Composites materials, processes, properties and applications

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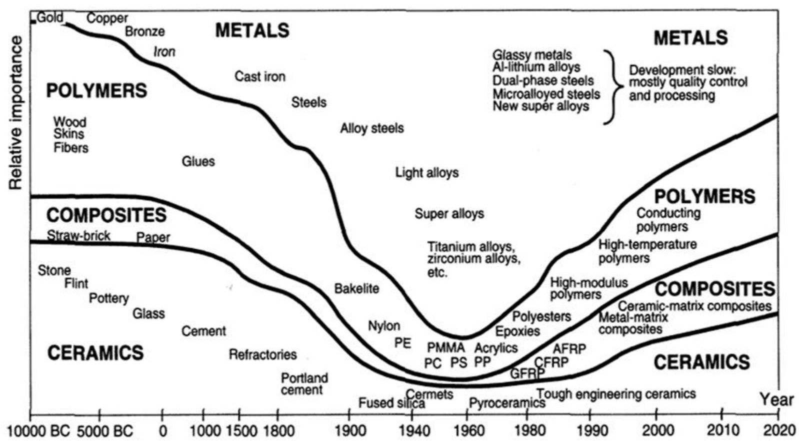
Abstract: Composites have been found to be the most promising material available in this century. Presently, composites reinforced with fibers of synthetic or natural materials are gaining more importance as demands for lightweight materials with high strength for specific applications are growing in the market. Fiber-reinforced polymer composite offers not only high strength to weight ratio, but also reveals exceptional properties such as high durability; stiffness; damping property; flexural strength; and resistance to corrosion, wear, impact, and fire. Performance of composite materials predominantly depends on their constituent elements and manufacturing techniques, therefore, functional properties of various fibers available worldwide. Their classifications, and the manufacturing techniques used to fabricate the composite materials need to be studied in order to figure out the optimized characteristic of the material for the desired application.

Keywords: *fiber properties, fiber-reinforced polymer, specific properties, composites productions, applications*

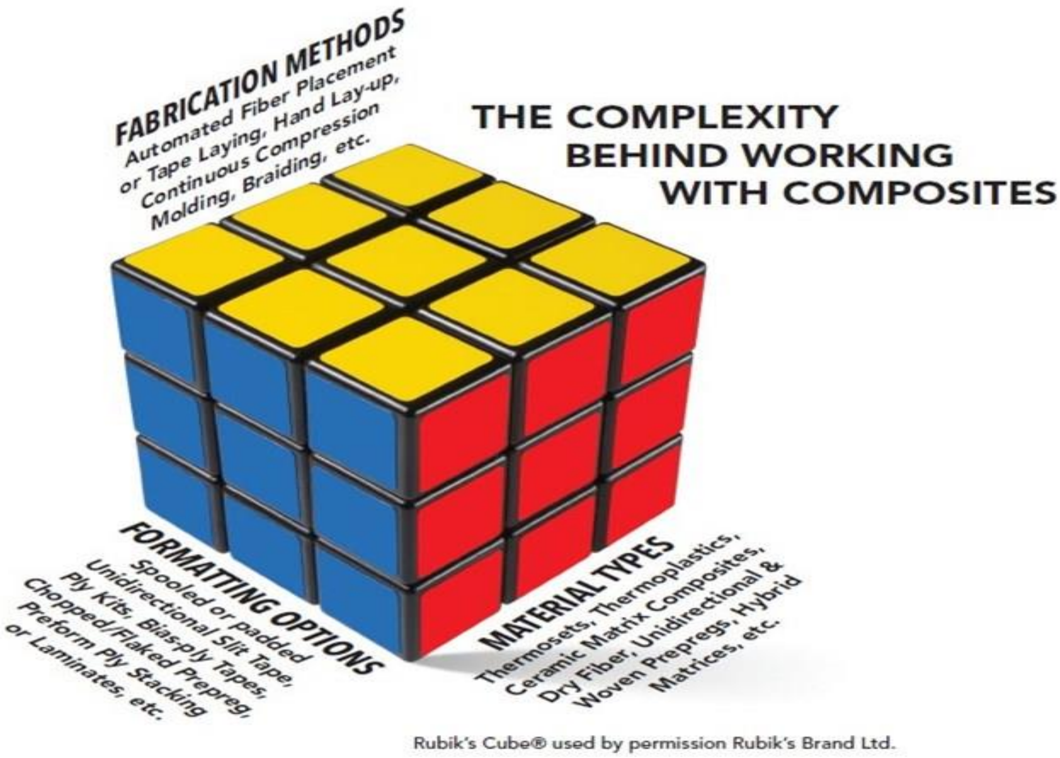
0. Introduction

The push for fuel economy in the face of nowadays drastically increasing oil and gas prices, for example, has made lightweighting a priority in almost every mode of mechanical transportation, from bicycles to large commercial aircraft. Over time, materials are changed by humanity.

