Composite Materials

Composite materials are made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure.

Most racquets are now made from composite materials. The composite material is normally epoxy resin reinforced with carbon fibers. The reinforcing fibers in the matrix give the composite material even more strength and stiffness and can withstand impacts better than either the resin or the fibrous material alone.

WANTED

ARTIST RENDERING

Joe Meach, alias

COMPOSITE SUPERMAN

Considered Dangerous
Do Not Approach

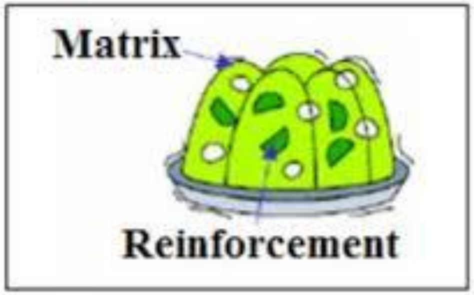
Contact local authorities with any information

History

- The earliest man-made composite materials were straw and mud combined to form bricks for building construction.
- **Concrete** is also a composite material, and is used more than any other man-made material in the world. It consists of a binder (cement) and a reinforcement (gravel).
- Composite materials occur in nature. **Wood** is a natural composite consisting of cellulose as the fiber and lignin as the matrix. In **bone**, the collagen acts like the resin and the HAP mineral crystals act like the reinforcment.
- The first artificial fiber reinforced plastic was bakelite (thermosetting phenol formaldehyde resin) which dates to 1907.

Most composites have two constituent materials:

- *Matrix*
- *Reinforcement*



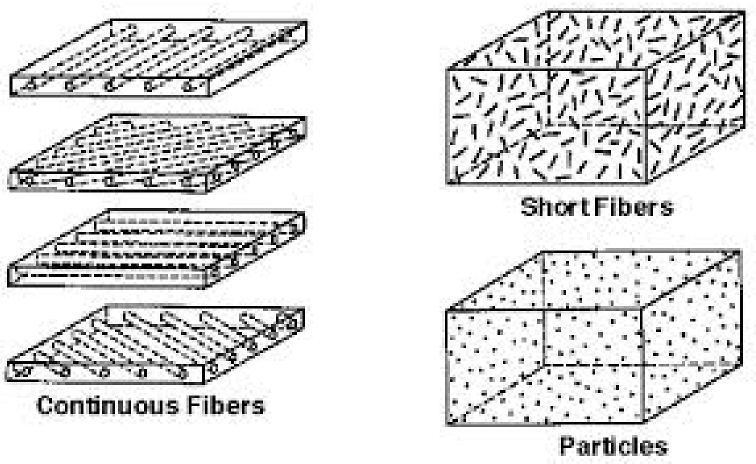
www.engineeringcivil.com

Fig 1 Matrix and Reinforcement in a Composite Material

Reinforcements

The role of reinforcement in composite materials is primarily to add mechanical properties to the material such as **strength** and **stiffness**

Reinforcements basically come in three forms:
•*particulate*
•*discontinuous fiber*
•*continuous fiber*



Reinforcements become fibers when one dimension becomes long compared to others. Discontinuous reinforcements (chopped fibers, milled fibers) vary in length from a few millimeters to a few centimeters.

Matrix

The role of the matrix is to bind the reinforcement together so that the applied stress is distributed among the reinforcement and to protect the surface of the reinforcement from being damaged.

Composites are classified according to their matrix phase:

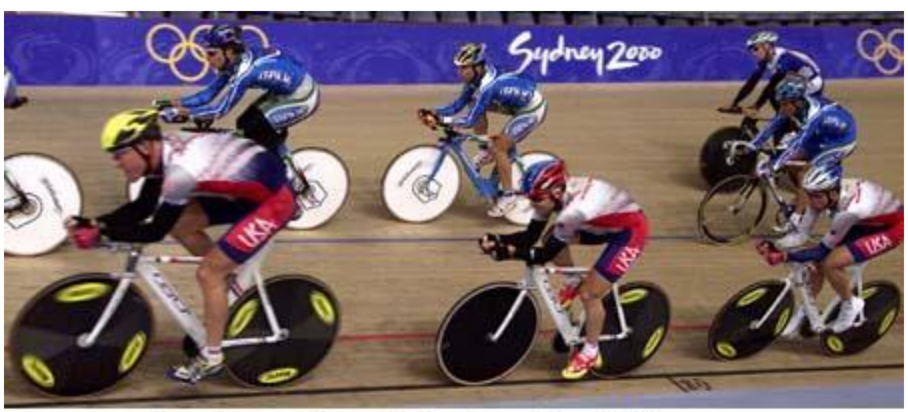
- Polymer matrix composites (PMC's)
- Ceramic matrix composites (CMC's)
- Metal matrix composites (MMC's)

Advantages of Polymer Matrix Composites

Polymer composites are ***lightweight materials*** providing an advantage for;

- aircraft hulls (gövde), bicycle bodywork,
- military and heavy goods vehicles use composites in both bodywork and engine and transmission systems.
- mass transit systems in trains, subways and buses use composites for ceilings, walls, floors and seating.

