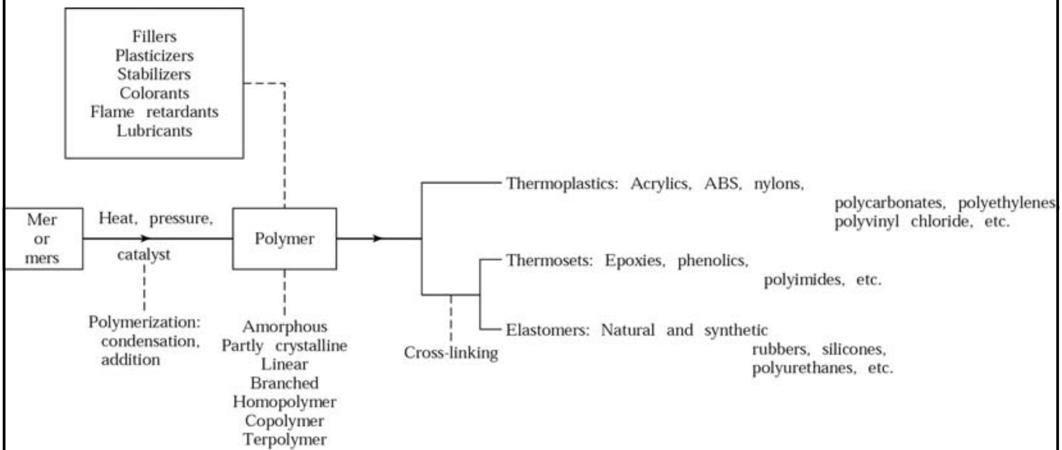
Properties of Polymers (chapter 10)

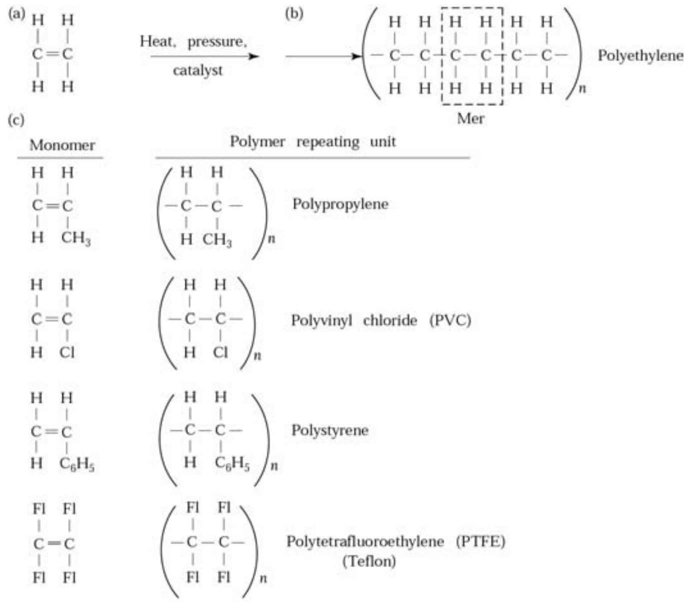


Range of Mechanical Properties for Various Engineering Plastics

Material	UTS (MPa)	*E* (GPa)	Elongation (%)	Poisson's ratio (ν)
ABS	28–55	1.4–2.8	75–5	—
ABS, reinforced	100	7.5	—	0.35
Acetal	55–70	1.4–3.5	75–25	—
Acetal, reinforced	135	10	—	0.35–0.40
Acrylic	40–75	1.4–3.5	50–5	—
Cellulosic	10–48	0.4–1.4	100–5	—
Epoxy	35–140	3.5–17	10–1	—
Epoxy, reinforced	70–1400	21–52	4–2	—
Fluorocarbon	7–48	0.7–2	300–100	0.46–0.48
Nylon	55–83	1.4–2.8	200–60	0.32–0.40
Nylon, reinforced	70–210	2–10	10–1	—
Phenolic	28–70	2.8–21	2–0	—
Polycarbonate	55–70	2.5–3	125–10	0.38
Polycarbonate, reinforced	110	6	6–4	—
Polyester	55	2	300–5	0.38
Polyester, reinforced	110–160	8.3–12	3–1	—
Polyethylene	7–40	0.1–1.4	1000–15	0.46
Polypropylene	20–35	0.7–1.2	500–10	—
Polypropylene, reinforced	40–100	3.5–6	4–2	—
Polystyrene	14–83	1.4–4	60–1	0.35
Polyvinyl chloride	7–55	0.014–4	450–40	—