Relative importance of material development through history

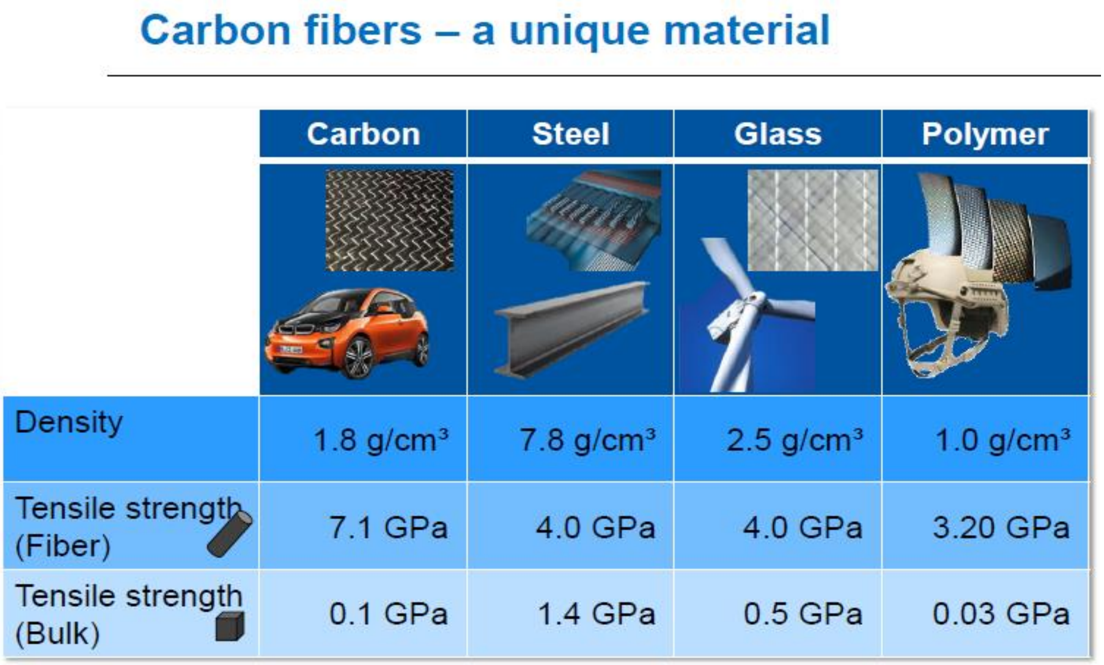


Composites from materials with significantly different properties (fiber, matrix), particular production process are a new material with excellent properties.



1. Reinforcement fibers

Compared to the block material, the fibrous form has many advantages in terms of mechanical and formability.



Carbon fibers – a unique material

	Carbon	Steel	Glass	Polymer
Density	1.8 g/cm³	7.8 g/cm³	2.5 g/cm³	1.0 g/cm³
Tensile strength (Fiber)	7.1 GPa	4.0 GPa	4.0 GPa	3.20 GPa
Tensile strength (Bulk)	0.1 GPa	1.4 GPa	0.5 GPa	0.03 GPa

Several high-performance fibers can be used to strengthen composites.

Fibers used in composites

Carbon (Sigrafil C, Tenax, Torayca, Panex)
Glass (E, R, S)
Basalt
Ceramics SiC
Quartz
Boron
Metal fibers
Para-aramid (Kevlar, Technora, Twaron)
PBO (PE, ZYLON) (p-phenylene-2,6-bensobisoxabole) (Toyobo, J)
Dyneema (UHMW PE – Ultra Hight Modulus Weight PoliEtilen, Toyobo)
Vectran (LCP - Liquid Crystal Polymers) (Kuraray)
Polyamide
Hard fibers (Hanf ,Flax, Jute, Kenaf)

Glass fibers are used in the largest amount in the reinforcement of composites, while carbon fiber has many excellent properties. Carbon fiber manufacturers produce carbon fiber bundles or "tows" consisting of thousands of continuous, untwisted and delicate filaments, much thinner than a human hair (d=7μm). The filament count designated by a number followed by "K," meaning multiplication by 1,000. So, 12K tow indicates a bundle containing 12,000 continuous filaments. Typical aerospace composite applications use finer tow sizes ranging from 1K to 12K. Heavy-tow carbon fibers, with filament counts from 50K to 320K, are available at a lower cost than aerospace-grade fibers, because of precursor and processing differences.