Polymer composites have a ***high resistance to chemical corrosion*** and ***scratching***. Their **resilience to seawater and rust** is an advantage when used in boats or other marine craft manufacture.



http://news.tvb.com/gallery/o_gallery154.htm

Easy to fabricate of very complex parts with low tooling cost.

Disadvantages of Polymer Matrix Composites

- Because the matrix decomposes at high temperatures, current PMCs are limited to ***service temperatures*** **below about 300° C**.

- Experience over the past 15 years with advanced composite structures in military aircraft indicates that reliable PMC structures can be fabricated.
However, their ***high cost*** remains a major barrier to more widespread use in commercial applications.

- Most advanced PMCs today are fabricated by a laborious process called lay-up. Although automation is beginning to speed up this process, ***production rates*** **are still too slow** to be suitable for high-volume, low-cost industrial applications such as automotive production lines. New fabrication methods that are much faster and cheaper will be required before PMCs can successfully compete with metals in these applications.

Composite products

Composite products range from skateboards to components of the space shuttle. The industry can be generally divided into two basic segments:

- **industrial composites**
- **advanced composites**

The distinction is based on the level of mechanical properties. Materials within these categories are often called **"advanced"** if they combine the properties of high strength and high stiffness, low weight and corrosion resistance.

Industrial Composites. The industrial composites industry has been in place for over 40 years in the world. This large industry utilizes various resin systems including polyester, epoxy, and other specialty resins. These materials, along with a catalyst or curing agent and some type of fiber reinforcement (typically glass fibers) are used in the production of a wide spectrum of industrial components and consumer goods: boats, piping, auto bodies, and a variety of other parts and components.

Advanced Composites : Advanced composites industry is characterized by the use of expensive, high-performance resin systems and high-strength, high-stiffness fiber reinforcement. The aerospace industry, including military and commercial aircraft is the major customer for advanced composites. These materials have also been adopted for use by the sporting goods suppliers who sell high-performance equipment to the golf, tennis, fishing, and archery markets.

While aerospace is the predominant market for advanced composites today, the industrial and automotive markets will increasingly see the use of advanced composites.

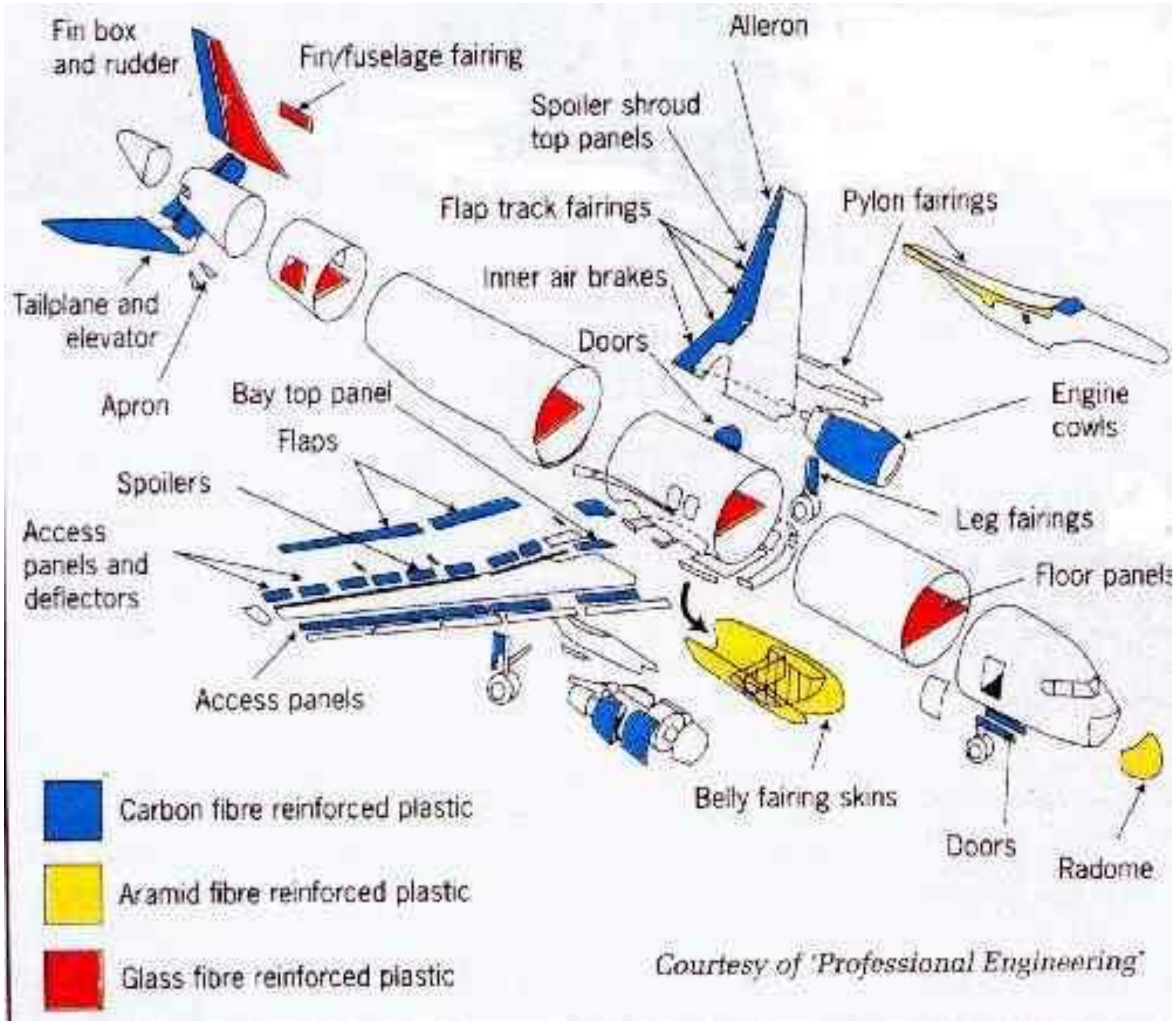
Surfboard with carbon nanotube reinforced epoxies