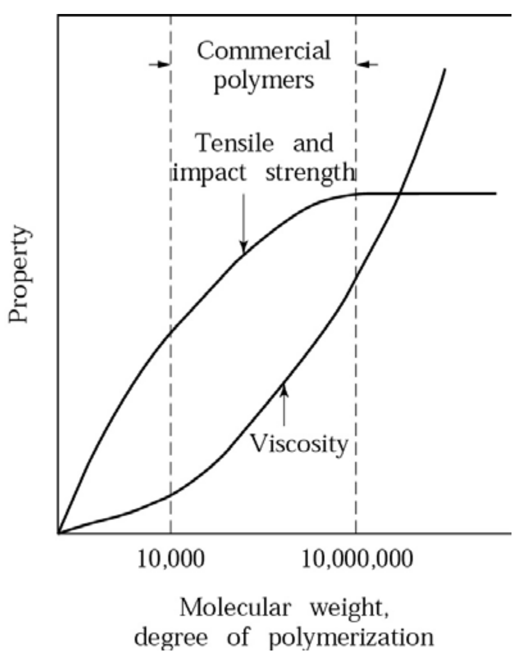
Structure of Polymer Molecules

Polymers are long-chain molecules, that are formed by polymerization, that is, by linking and cross-linking different monomers. Many of a polymer's properties depend largely on (a) the structure of individual polymer molecules , (b) the shape and size of the molecules, and (c) how the molecules are arranged to form a polymer structure.



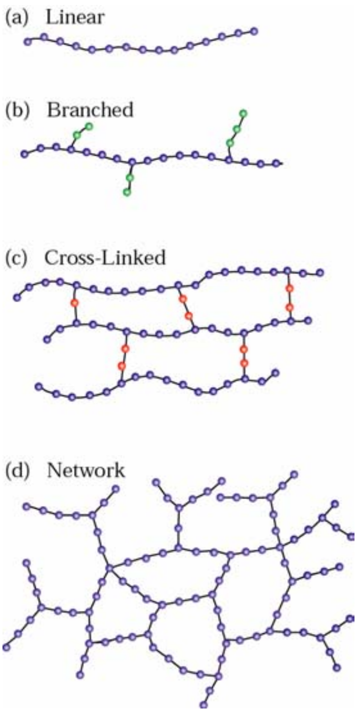
Basic structure of polymer molecules: (a) ethylene molecule; (b) polyethylene, a linear chain of many ethylene molecules; molecular structure of various polymers. These are examples of the basic building blocks for plastics

Molecular Weight and Degree of Polymerization



Effect of molecular weight and degree of polymerization (size of molecules) on the strength and viscosity of polymers. Molecular weight have a strong influence on the properties of polimers on mechanical and rheological characteristics

Polymer Chains



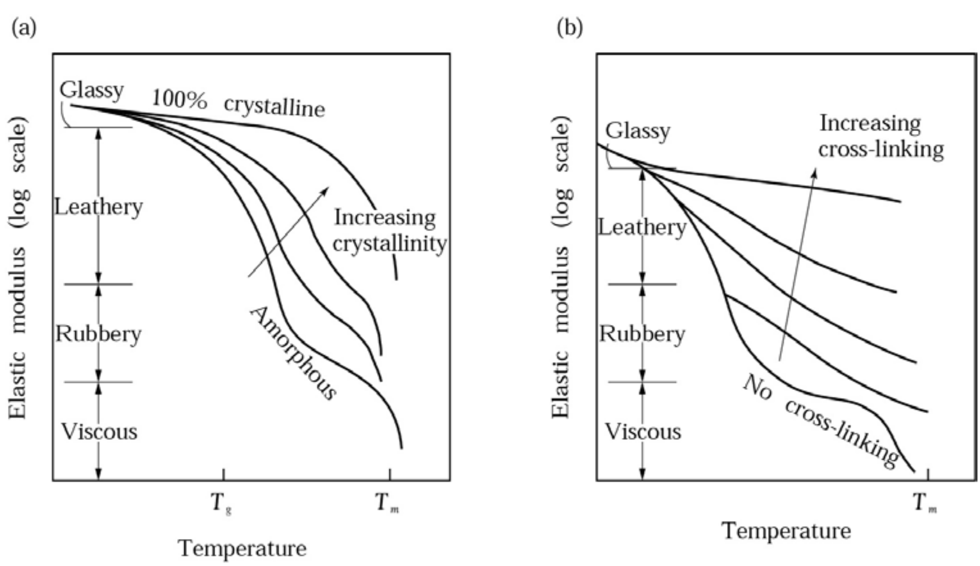
Schematic illustration of polymer chains. (a) Linear structure; thermoplastics such as acrylics, nylons, polyethylene, and polyvinyl chloride have linear structures. (b) Branched structure, such as in polyethylene. (c) Cross-linked structure-many rubbers or elastomers have this structure, and the vulcanization of rubber produces this structure. (d) Network structure, which is basically highly cross-linked--examples are thermosetting plastics, such as epoxies and phenolics.

