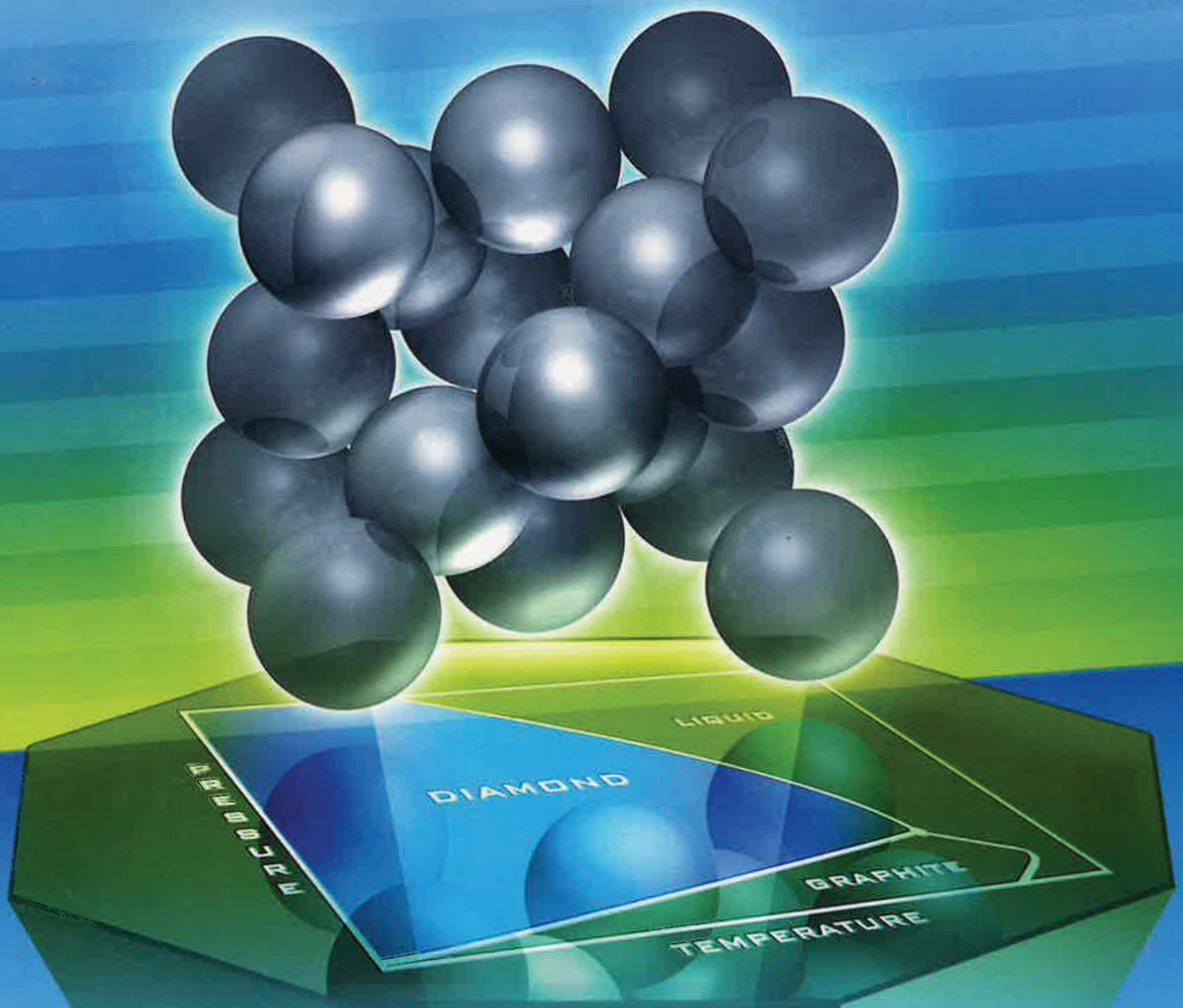
SEVENTH EDITION

MATERIALS SCIENCE AND ENGINEERING AN INTRODUCTION

William D. Callister, Jr.



SEVENTH EDITION

Materials Science and Engineering

An Introduction

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The University of Utah

with special contributions by
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The University of Iowa



John Wiley & Sons, Inc.