• Also BMW goes for composites. The BMW M6 has an overall weight of only 1710 kg. The composite roof is 6 kg lighter than a conventional steel roof.

• In the BMW M3 model, the aluminium bumper beam has been replaced by a glass/polyamide bumper beam. A weight reduction from 7 kg to 3.1 kg was realized, and its crash performance was three to four times better than the metal beam.

BMW M6 with carbon fibre roof

Glass/polyamide bumper beam for BMW M3



http://www.hsc.csu.edu.au/engineering_studies/focus/aero/2579/polymer_composites.html

Matrix Materials

Polymer matrix composites are the most commonly used type of composite material

Matrix material;

- Holds the fibers together, thus transferring the load between fibers and

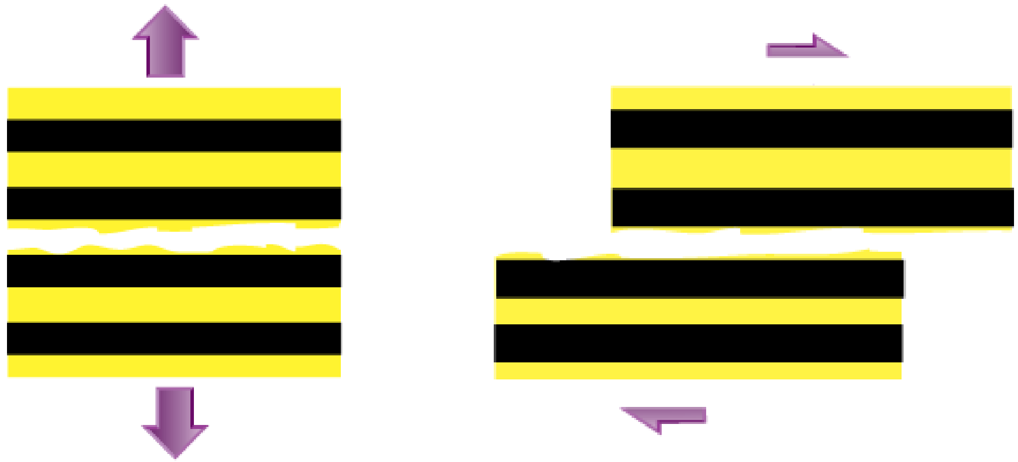
between the composite and the supports,

- Protects the fibers from environment and mechanical abrasion
- Carries some of the loads particularly transverse stress and interlaminar shear stress.

(Some properties of the composite such as transverse stifness and strength are matrix dominated. Matrix dominated properties depend strongly on the operating temperature)

The matrix of PMCs is a polymer that can be either:

- Thermoset
- Thermoplastic



transverse tensile failure *shear failure*

yellow part: matrix
black part: long fiber

Thermoset Matrices

A thermoset matrix is formed by the irriversible chemical transformation of a resin system into an amorphous cross-linked polymer matrix.

The polymer is called ***resin system*** during processing and ***matrix*** after the polymer has cured.

Thermosetting resins have ***low viscosity*** which allows for excellent impregnation of the fiber reinforcement and high processing speeds.

Shelf life: is the time the unmixed resin system can be stored without degredation. (Refrigerated storage is usually recommended)

Pot life or gel time: is the time the mixed resin can be handled before the viscosity grows to a point where processing is no longer possible.

