Composite Materials and Their Uses in Cars

Part I: What Is A Composite Material?

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A composite material is a macroscopic combination of two or more distinct materials having a discrete and recognizable interface separating them. The combination produces properties that cannot be obtained with either constituent acting alone. Examples are reinforced concrete, wood, and polymer composites. Usually, a composite consists of a matrix and fillers. In the case of carbon fiber-reinforced polymers (CFRPs), the matrix is a polymer (resin) and the fillers are small carbon fibers. The morphology and distribution of the fillers in the matrix is one important parameter determining the properties of the composite material. Figure 1 shows possible ways fillers can be shaped and mixed with the matrix material. Historically, the Pharaohs of Egypt and the ancient Incan and Mayan civilizations practiced the usage of plant fibers for strengthening and preventing bricks and pottery from cracking. Several matrix materials such as metals, ceramics, and polymers have been used. The purpose of the matrix is to bind the fibers together, transfer load to and between fibers, protect fibers from environments and handling, distribute the load evenly amongst the fibers, and to provide the interlaminar shear strength of the composite. The matrix generally determines the overall service temperature limitations of a composite material.

Consider a laminate made of CFRP composite. If it is pulled at two ends, a tensile stress, defined as the force of the tension divided by the laminate's cross sectional area, is applied to the material. The measurement of how much the part bends or changes size (in this case, changes in length) under load compared to the original dimension or shape is called strain. Strain applies to small changes in size and is defined as: [(final length - original length) / original length] = Change in length or deformation divided by the original length. In the elastic region of the material behavior, the tensile stress is linearly related to strain with a proportionality constant known as Young's tensile modulus of elasticity (E). The larger the value of E, the stiffer the material is. The maximum strength of a material without breaking when the load is trying to pull it apart is called "tensile strength". A good way to visualize this property is to think of pulling a fresh marshmallow apart and then pulling a piece of taffy apart. The force or pounds required to pull the taffy apart would be much greater than required to pull the marshmallow apart. If that force is measured and the taffy and marshmallow each had a cross-sectional area of one square inch, then the taffy has the higher "tensile strength" in terms of pounds per square inch.

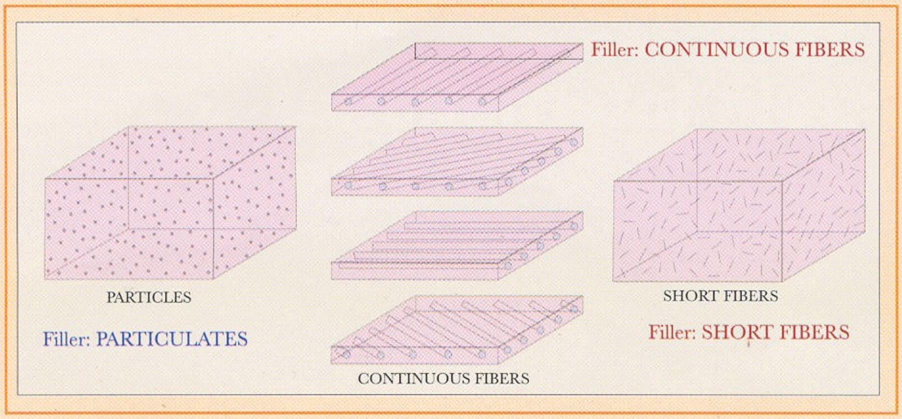


Figure 1: Changes in these parameters (i.e., fiber distribution, concentration, orientation, shape, and size) and fiber material change the mechanical properties of the composite materials.

One popular type of composite material uses a polymer matrix with glass fibers. Glass fiber composites of all descriptions have found extensive and successful applications including low-performance non-structural applications as well as high-performance structural applications. The applications range from the building construction trades, to auto, truck and rail transportation, seagoing applications including high-performance racing craft, and commercial and military aerospace. Specific applications involve decorative panels, appliances, ship and boat hulls, light aircraft and glider construction, nearly all forms of recreational equipment, high-pressure gas containers and rocket motor casings. This wide spread use of glass fiber-reinforced organic composites and their continued future growth is due to many factors, including: cost, availability, handling and processing ability, useful properties and characteristics and past good experience in service.