Carbon fiber demand, application and manufacturers are listed in Table 1.

Carbon Fiber Supply & Demand (2015-2025)

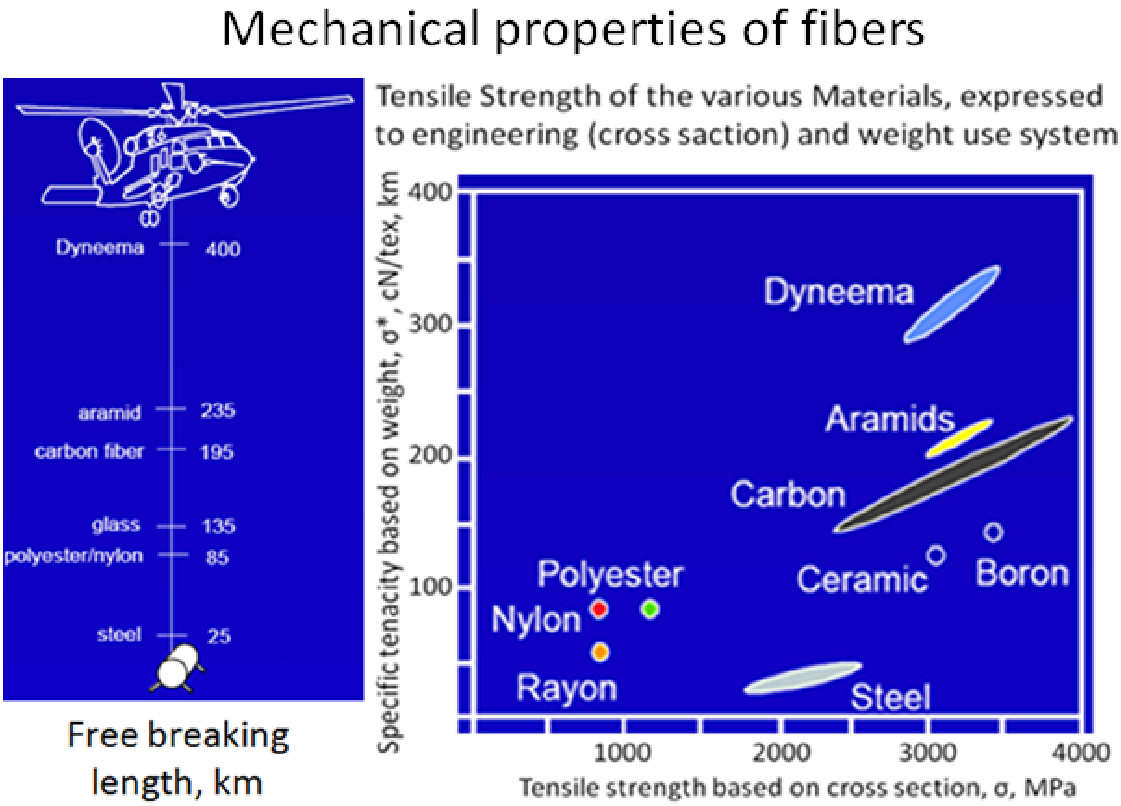
Carbon fiber demand (all tow sizes, all types)	
2015	65,000 MT
2020	120,000 MT
2025	170,000 MT

Market share, 2020	
Aerospace/defense	18%, 21,600 MT
Industrial	69%, 82,800 MT
Sports/leisure	13%, 15,600 MT

Carbon fiber suppliers, 2020 (nameplate)	
Toray	50,000 MT
Toho-Tenax	20,000 MT
Mitsubishi Rayon Carbon Fiber & Composites	15,000 MT
SGL Group	14,000 MT
Hexcel	13,000 MT
China	12,000 MT
Rest of World	5,000 MT

There is virtually no alternative to lightweight constructions: carbon fibres, the black wonder fibres that are superior to steel and aluminium in almost all respects when it comes to cutting weight. And, in terms of stability and lightness, carbon-reinforced plastic is simply unbeatable.
Carbon fibers have higher strength and significantly higher stiffness than glass fibers, the specific gravity of laminates is slightly lower. Therefore, they are mainly used for rigid structures. For

example, the wide-span wing of a fiberglass glider, or the blade stiffener of a wind turbine, bends to a greater extent and is heavier when compared to carbon fiber reinforced composites (CFRP).