- Curing can vary from minutes to hours (depending on the choice of the catalyst and reactivity of the resin).

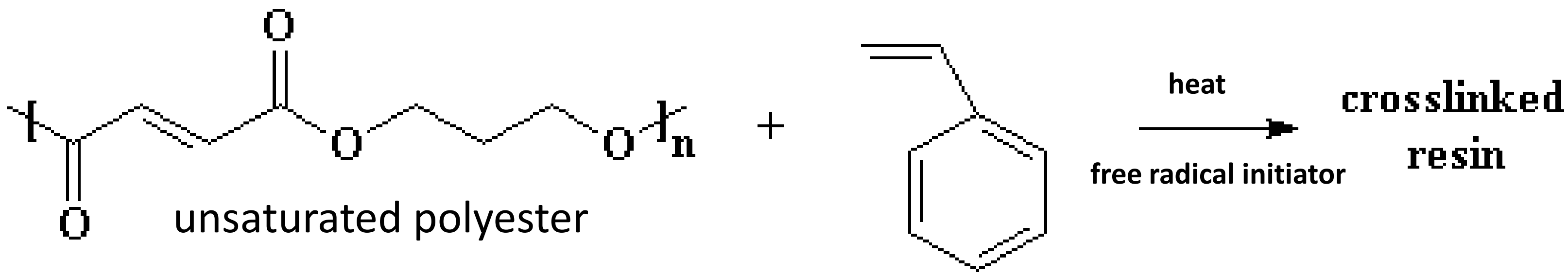
- The reactions are exothermic.

- Once cured, the mixture thickens, releases heat, solidifies and shrinks. The volumetric shrinkage upon curing varies from 4% for epoxy to 8% for polyester. Since the fiber reinforcement does not shrink, internal stress can be induced causing cracking, fiber misalignment, dimensional inaccuracy and surface roughness.

- Thermosets, because of their three-dimensional crosslinked structure, tend to have high dimensional stability, high-temperature resistance, and good resistance to solvents.

- The most common thermoset resins are polyester, vinyl ester, epoxy and phenolics. Thermosetting polyesters are commonly used in fiber-reinforced plastics, and epoxies make up most of the current market for advanced composites resins.

Polyester Resins



* Cross linking can be accomplished at room temperature using suitable activators.

*Polyester resins can be used in many outdoor applications. Superior durability, color retention and resistance to fiber erosion can be obtained when styrene-MMA monomer blends are used.

*MMA-polyesters have refractive index matched to that of glass fibers allowing to prepare transparent building panels.

*Polyester resins are considered low cost resins.

Applications include;

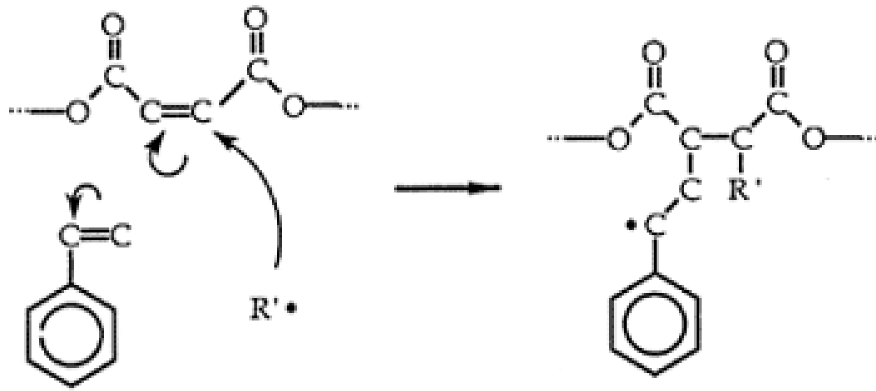
- transportation markets (large body parts for automobiles, trucks, trailers, buses)
- marine (small and large boat hulls and other marine equipment)
- building (panels, bathtub and shower shells)