A popular glass fiber that is the industry standard is E-glass, which is a calcium aluminoborosilicate formulation having very good mechanical and electrical characteristics at very reason-able cost. Average mechanical property levels for individual filaments are 3450 MPa (500 ksi) for tensile strength and 72.4 GPa (10.5 x 10^6 psi) for Young's modulus. Extensive research has been conducted to develop glass fibers possessing higher strength and stiffness characteristics. Glass formulations producing filaments of increased strength and stiffness have been found to be toxic (beryllium glasses) or very high melting and difficult to handle in com-mercial scale equipment. S-glass fibers contain a higher percentage of alumina compared to E-glass. Filament strength, modulus and melting point are higher than for E-glass. Typical filament strength and stiffness for S-glass are close to 4600 MPa (670 ksi) and 85.5 CPa (12.4 x 10^6 psi).

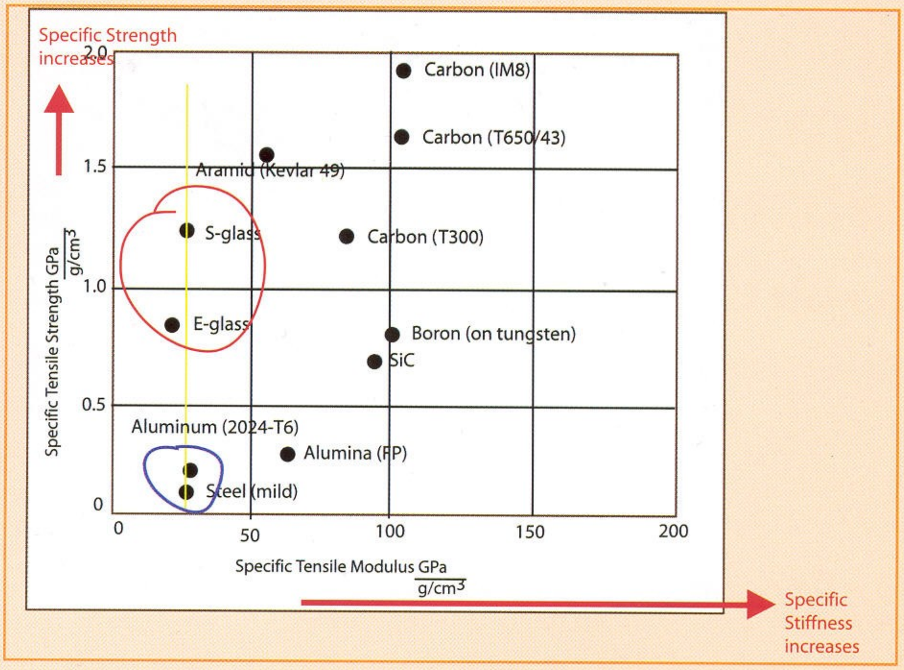
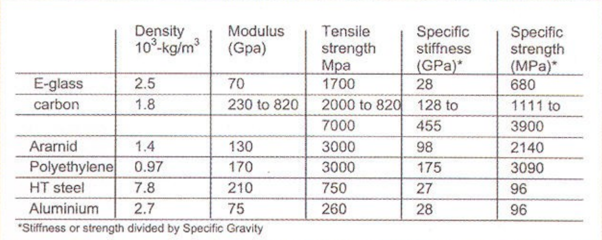


Figure 2: "Specific" tensile strength as a function of "specific" tensile modulus (indicating stiffness). A number of fibers (S-glass, E-glass, Aramid, Carbon, SiC, Alumina, and Boron) are shown.