Front Cover: A unit cell for diamond (blue-gray spheres represent carbon atoms), which is positioned above the temperature-versus-logarithm pressure phase diagram for carbon; highlighted in blue is the region for which diamond is the stable phase.
Back Cover: Atomic structure for graphite; here the gray spheres depict carbon atoms. The region of graphite stability is highlighted in orange on the pressure-temperature phase diagram for carbon, which is situated behind this graphite structure.

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Concept Check 15.7

For each of the following two polymers, plot and label a schematic specific volume-versus-temperature curve (include both curves on the same graph):

- Spherulitic polypropylene, of 25% crystallinity, and having a weight-average molecular weight of 75,000 g/mol
- Spherulitic polystyrene, of 25% crystallinity, and having a weight-average molecular weight of 100,000 g/mol.

[*The answer may be found at www.wiley.com/college/callister (Student Companion Site).*]

Concept Check 15.8

For the two polymers described below, do the following: (1) state whether or not it is possible to determine whether one polymer has a higher melting temperature than the other; (2) if it is possible, note which has the higher melting temperature and then cite reason(s) for your choice; and (3) if it is not possible to decide, then state why not.

- Isotactic polystyrene that has a density of 1.12 g/cm^3 and a weight-average molecular weight of 150,000 g/mol
- Syndiotactic polystyrene that has a density of 1.10 g/cm^3 and a weight-average molecular weight of 125,000 g/mol.

[*The answer may be found at www.wiley.com/college/callister (Student Companion Site).*]

Polymer Types

There are many different polymeric materials that are familiar to us and find a wide variety of applications; in fact, one way of classifying them is according to their end-use. Within this scheme the various polymer types include plastics, elastomers (or rubbers), fibers, coatings, adhesives, foams, and films. Depending on its properties, a particular polymer may be used in two or more of these application categories. For example, a plastic, if crosslinked and utilized above its glass transition temperature, may make a satisfactory elastomer. Or a fiber material may be used as a plastic if it is not drawn into filaments. This portion of the chapter includes a brief discussion of each of these types of polymer.

15.15 PLASTICS

plastic

Possibly the largest number of different polymeric materials come under the plastic classification. **Plastics** are materials that have some structural rigidity under load, and are used in general-purpose applications. Polyethylene, polypropylene, poly(vinyl chloride), polystyrene, and the fluorocarbons, epoxies, phenolics, and polyesters may all be classified as plastics. They have a wide variety of combinations of properties. Some plastics are very rigid and brittle (Figure 15.1, curve *A*). Others are flexible, exhibiting both elastic and plastic deformations when stressed, and sometimes experiencing considerable deformation before fracture (Figure 15.1, curve *B*).

Polymers falling within this classification may have any degree of crystallinity, and all molecular structures and configurations (linear, branched, isotactic, etc.) are possible. Plastic materials may be either thermoplastic or thermosetting; in fact, this is the manner in which they are usually subclassified. However, to be considered

plastics, linear or branched polymers must be used below their glass transition temperatures (if amorphous) or below their melting temperatures (if semicrystalline), or must be crosslinked enough to maintain their shape. The trade names, characteristics, and typical applications for a number of plastics are given in Table 15.3.

Several plastics exhibit especially outstanding properties. For applications in which optical transparency is critical, polystyrene and poly(methyl methacrylate) are especially well suited; however, it is imperative that the material be highly amorphous or, if semicrystalline, have very small crystallites. The fluorocarbons have a low coefficient of friction and are extremely resistant to attack by a host of chemicals, even at relatively high temperatures. They are utilized as coatings on nonstick cookware, in bearings and bushings, and for high-temperature electronic components.