<u>Copolymer and terpolymers</u>.

If the repeating units in a polymer chain are all of the same type, the molecule is called homoplymer. However two or three different types of monomers can be combined to impart certain special propertiesand characteristics to the polymer. *Copolymers* contain two types of monomer, instead *terpolymers* contain three types of monomer.

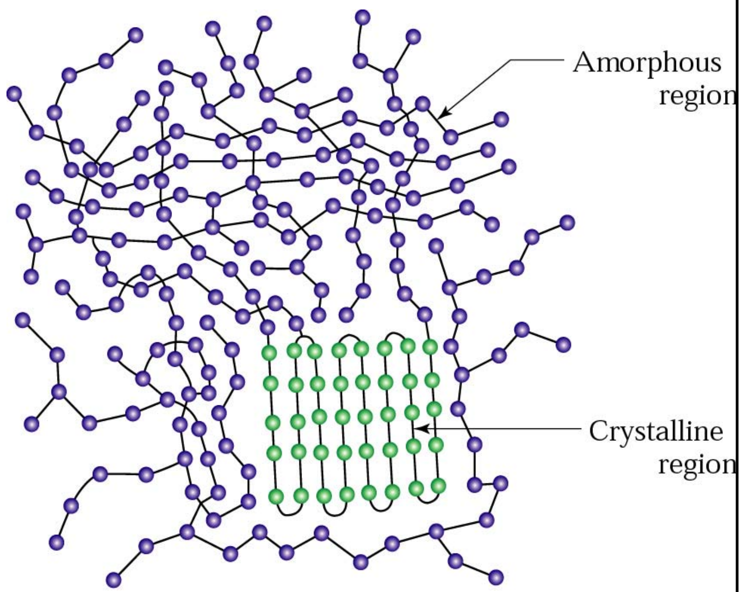
Polymer Behavior

Behavior of polymers as a function of temperature and (a) degree of crystallinity and (b) cross-linking. The combined elastic and viscous behavior of polymers is known as viscoelasticity.

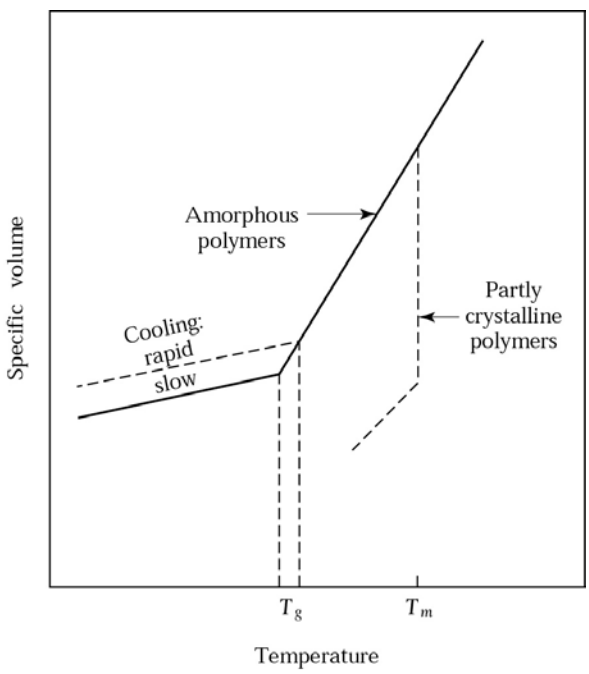


Crystallinity

Amorphous and crystalline regions in a polymer. The crystalline region (crystallite) has an orderly arrangement of molecules. The mechanical and physical properties of greatly influenced by the degree of crystallinity. The higher the crystallinity, the harder, stiffer, more dense and less ductile the polymer.



