automotive components and sports equipment such as golf clubs, oars, boats and racquets; springs; pressure vessels.

Tradenames

Cycom, Fiberdux, Scotchply

Links

Reference

ProcessUniverse

Producers