Figure 1. Free radical crosslinking of a traditional unsaturated polyester

$$ROOH + Me^{n} \rightarrow RO\bullet + Me^{n+1} + OH^{-}$$

$$ROOH + Me^{n+1} \rightarrow ROO\bullet + Me^{n} + H^{+}$$

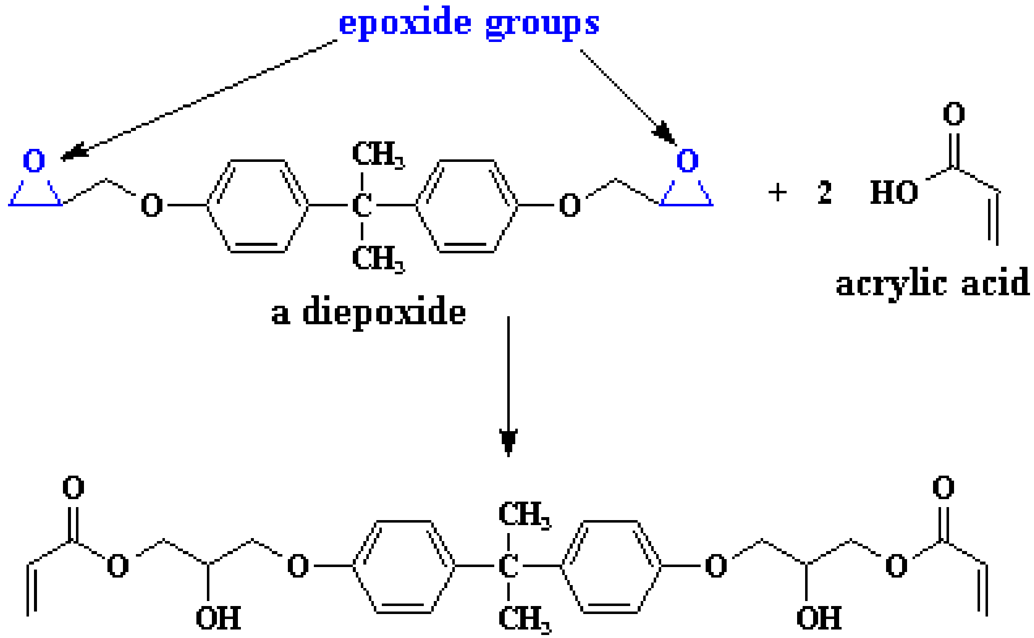
$$Me^{n+1} + RH \rightarrow Me^{n} + R'\bullet + H^{+}$$



Traditional unsaturated polyesters are polycondensation products based on saturated and unsaturated dicarboxylic acids and primary bivalent alcohols. Typically, these systems are dissolved in styrene which reacts with and cross-links the unsaturated resin when a cobalt salt and an organic peroxide, are used. The cobalt salt decomposes the peroxide to form free radicals, R'·, which initiate the crosslinking of the system. This reaction mechanism is described in Figure 1.

(Ref. Bayer Material Science)

Vinyl Ester Resins



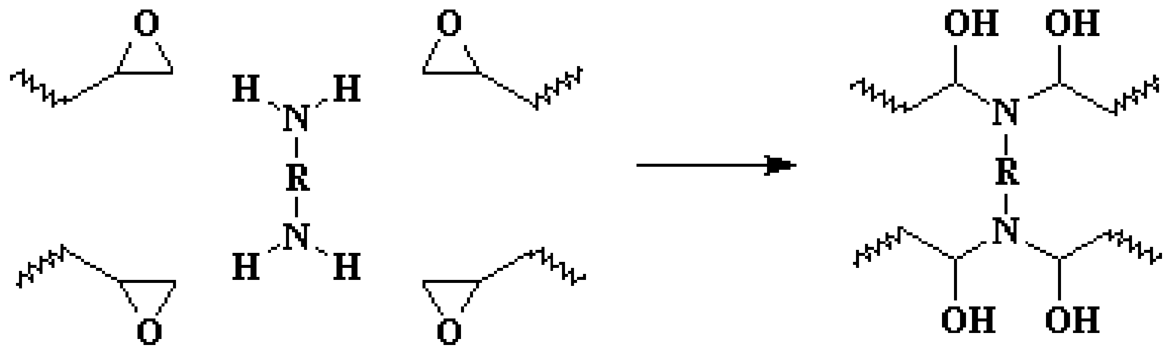
Vinyl ester resins have some advantages over unsaturated polyesters:

- They don't absorb as much water,
- They don't shrink nearly as much when cured.
- They have very good chemical resistance.
- Because of the hydroxyl groups, it bonds well to glass.

It is a common resin in the marine industry due to its increased corrosion resistance and ability to withstand water absorption.

* The cost of vinyl ester resins is between that of polyesters and epoxies.