Specific Volume as a Function of Temperature

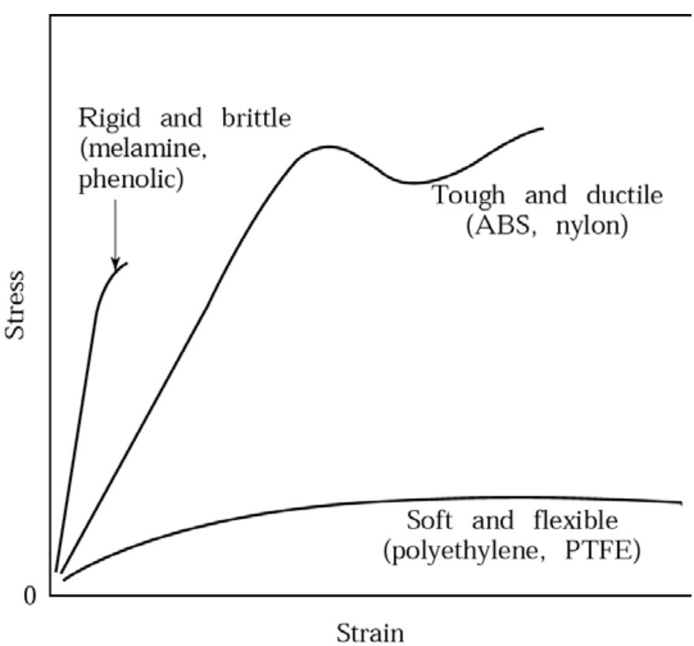


Specific volume of polymers as a function of temperature. Amorphous polymers, such as acrylic and polycarbonate, have a glass-transition temperature, T_g, but do not have a specific melting point, T_m. Partly crystalline polymers, such as polyethylene and nylons, contract sharply while passing through their melting temperatures during cooling.

Glass-Transition and Melting Temperatures of Some Polymers

Material	T_g (°C)	T_m (°C)
Nylon 6,6	57	265
Polycarbonate	150	265
Polyester	73	265
Polyethylene		
High density	–90	137
Low density	–110	115
Polymethylmethacrylate	105	—
Polypropylene	–14	176
Polystyrene	100	239
Polytetrafluoroethylene	–90	327
Polyvinyl chloride	87	212
Rubber	–73	—

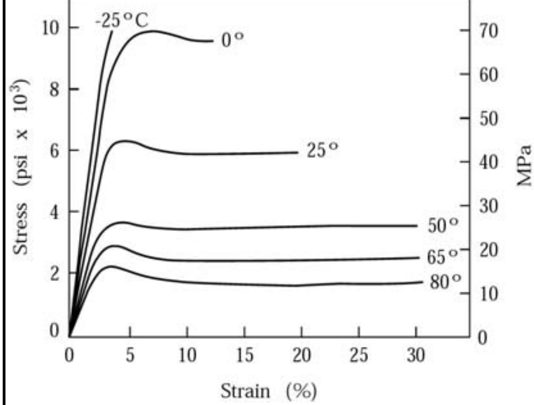
Behavior of Plastics



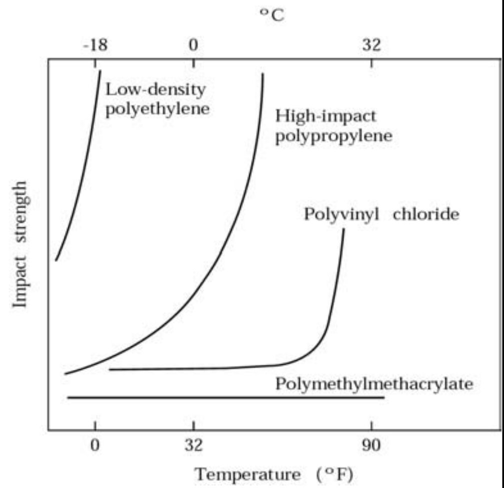
Typical stress-strain curves for some thermoplastics and thermosets at room temperature. Note that this plastics exhibit different behaviour: rigid, ductile, flexible. Plastics, as metals, undergo fatigue and creep phenomena as well.

PTFE (polytetrafluoroethylene) has *Teflon* as its trade name.