Table 15.3 Trade Names, Characteristics, and Typical Applications for a Number of Plastic Materials

Material Type	*Trade Names*	*Major Application Characteristics*	*Typical Applications*
		Thermoplastics	
Acrylonitrile-butadiene-styrene (ABS)	Abson Cycolac Kralastic Lustran Novodur Tybrene	Outstanding strength and toughness, resistant to heat distortion; good electrical properties; flammable and soluble in some organic solvents	Refrigerator linings, lawn and garden equipment, toys, highway safety devices
Acrylics [poly(methyl methacrylate)]	Acrylite Diakon Lucite Plexiglas	Outstanding light transmission and resistance to weathering; only fair mechanical properties	Lenses, transparent aircraft enclosures, drafting equipment, outdoor signs
Fluorocarbons (PTFE or TFE)	Teflon Fluon Halar Hostaflon TF Neoflon	Chemically inert in almost all environments, excellent electrical properties; low coefficient of friction; may be used to 260°C (500°F); relatively weak and poor cold-flow properties	Anticorrosive seals, chemical pipes and valves, bearings, antiadhesive coatings, high-temperature electronic parts
Polyamides (nylons)	Nylon Baylon Durethan Herox Nomex Ultramid Zytel	Good mechanical strength, abrasion resistance, and toughness; low coefficient of friction; absorbs water and some other liquids	Bearings, gears, cams, bushings, handles, and jacketing for wires and cables
Polycarbonates	Calibre Iupilon Lexan Makrolon Merlon	Dimensionally stable; low water absorption; transparent; very good impact resistance and ductility; chemical resistance not outstanding	Safety helmets, lenses, light globes, base for photographic film
Polyethylene	Alathon Alkathene Fortiflex Hi-fax Petrothene Rigidex Rotothene Zendel	Chemically resistant and electrically insulating; tough and relatively low coefficient of friction; low strength and poor resistance to weathering	Flexible bottles, toys, tumblers, battery parts, ice trays, film wrapping materials

Table 15.3 (Continued)

Material Type	Trade Names	Major Application Characteristics	Typical Applications
Polypropylene	Herculon Meraklon Moplen Poly-pro Pro-fax Propak Propathene	Resistant to heat distortion; excellent electrical properties and fatigue strength; chemically inert; relatively inexpensive; poor resistance to UV light	Sterilizable bottles, packaging film, TV cabinets, luggage
Polystyrene	Carinex Dylene Hostyren Lustrex Styron Vestyron	Excellent electrical properties and optical clarity; good thermal and dimensional stability; relatively inexpensive	Wall tile, battery cases, toys, indoor lighting panels, appliance housings
Vinyls	Darvic Exon Geon Pliovic Saran Tygon Vista	Good low-cost, general-purpose materials; ordinarily rigid, but may be made flexible with plasticizers; often copolymerized; susceptible to heat distortion	Floor coverings, pipe, electrical wire insulation, garden hose, phonograph records
Polyester (PET or PETE)	Celanar Dacron Eastapak Hylar Melinex Mylar Petra	One of the toughest of plastic films; excellent fatigue and tear strength, and resistance to humidity, acids, greases, oils, and solvents	Magnetic recording tapes, clothing, automotive tire cords, beverage containers
		Thermosetting Polymers	
Epoxies	Araldite Epikote Epon Epi-rez Lekutherm Lytex	Excellent combination of mechanical properties and corrosion resistance; dimensionally stable; good adhesion; relatively inexpensive; good electrical properties	Electrical moldings, sinks, adhesives, protective coatings, used with fiberglass laminates
Phenolics	Bakelite Amberol Arofene Durite Resinox	Excellent thermal stability to over 150°C (300°F); may be compounded with a large number of resins, fillers, etc.; inexpensive	Motor housings, telephones, auto distributors, electrical fixtures
Polyesters	Aropol Baygal Derakane Laminac Selectron	Excellent electrical properties and low cost; can be formulated for room- or high-temperature use; often fiber reinforced	Helmets, fiberglass boats, auto body components, chairs, fans

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MATERIAL OF IMPORTANCE

Phenolic Billiard Balls

Up until about 1912 virtually all billiard balls were made of ivory that came only from the tusks of elephants. For a ball to roll true, it needed to be fashioned from high-quality ivory that came from the center of flaw-free tusks—on the order of one tusk in fifty had the requisite consistency of density. At this time, ivory was becoming scarce and expensive as more and more elephants were being killed (and billiards was becoming popular). Also, there was then (and still is) a serious concern about reductions in elephant populations (and their ultimate extinction) due to ivory hunters, and some countries had imposed (and still impose) severe restrictions on the importation of ivory and ivory products.