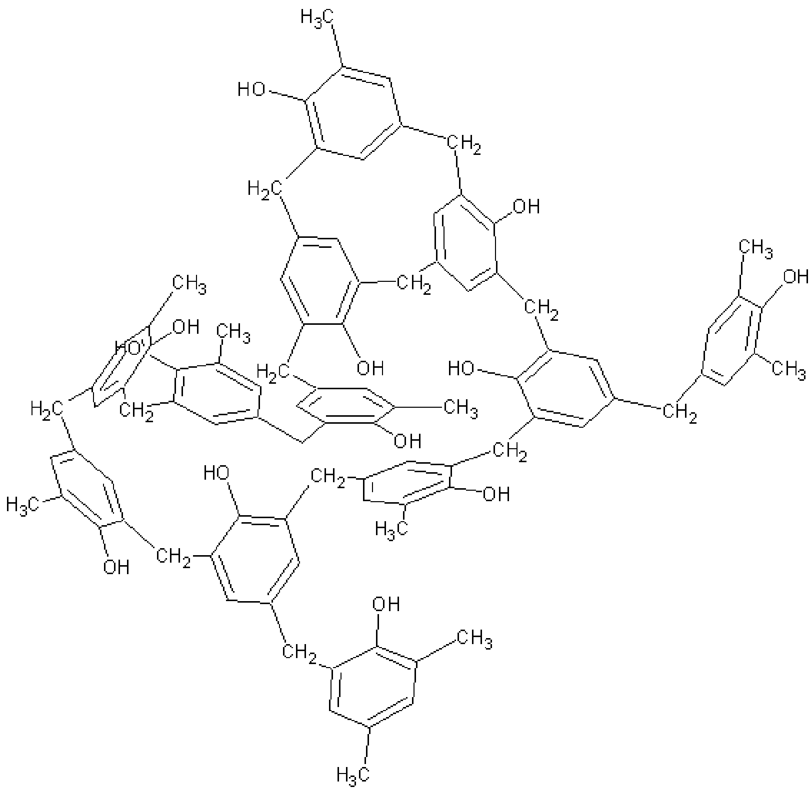
Epoxy Resins



•Because of all those hydroxyl groups, epoxy resins can bond well to glass fibers.
•Epoxies shrink less than other materials when they're cured (1.2-4% by volume).
•Epoxy resins are widely used because of their high mechanical properties and high corrosion resistances.
•Epoxy systems are used in applications like aerospace, defense, marine, sports equipment. They are also used as adhesives, body solders (lehim), sealant and casting compounds. Besides, they have a wide range of uses in the electrical business because of their excellent electrical insulation.,

Phenolic Resins

- Phenolic resins have low flammability and low smoke production compared with other low-cost resins.
- They have good dimensional stability under temperature fluctuations and good adhesive properties.



Used as molded disc brake cylinders, saucepan handles, electrical plugs and switches, parts for electrical irons and interior construction materials of aircraft and mass transit vehicles where smoke production must be extremely low.

*Cost of phenolic resins is competitive with polyesters. Disadvantages of these resins include high curing temperatures and pressures, longer curing times than polyesters, and limited color range.

NOTE

- Temperature has a detrimental influence on modulus and strength for polymers.

- Higher Tg results in a more brittle matrix with lower elongation and mechanical properties. The operating temperature is always below the Tg, which is high for brittle resins and lower for toughened resins. This means there is always a trade-off between high temperature application and mechanical properties.

- Moisture absorption is another consideration because of the detrimental effects the moisture has on mechanical properties of the matrix and the composite.

- Unreinforced polymers provide unlimited freedom for aesthetic design, they suffer from creep problems. Reinforcing plastics with fibers virtually eliminates the creep problem and opens unlimited variation of mechanical properties under the designer’s control.

Thermoplastic Matrices

- Unlike the curing process of thermosetting resins, the **processing of thermoplastics is *reversible***, and, by simply reheating to the process temperature, the resin can be formed into another shape if desired.
- Thermoplastics have ***high viscosity*** at processing temperatures, which makes them more difficult to process. The high shear stresses needed to make thermoplastic flow cause damage to the fibers resulting in a reduction of fiber length. Since, impregnation is impaired by high viscosity, special care must be taken to assure contact between the fibers and the polymer.
- Thermoplastics do not require refrigerated storage.
- Have unlimited shelf or pot life.
- Thermoplastics, although generally **inferior to thermosets in high-temperature strength and chemical stability**, ***are more resistant to cracking and impact damage.*** However, it should be noted that recently developed **high-performance thermoplastics or engineering thermoplastics**, such as PEEK, exhibit excellent high temperature strength and solvent resistance.

Engineering Thermoplastics / High Performance Thermoplastics

Poly ether etherketone (PEEK)

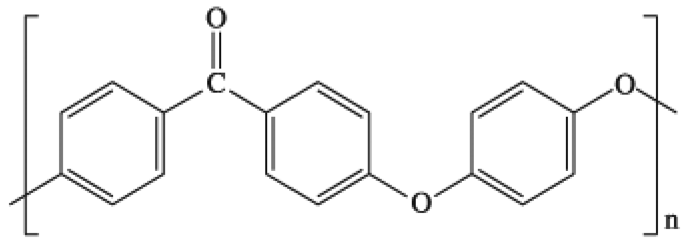
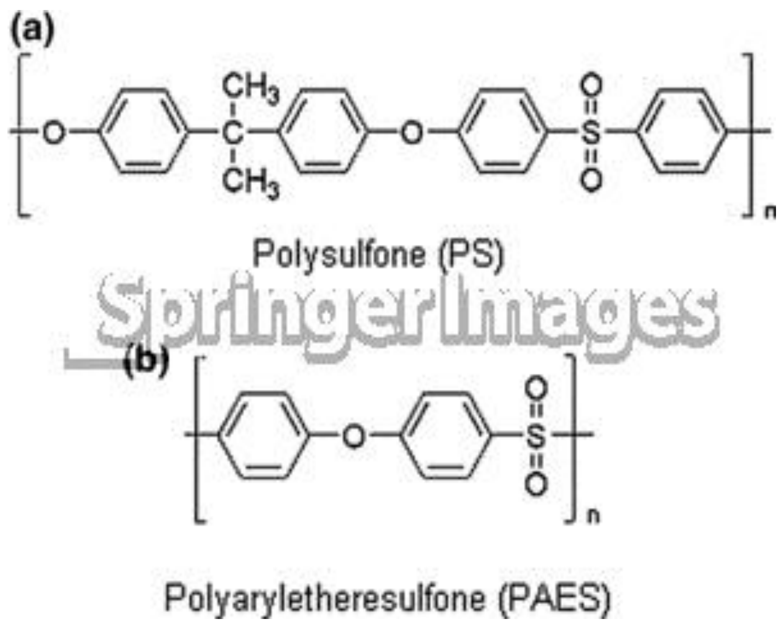