The mechanical comparison of different structural materials can be expressed with specific characteristics, referring to the mass (weight) due to the significantly different densities.

Comparison of fiber properties of glass, aramid and carbon

Fiber materials	glass	aramid	carbon
Fiber isotropy	+	-	-
Tensile strength	+-	+	++
Young's-Modulus	-	+-	+
Impact	+-	+-	-
Humidity absorption	+	--	++
Creep	+-	++	++
Electrical conductivity	-	-	++
Chemical resistance	++	++	++
Temperature resistance	+	++	++
Matrix bonding/adhesion	+	-	+
Processibility	+-	+-	-
Aluminum corrosion	+	+	--
Costs	++	-	--

2. Matrices

A wide range the matrices, so called bedding materials the shape of parts determining.

Fiber-reinforced composite matrices can be:

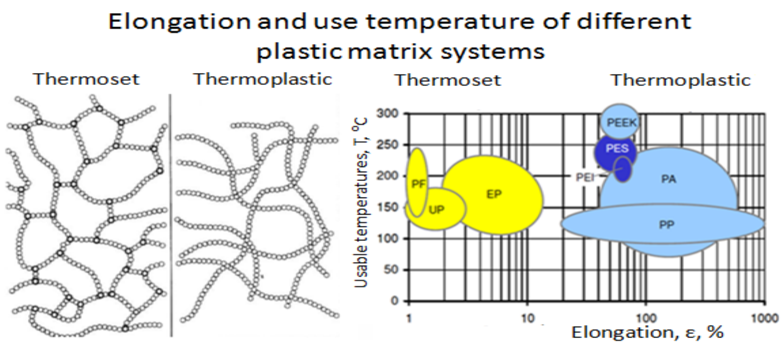
- Polymer (FRP)
- Elastomer (Tyre)
- Concrete (building) amplifier structures
- Gain Wood,
- C & C composites
- C & Ceramics
- C & Metal
- Bio-Plastic

A CFRP alkatrészek előállításához használt kereskedelmi és nagy teljesítményű gyanták kompozitjaihoz legszélesebb körben használt polimer mátrixok két nagy kategóriába sorolhatók: hőre keményedő és hőre lágyuló molekuláris polimer láncokból álló műanyagok.

Thermoset (TS) resin permanently cures into a cross-linked network when mixed with a catalyst, exposed to heat, or both. Fabricators can control the cure profile and viscosity through careful formulation of the catalyst package, which may include inhibitors, promoters and accelerators. For aerospace applications using CFRP, cure takes place in an airtight autoclave vessel, which applies heat and pressure to ensure good consolidation of the laminate to minimize any voids or air bubbles that can weaken the part. Alternative but less used curing technologies include electron beam, ultraviolet (UV) radiation, X-ray and microwave processes.

The thermoplastic (TP) resin is the other most commonly used matrix type, which is proving an increasingly popular option for composites manufacturers. Thermoplastic linear polymer chains are permanently cured into a crosslinked network when mixed with a catalyst, exposed to heat, or both formed and can be reformed into shaped solids by melting or softening and then cooling the material.

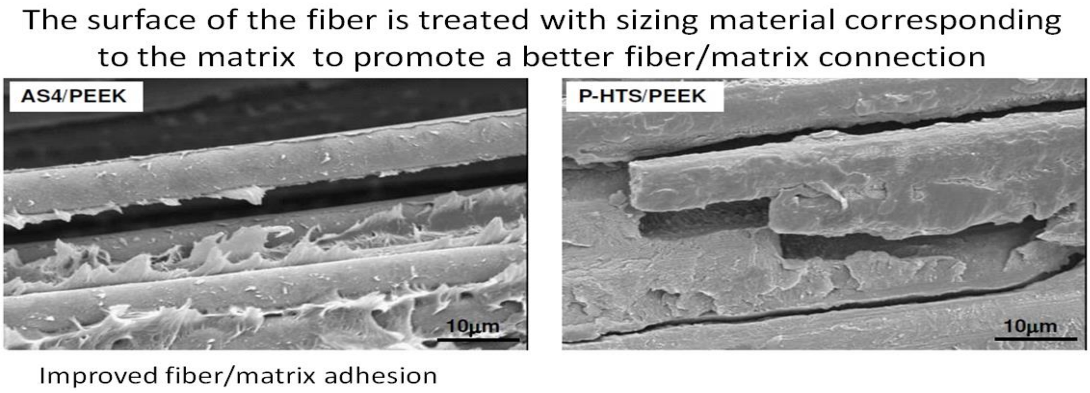
Often sold in sheet or panel form, thermoplastics can be processed by in-situ consolidation techniques, such as simple press forming to make tough, near-net shape parts without the autoclave or vacuum-bag cure required by thermosets. TP reformability offers the potential to correct anomalies or repair in-service damage.Although there are many high-performance thermoplastic resin matrices available, such as polyetheretherketone (PEEK), which are finding their way into critical aircraft structures like access doors and panels and wing leading edges.