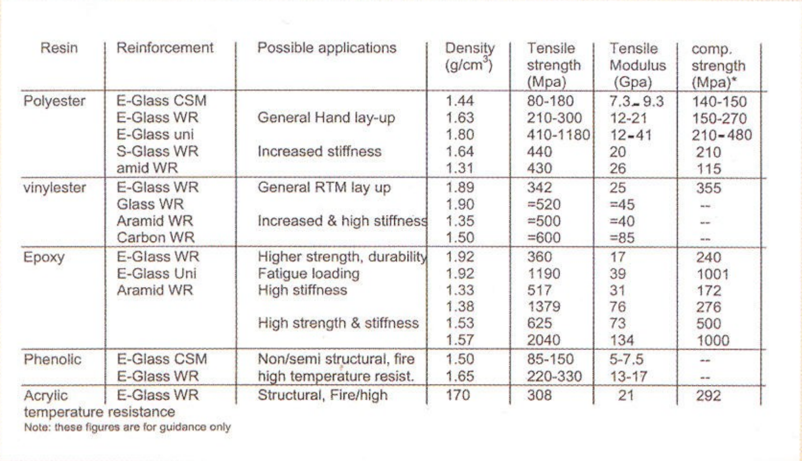
Here, we would like to demonstrate what can be achieved by formation of a composite material and it is explained through an example using glass-fiber polymer-matrix composite materials. Fibrous materials such S-glass, (Kevlar 49) aramid, Spectra, boron and the many types of carbon fibers produced commercially possess specific properties (strength/density) and (modulus/density) many times greater than those of structural alloys of aluminum, titanium or steel. However, when the fibers are combined with a matrix into a near quasi-isotropic lay-up, a highly useful engineering form of the material, the specific properties are greatly reduced but are still superior compared to conventional homogeneous metallic materials. Figure 2 shows the strength- and stiffness-to-weight (i.e., specific properties) relationships for several fibers when arrayed in unidirec-tional laminates. These are calculated values based upon literature fiber values and 65 vol.% fiber content. It can readily be seen that these high-performance fiber materials form the basis for the advanced composites technology. Fiber composites are both lighter and stronger than steel. They can also be stiffer than steel depending on the fiber used. The wide variety of materials that can be combined to form composites having highly acceptable levels of engineering properties can make the selection of specific materials a challenging task. In Part II of this series, some other types of composites are discussed with specific applications in automotive industry.



	Density 10^3-kg/m^3	Modulus (Gpa)	Tensile strength Mpa	Specific stiffness (GPa)*	Specific strength (MPa)*
E-glass	2.5	70	1700	28	680
carbon	1.8	230 to 820	2000 to 820	128 to	1111 to
			7000	455	3900
Ararnid	1.4	130	3000	98	2140
Polyethylene	0.97	170	3000	175	3090
HT steel	7.8	210	750	27	96
Aluminium	2.7	75	260	28	96

*Stiffness or strength divided by Specific Gravity

Table 1: Fibers and metals



Resin	Reinforcement	Possible applications	Density (g/cm^3)	Tensile strength (Mpa)	Tensile Modulus (Gpa)	comp. strength (Mpa)*
Polyester	E-Glass CSM		1.44	80-180	7.3‒9.3	140-150
	E-Glass WR	General Hand lay-up	1.63	210-300	12-21	150-270
	E-Glass uni		1.80	410-1180	12-41	210-480
	S-Glass WR	Increased stiffness	1.64	440	20	210
	amid WR		1.31	430	26	115
vinylester	E-Glass WR	General RTM lay up	1.89	342	25	355
	Glass WR		1.90	=520	=45	--
	Aramid WR	Increased & high stiffness	1.35	=500	=40	--
	Carbon WR		1.50	=600	=85	--
Epoxy	E-Glass WR	Higher strength, durability	1.92	360	17	240
	E-Glass Uni	Fatigue loading	1.92	1190	39	1001
	Aramid WR	High stiffness	1.33	517	31	172
			1.38	1379	76	276
		High strength & stiffness	1.53	625	73	500
			1.57	2040	134	1000
Phenolic	E-Glass CSM	Non/semi structural, fire	1.50	85-150	5-7.5	--
	E-Glass WR	high temperature resist.	1.65	220-330	13-17	--
Acrylic	E-Glass WR	Structural, Fire/high	170	308	21	292

temperature resistance

Note: these figures are for guidance only

Table 2: Material Properties

MEET THE CONTRIBUTORS

Dr. Bruce Chehroudi is currently a Principal Scientist and Group Leader at the Engineering Research Corporation Inc. He has been a Chief Scientist at Raytheon STX (formerly Hughes Aircraft STX) and is a former Professor of Mechanical Engineering. Dr. Chehroudi previously served as a Research Staff Member at Princeton University and has established and directed an Engine Laboratory at the Univ. of Illinois. Dr. Chehroudi has more than 100 publications in conferences, national and international journals. Dr. Chehroudi, received his PhD from Princeton University.

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Dr. Frank Mertins studied physics and detained his Ph.D. in physical chemistry at the University of Heidelberg in 1995. After a post-doc at the Max-Planck-Institute in Dresden, he worked for several different companies. In 2002 he joined IAV, where he currently is responsible for the development of the simulation software IAV-Exhaust.

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