Figure 1. Chemical structure of PEEK[2,15].

- The most common thermoplastic matrix for **high performance applications**.
- Have a semicrystalline microstructure with very ***low water absorption*** (0.5% by weight) at room temperature, much lower than for most epoxies.
- PEEK has a glass transition temperature of around 143°C and melts around 343°C. The operating temperature is around 250°C (operating temperature for brittle epoxies is ~250°C and toughened epoxies between 75-185°C).
- CF/*PEEK* is shown to be more than 10 times ***tougher*** *than* CF/*epoxy**.

*Ahmed Khairy Noor, Samuel L. Venneri, Future Aeronautical and Space Systems, *ISBN:1563471884*, 1997

Polysulfones



- Amorphous thermoplastic.
- **Excellent stability under hot and wet conditions**.
- Their high hydrolysis stability allows their use in medical applications requiring autoclave and steam sterilization.
- They rated as **self-extinguishing**, with low smoke and toxic fume generation.
- PS has a glass transition temperature of around 185°C and the operating temperature is around 165°C.
- Due to the high cost of raw materials and processing, polysulfones are used in specialty applications.
- Not UV-stable ☹

Headlamp housing made of a newly developed, heat-stabilized polyethersulfone

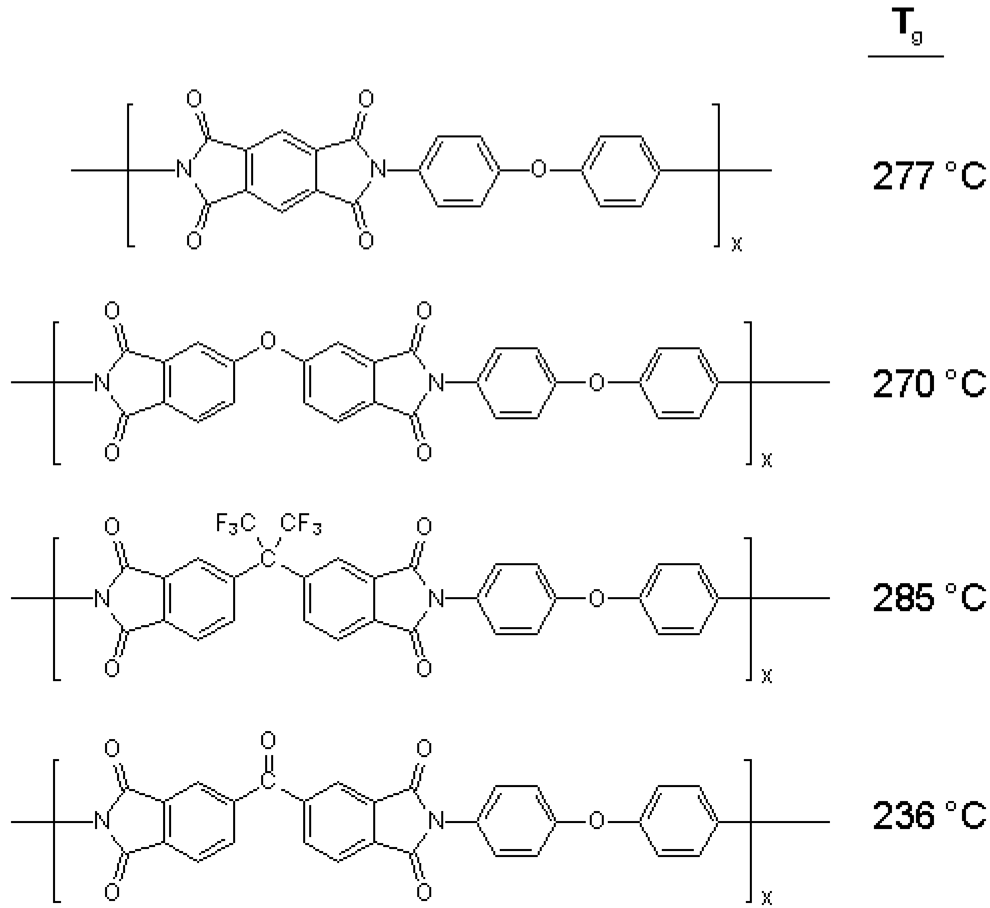
Polyarylsulfones (PSU, PESU, PPSU)

Polyimides

• Amorphous thermoplastics with high glass transition temperatures.