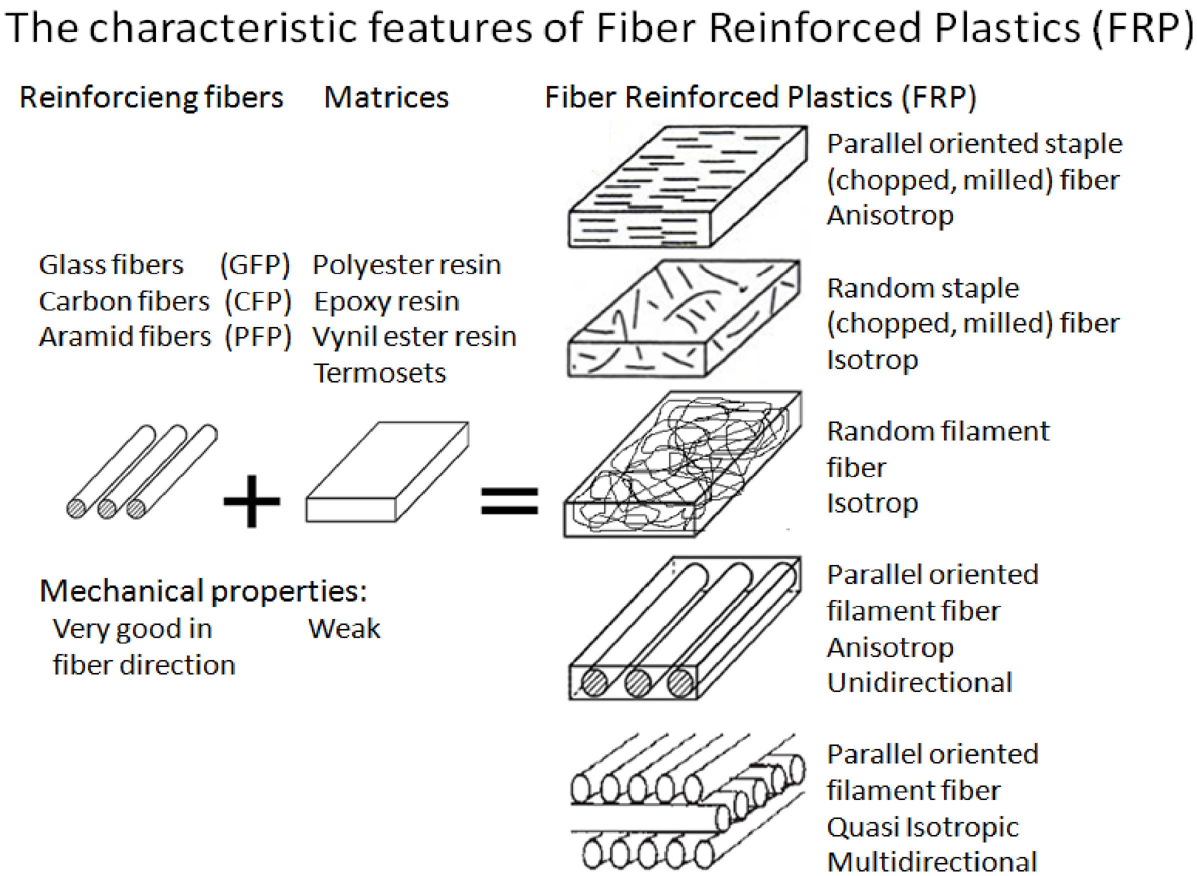
The newly application nanotechnologies that, when used as resin additives, can enhance the performance of resins in composites applications.

3. Composites manufacturing process

The surface of the fiber is treated with a material (sizing) corresponding to the matrix to promote a better fiber/matrix connection.