Consequently, substitutes for ivory were sought for billiard balls. For example, one early alternative was a pressed mixture of wood pulp and bone dust; this material proved quite unsatisfactory. The most suitable replacement (which is still being used for billiard balls today) is one of the first man-made polymers—phenol-formaldehyde, sometimes also called "phenolic".

The invention of this material is one of the important and interesting events in the annals of man-made polymers. The discoverer of the process for synthesizing phenol-formaldehyde was Leo Baekeland. As a young and very bright Ph.D. chemist, he immigrated from Belgium to the United States in the early 1900s. Shortly after his arrival, he began research into creating a synthetic shellac, to replace the natural material, which was relatively expensive to manufacture; shellac was (and is still) used as a lacquer, a wood preservative, and as an electrical insulator in the then-emerging electrical industry. His efforts eventually led to the discovery that a suitable substitute could be synthesized by reacting phenol [or carbolic acid (C_6H_5OH), a white crystalline material] with formaldehyde (HCHO, a colorless and poisonous gas) under controlled conditions of heat and pressure. The product of this reaction was a liquid that subsequently hardened into a transparent and amber-colored solid. Baekeland named his new material "Bakelite"; today we use the generic names "phenol-formaldehyde" or just "phenolic". Shortly after its discovery, Bakelite was found to be the ideal synthetic material for billiard balls (per the chapter-opening photograph for this chapter).

Phenol-formaldehyde is a thermosetting polymer, and has a number of desirable properties: for a polymer it is very heat resistant and hard, is less brittle than many of the ceramic materials, is very stable and unreactive with most common solutions and solvents, and doesn't easily chip, fade, or discolor. Furthermore, it is a relatively inexpensive material, and modern phenolics can be produced having a large variety of colors. The elastic characteristics of this polymer are very similar to those of ivory, and when phenolic billiard balls collide, they make the same clicking sound as ivory balls. Other uses of this important polymeric material are found in Table 15.3.

15.16 ELASTOMERS

The characteristics of and deformation mechanism for elastomers were treated previously (Section 15.9). The present discussion, therefore, focuses on the types of elastomeric materials.

Table 15.4 lists properties and applications of common elastomers; these properties are typical and, of course, depend on the degree of vulcanization and on whether any reinforcement is used. Natural rubber is still utilized to a large degree because it has an outstanding combination of desirable properties. However, the most important synthetic elastomer is SBR, which is used predominantly in automobile tires, reinforced with carbon black. NBR, which is highly resistant to degradation and swelling, is another common synthetic elastomer.

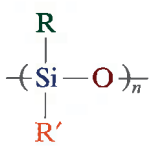
Table 15.4 Tabulation of Important Characteristics and Typical Applications for Five Commercial Elastomers

Chemical Type	*Trade (Common) Names*	*Elongation (%)*	*Useful Temperature Range [°C (°F)]*	*Major Application Characteristics*	*Typical Applications*
Natural polyisoprene	Natural rubber (NR)	500–760	−60 to 120 (−75 to 250)	Excellent physical properties; good resistance to cutting, gouging, and abrasion; low heat, ozone, and oil resistance; good electrical properties	Pneumatic tires and tubes; heels and soles; gaskets
Styrene-butadiene copolymer	GRS, Buna S (SBR)	450–500	−60 to 120 (−75 to 250)	Good physical properties; excellent abrasion resistance; not oil, ozone, or weather resistant; electrical properties good, but not outstanding	Same as natural rubber
Acrylonitrile-butadiene copolymer	Buna A, Nitrile (NBR)	400–600	−50 to 150 (−60 to 300)	Excellent resistance to vegetable, animal, and petroleum oils; poor low-temperature properties; electrical properties not outstanding	Gasoline, chemical, and oil hose; seals and O-rings; heels and soles
Chloroprene	Neoprene (CR)	100–800	−50 to 105 (−60 to 225)	Excellent ozone, heat, and weathering resistance; good oil resistance; excellent flame resistance; not as good in electrical applications as natural rubber	Wire and cable; chem. tank linings; belts, hoses, seals, and gaskets
Polysiloxane	Silicone (VMQ)	100–800	−115 to 315 (−175 to 600)	Excellent resistance to high and low temperatures; low strength; excellent electrical properties	High- and low-temperature insulation; seals, diaphragms; tubing for food and medical uses

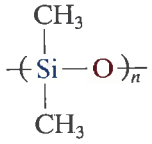
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For many applications (e.g., automobile tires), the mechanical properties of even vulcanized rubbers are not satisfactory in terms of tensile strength, abrasion and tear resistance, and stiffness. These characteristics may be further improved by additives such as carbon black (Section 16.2).