•**Polyamide-imides** have exceptional mechanical, thermal and chemical resistant properties. These properties put polyamide-imides **at the top of the price and performance pyramid.**

•PAI has low processability ☹.



http://www.dupont.com/products-and-services/membranes-films/polyimide-films/brands/kapton-polyimide-film/videos/video-kapton-unlock-your-imgination.html

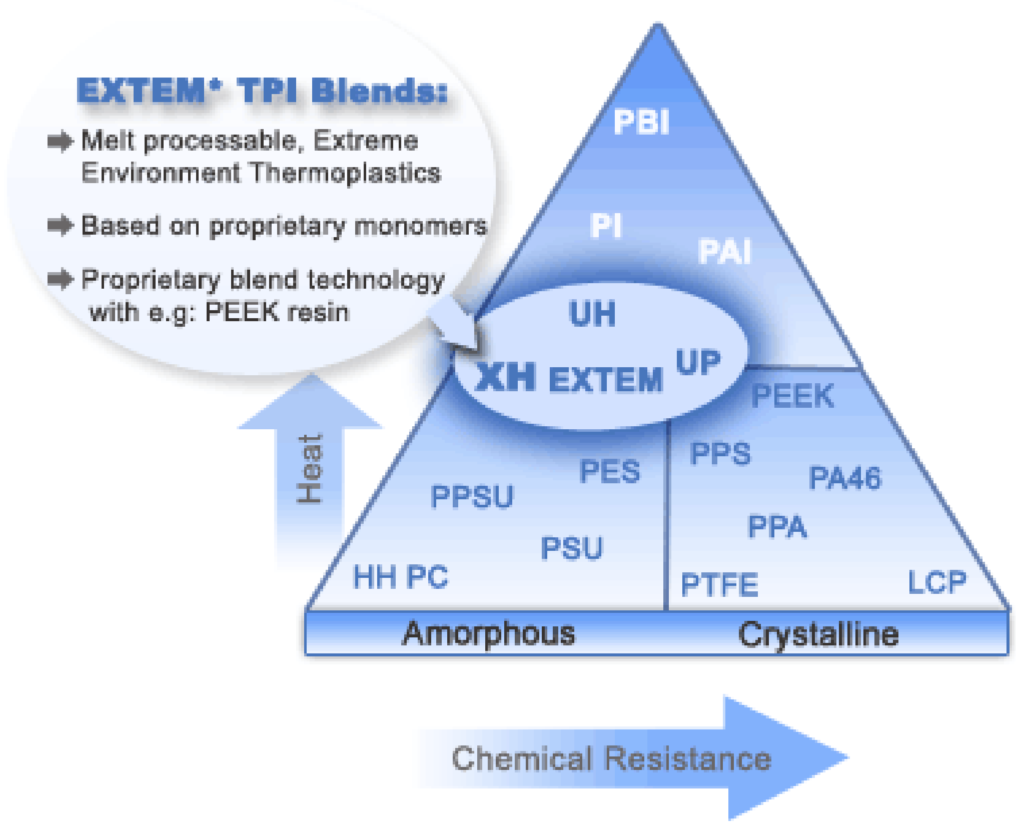
You should consider TPI Blends if you are looking for an **easy-to-process high heat material** providing **superior part reliability** through:

•**Great dimensional stability** under **high heat conditions**

•**Higher retention of mechanical properties** under high continuous / peak temperature (**up to 300°C with TPI!)**

•**Better infrared heat resistance** and **improved surface reflection** (i.e. metalized surfaces) through excellent **light transmission properties**

•**Continuity of part performance in harsh environments** through **excellent chemical resistance** (i.e. Oil & Gas Industry, Aerospace, Under-the-hood in Automotive etc...)



Thermoplastics offer great promise for the future from a manufacturing point of view, because;

it is easier and faster to heat and cool a material than it is to cure it

This makes thermoplastic matrices attractive to high-volume industries such as the automotive industry. Currently, thermoplastics are used primarily with discontinuous fiber reinforcements such as chopped glass or carbon/graphite. However, there is great potential for high-performance thermoplastics reinforced with continuous fibers. For example, thermoplastics could be used in place of epoxies in the composite structure of the next generation of fighter aircraft*.

*Barbero E. J. Introduction to Composite Materials Design , Taylor and Francis, 1999.