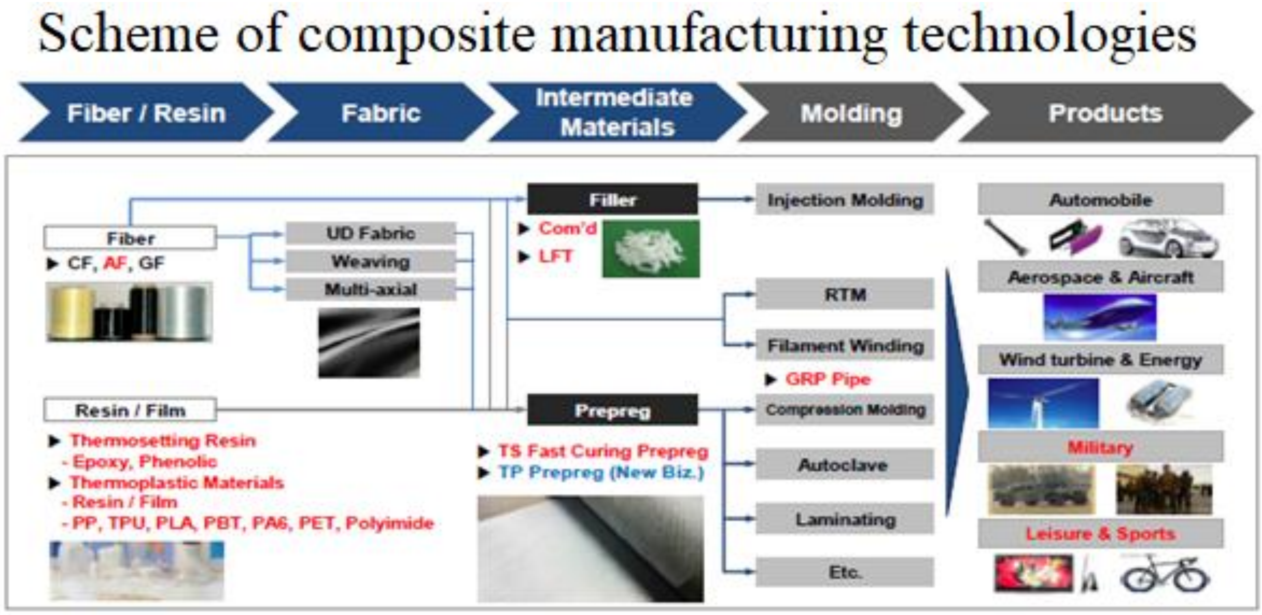
The mechanical properties of composite materials are derived primarily from the fiber reinforcement. Commercial composites for large markets, such as automotive components, boats, consumer goods and corrosion-resistant industrial parts, often are made from noncontinuous, random glass fibers or continuous but nonoriented fiber forms.



The high-performance filament fibers in the composites are oriented according to the loads (unidirectional (UD), multidirectional (MD)).

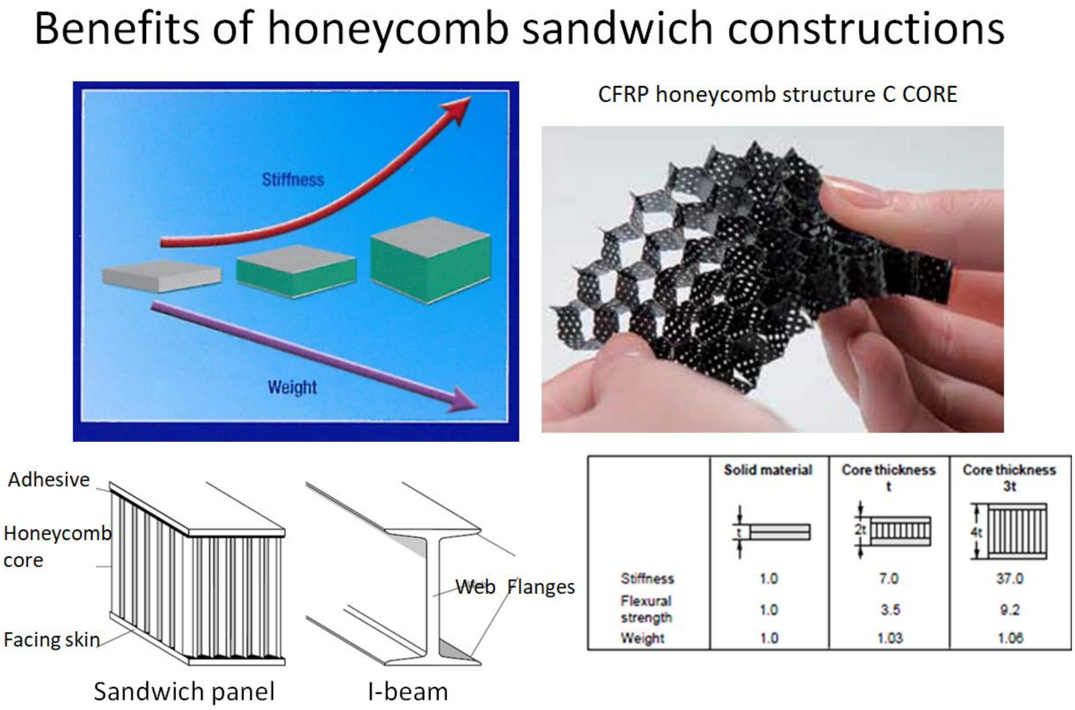
Curing usually occurs under elevated temperature and/or pressure conditions in an oven and/or vacuum bag or in an autoclave.