Finally, some mention should be made of the silicone rubbers. For these materials, the backbone chain is made of alternating silicon and oxygen atoms:



where R and R′ represent side-bonded atoms such as hydrogen or groups of atoms such as CH_3. For example, polydimethylsiloxane has the repeat unit



Of course, as elastomers, these materials are crosslinked.

The silicone elastomers possess a high degree of flexibility at low temperatures [to −90°C (−130°F)] and yet are stable to temperatures as high as 250°C (480°F). In addition, they are resistant to weathering and lubricating oils, which makes them particularly desirable for applications in automobile engine compartments. Biocompatibility is another of their assets, and, therefore, they are often employed in medical applications such as blood tubing. A further attractive characteristic is that some silicone rubbers vulcanize at room temperature (RTV rubbers).

Concept Check 15.9

During the winter months, the temperature in some parts of Alaska may go as low as −55°C (−65°F). Of the elastomers natural isoprene, styrene-butadiene, acrylonitrile-butadiene, chloroprene, and polysiloxane, which would be suitable for automobile tires under these conditions? Why?

[*The answer may be found at www.wiley.com/college/callister (Student Companion Site).*]

Concept Check 15.10

Silicone polymers may be prepared to exist as liquids at room temperature. Cite differences in molecular structure between them and the silicone elastomers. *Hint:* You may want to consult Sections 14.5 and 15.9.

[*The answer may be found at www.wiley.com/college/callister (Student Companion Site).*]

15.17 FIBERS

fiber

The **fiber** polymers are capable of being drawn into long filaments having at least a 100:1 length-to-diameter ratio. Most commercial fiber polymers are utilized in the textile industry, being woven or knit into cloth or fabric. In addition, the aramid fibers are employed in composite materials, Section 16.8. To be useful as a textile material, a fiber polymer must have a host of rather restrictive physical and chemical properties. While in use, fibers may be subjected to a variety of mechanical deformations—stretching, twisting, shearing, and abrasion. Consequently, they must have a high tensile strength (over a relatively wide temperature range) and a high modulus of elasticity, as well as abrasion resistance. These properties are governed by the chemistry of the polymer chains and also by the fiber drawing process.

The molecular weight of fiber materials should be relatively high or the molten material will be too weak and will break during the drawing process. Also, because the tensile strength increases with degree of crystallinity, the structure and configuration of the chains should allow the production of a highly crystalline polymer. That translates into a requirement for linear and unbranched chains that are

symmetrical and have regular repeat units. Polar groups in the polymer also improve the fiber-forming properties by increasing both crystallinity and the intermolecular forces between the chains.

Convenience in washing and maintaining clothing depends primarily on the thermal properties of the fiber polymer, that is, its melting and glass transition temperatures. Furthermore, fiber polymers must exhibit chemical stability to a rather extensive variety of environments, including acids, bases, bleaches, dry cleaning solvents, and sunlight. In addition, they must be relatively nonflammable and amenable to drying.

15.18 MISCELLANEOUS APPLICATIONS

Coatings

Coatings are frequently applied to the surface of materials to serve one or more of the following functions: (1) to protect the item from the environment that may produce corrosive or deteriorative reactions; (2) to improve the item's appearance; and (3) to provide electrical insulation. Many of the ingredients in coating materials are polymers, the majority of which are organic in origin. These organic coatings fall into several different classifications, as follows: paint, varnish, enamel, lacquer, and shellac.

Many common coatings are *latexes*. A latex is a stable suspension of small insoluble polymer particles dispersed in water. These materials have become increasingly popular because they don't contain large quantities of organic solvents that are emitted into the environment—that is, they have low volatile organic compound (VOC) emissions. VOCs react in the atmosphere to produce smog. Large users of coatings such as automobile manufacturers continue to reduce their VOC emissions to comply with environmental regulations.