Temperature Effects



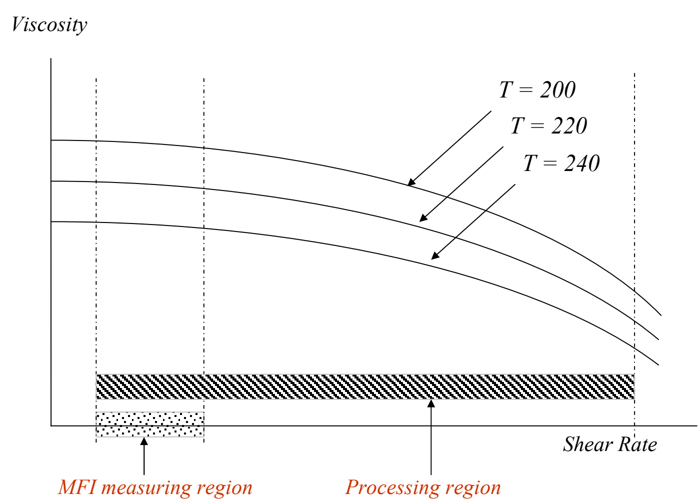
Effect of temperature on the stress-strain curve for cellulose acetate, a thermoplastic. Note the large drop in strength and the large increase in ductility with a relatively small increase in temperature.



Effect of temperature on the impact strength of various plastics. Small changes in temperature can have a significant effect on impact strength.

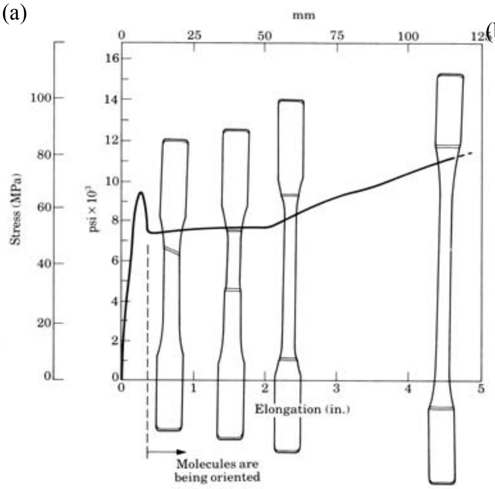
Deformation rate effects

The *viscosity*, one of the most important polymer's properties in plastics processing, is function of temperature and shear rate. This characteristic indicates that for many polymers, Newtonian behavior is not a good approximation. This rheological behavior has great influence on plastic's production process.

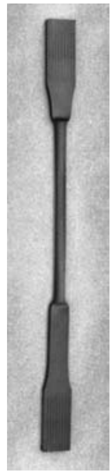


Elongation and polymer properties

(a)



(b)



(a) Load-elongation curve , that shows *visco-elastic plastic behavior*, for polycarbonate, a thermoplastic. (b) High-density polyethylene tensile-test specimen, showing uniform elongation (the long, narrow region in the specimen).

Creep and stress relaxation: these terms indicates the permanent elongationof a component under a static load maintained for a period of time. Beacause of their viscoelastic behaviour, thermoplastics are particularly susceptible to these phenomena.

Orientation: when termoplastics are permanently deformed the long chain align in the direction of elongation. This process is called elongation and, because of this, the polymer becomes anisotropic.

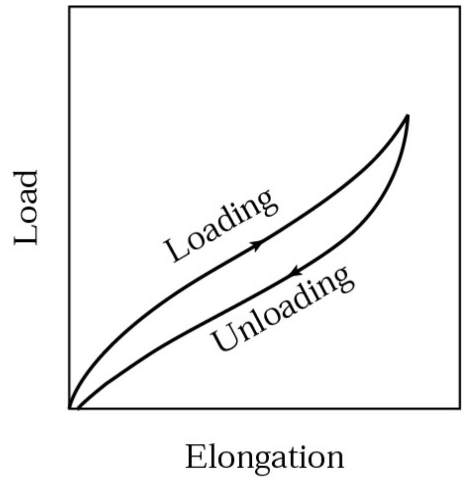
Water absorption: an important limitation of some polymer is their ability of absorb water (hygroscopy). Water, acting as a plasticizing, makes polymer more plastic.