Several processes have been developed for the production of composites.



Composite materials are fabricated with a number of different techniques, among which every technique is applicable for certain material. Effectiveness of manufacturing technique is dependent on the combination of type and volume of matrix or fiber material used, as each material possesses different physical properties, such as melting point, stiffness, tensile strength, etc. Therefore, manufacturing techniques are defined as per the choice of material.

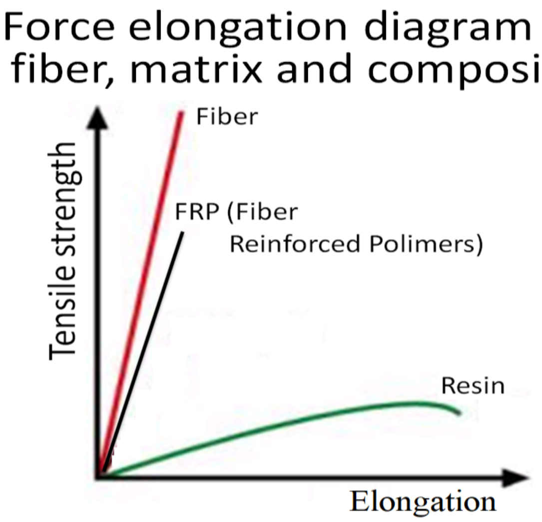
When making structures with high bending stiffness, a light core material sandwiched between the composite planes is placed.



4. Composites properties

Most composites are made up of two materials - the matrix (or binder) surrounds a cluster of fibers or fragments of a stronger material (reinforcement). A common example of this structure is fiberglass, which was developed in the 1940's to be the first modern composite and is still in widespread use. In fiberglass, fine fibers of glass, which are woven into a cloth of sorts, act as the reinforcement in a plastic or resin matrix.

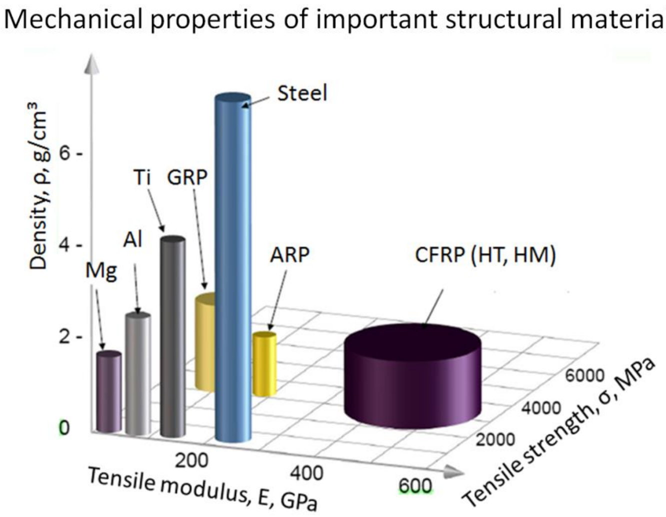
Composites differ from traditional materials in that composite parts comprise two distinctly different components — fibers and a matrix material (most often, a polymer resin) — that, when combined, remain discrete but function interactively to make a new material, the properties of which cannot be predicted by simply summing the properties of its components. In fact, one of the major advantages of the fiber/resin combination is its complementary nature. Thin glass fibers, for example, exhibit relatively high tensile strength, but are susceptible to damage. By contrast, most polymer resins are weak in tensile strength but are extremely tough and malleable. When combined, however, the fiber and resin each counteract the other's weakness, producing a material far more useful than either of its individual components.



These materials do not blend or dissolve together but remain distinct within the final composite structure. Composite materials can be made to be stronger, lighter or more durable than traditional materials due to properties they gain from combining their different components.

High-performance composites derive their structural properties from continuous, oriented, high-strength fiber reinforcement — most commonly carbon, aramid or glass — in a matrix that promotes processability and enhances mechanical properties, such as stiffness and chemical resistance. Composites have proven resistance to temperature extremes, corrosion and wear, especially in industrial settings, where these properties do much to reduce product lifecycle costs. These characteristics have propelled composites into wide use.

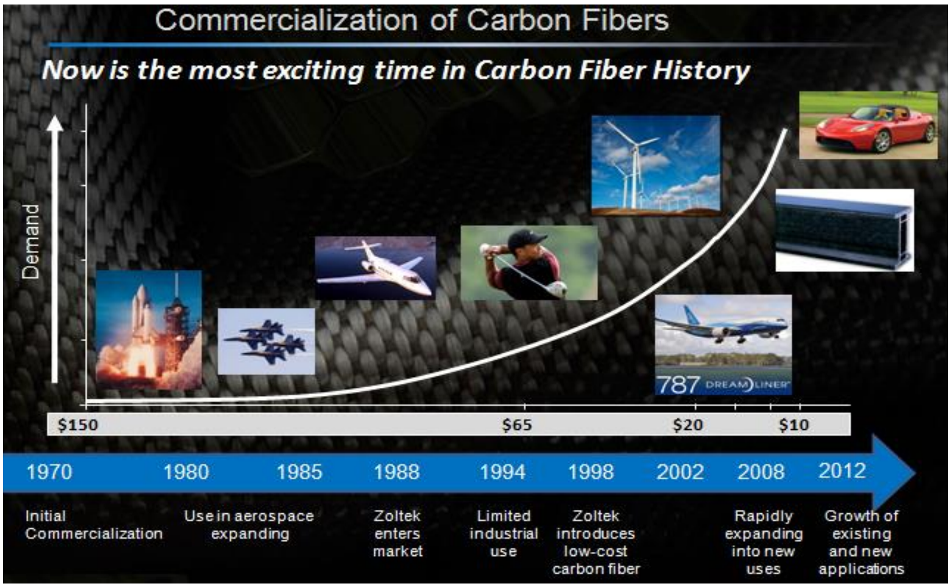
High strength and low weight remain the winning combination that propels composite materials into new arenas.



Composite materials offer good vibrational damping and low coefficient of thermal expansion (CTE), characteristics that can be engineered for specialized applications. Composites are resistant to fatigue and provide design/fabrication flexibility that can significantly decrease the number of parts needed for specific applications — which translates into a finished product that requires less raw material, fewer joints and fasteners and shorter assembly time.

5. Applications

Advanced composites, initially developed for the military aerospace market, offer performance superior to that of conventional structural metals and now find applications in communication satellites, aircraft, sporting goods, transportation, heavy industry and in the energy sector in oil and gas exploration and wind turbine construction.
With the decrease in the price of carbon fiber and the development of composite technologies, the field of application is widening, and the quantity is growing rapidly.



Fiber orientation can be controlled, a factor that can improve performance in any application. In composite golf club shafts, for example, boron and carbon fibers oriented at different angles within the composite shaft enable it to take best advantage of their strength and stiffness properties and withstand torque loads and multiple flexural, compressive and tensile forces.

The important large-volume use of the composite is aerospace, transpotation, energy (wind blade), chemistry industry, high performance maschinen parts, sportarical, etc.

They are trying to introduce hydrogen technology to store and use energy. In order to reduce the weight of high-pressure (p=700bar) tanks, he predicts a high demand for carbon fiber in the near future.

6. CONCLUSIONS AND RECOMMENDATIONS

Fibre-reinforced plastic materials or composites are recognised as possessing superior specific properties when compared to conventional engineering materials. However, the widespread use of these materials is still limited, with engineering designers choosing to stick with what they know best. Composite technology requires new knowledge and a new approach from technical specialists. Over the past decade the global economy and energy concerns have remade the markets for advanced composite materials, services, and technologies. Despite challenges, the global demand for carbon fiber is expected to nearly double of the next five years. Lightweight composite materials offer potential benefits for energy efficiency and renewable energy.

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