General Recommendations for Plastic Products

Design requirement	Applications	Plastics
Mechanical strength	Gears, cams, rollers, valves, fan blades, impellers, pistons	Acetal, nylon, phenolic, polycarbonate
Functional and decorative	Handles, knobs, camera and battery cases, trim moldings, pipe fittings	ABS, acrylic, cellulosic, phenolic, polyethylene, polypropylene, polystyrene, polyvinyl chloride
Housings and hollow shapes	Power tools, pumps, housings, sport helmets, telephone cases	ABS, cellulosic, phenolic, polycarbonate, polyethylene, polypropylene, polystyrene
Functional and transparent	Lenses, goggles, safety glazing, signs, food-processing equipment, laboratory hardware	Acrylic, polycarbonate, polystyrene, polysulfone
Wear resistance	Gears, wear strips and liners, bearings, bushings, roller-skate wheels	Acetal, nylon, phenolic, polyimide, polyurethane, ultrahigh molecular weight polyethylene

Elastomers (Rubbers)

Typical load-elongation curve for rubbers. A Rubber or an elastomer are defined as being capable recovering substantially in shape and size after a load has been removed. The structure of these polymers is higly linked. Once the elastomer is cross-linked, it cannot be reshaped. The clockwise lop, indicating the loading and the unloading paths, displays the hysteresis loss. Hysteresis gives rubbers the capacity to dissipate energy, damp vibraion, and absorb shock loading, as is necessary in automobile tires and in vibration dampers placed under machinery.



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Reinforced plastics

Among the major developments in materials are *reinforced plastics.* These materials can be defined as a combination of two or more chenically distinct and insoluble phaseswhose properties are superior to those of the the costituent acting separately. Plastics posses low mechanical properties. These properties can be improved by embedding reinforcements of varios type Reinforced plastics consists in fibers (the discontinuos or dispersed phase) in a polymer matrix. Fibers are classified as short or long fibers also calle d discontinuos fibers.The short and long-fiber designation are in general based on following observation: in a given fiber, if the mechanical properties improve as a result of increasing the fiber length, then the fibers is denoted as a short fiber. On contrary the fibers are denoted long fiber.

Types and General Characteristics of Reinforced Plastics and Metal-Matrix and Ceramic-Matrix Composites

Material	Characteristics
FIBER	
Glass	High strength, low stiffness, high density; E (calcium aluminoborosilicate) and S (magnesia–aluminosilicate) types are commonly used; lowest cost.
Graphite	Available typically as high modulus or high strength; less dense than glass; low cost.
Boron	High strength and stiffness; has tungsten filament at its center (coaxial); highest density; highest cost.
Aramids (Kevlar)	Highest strength-to-weight ratio of all fibers; high cost.
Other	Nylon, silicon carbide, silicon nitride, aluminum oxide, boron carbide, boron nitride, tantalum carbide, steel, tungsten, and molybdenum; see Chapters 3, 8, 9, and 10.
MATRIX	
Thermosets	Epoxy and polyester, with the former most commonly used; others are phenolics, fluorocarbons, polyethersulfone, silicon, and polyimides.
Thermoplastics	Polyetheretherketone; tougher than thermosets, but lower resistance to temperature.
Metals	Aluminum, aluminum–lithium alloy, magnesium, and titanium; fibers used are graphite, aluminum oxide, silicon carbide, and boron.
Ceramics	Silicon carbide, silicon nitride, aluminum oxide, and mullite; fibers used are various ceramics.

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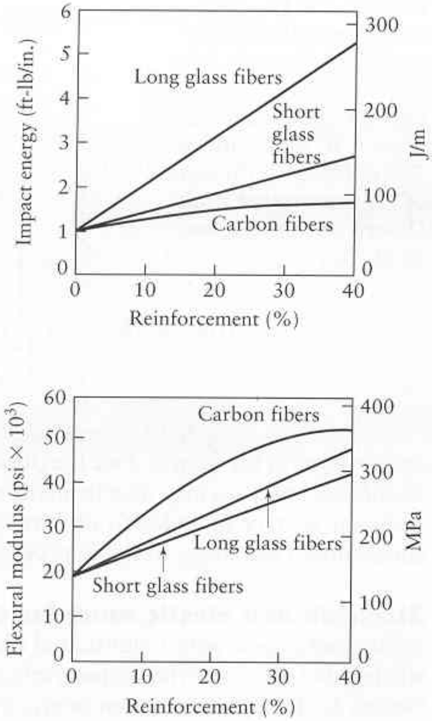
Properties of reinforced plastics



The properties of reinforced plastics are influenced by several factors. The most important are: type and shape of reinforcing material; the lenght of the fiber (short fiber are less effective than long); and the volume fraction of the reinforcing material. Another critical factor in reiforced plastic is the kind of bond between fiber and matrix.