Adhesives

adhesive

An **adhesive** is a substance used to bond together the surfaces of two solid materials (termed "adherends"). There are two types of bonding mechanisms: mechanical and chemical. For mechanical there is actual penetration of the adhesive into surface pores and crevices. Chemical bonding involves intermolecular forces between the adhesive and adherend, which forces may be covalent and/or van der Waals; degree of van der Waals bonding is enhanced when the adhesive material contains polar groups.

Although natural adhesives (animal glue, casein, starch, and rosin) are still used for many applications, a host of new adhesive materials based on synthetic polymers have been developed; these include polyurethanes, polysiloxanes (silicones), epoxies, polyimides, acrylics, and rubber materials. Adhesives may be used to join a large variety of materials—viz. metals, ceramics, polymers, composites, skin, etc.—and the choice of which adhesive to use will depend on such factors as (1) the materials to be bonded and their porosities; (2) the required adhesive properties (i.e., whether the bond is to be temporary or permanent); (3) maximum/minimum exposure temperatures; and (4) processing conditions.

For all but the pressure-sensitive adhesives (discussed below), the adhesive material is applied as a low-viscosity liquid, so as to cover evenly and completely the adherend surfaces, and allow for maximum bonding interactions. The actual bonding joint forms as the adhesive undergoes a liquid-to-solid transition (or cures), which may be accomplished through either a physical process (e.g., crystallization, solvent evaporation) or a chemical process [e.g., addition polymerization, condensation polymerization (Section 15.20), vulcanization]. Characteristics of a sound joint should include high shear, peel, and fracture strengths.

Adhesive bonding offers some advantages over other joining technologies (e.g., riveting, bolting, and welding) including lighter weight, the ability to join dissimilar materials and thin components, better fatigue resistance, and lower manufacturing costs. Furthermore, it is the technology of choice when exact positioning of components as well as processing speed are essential. The chief drawback of adhesive joints is service temperature limitation; polymers maintain their mechanical integrity only at relatively low temperatures, and strength decreases rapidly with increasing temperature. The maximum temperature possible for continuous use for some of the newly-developed polymers is 300°C. Adhesive joints are found in a large number applications, especially in the aerospace, automotive, and construction industries, in packaging, and some household goods.

A special class of this group of materials is the pressure-sensitive adhesives (or self-adhesive materials), such as those found on self-stick tapes, labels, and postage stamps. These materials are designed to adhere to just about any surface by making contact and with the application of slight pressure. Unlike the adhesives described above, bonding action does not result from a physical transformation or a chemical reaction. Rather, these materials contain polymer tackifying resins; during detachment of the two bonding surfaces, small fibrils form that are attached to the surfaces and tend to hold them together. Polymers used for pressure-sensitive adhesives include the acrylics, styrenic block copolymers (Section 15.19), and natural rubber.

Films

Polymeric materials have found widespread use in the form of thin *films*. Films having thicknesses between 0.025 and 0.125 mm (0.001 and 0.005 in.) are fabricated and used extensively as bags for packaging food products and other merchandise, as textile products, and a host of other uses. Important characteristics of the materials produced and used as films include low density, a high degree of flexibility, high tensile and tear strengths, resistance to attack by moisture and other chemicals, and low permeability to some gases, especially water vapor (Section 14.14). Some of the polymers that meet these criteria and are manufactured in film form are polyethylene, polypropylene, cellophane, and cellulose acetate.

Foams

foam

Foams are plastic materials that contain a relatively high volume percentage of small pores and trapped gas bubbles. Both thermoplastic and thermosetting materials are used as foams; these include polyurethane, rubber, polystyrene, and poly(vinyl chloride). Foams are commonly used as cushions in automobiles and furniture as well as in packaging and thermal insulation. The foaming process is often carried out by incorporating into the batch of material a blowing agent that, upon heating, decomposes with the liberation of a gas. Gas bubbles are generated throughout the now-fluid mass, which remain in the solid upon cooling and give rise to a sponge-like structure. The same effect is produced by dissolving an inert gas into a molten polymer under high pressure. When the pressure is rapidly reduced, the gas comes out of solution and forms bubbles and pores that remain in the solid as it cools.

15.19 ADVANCED POLYMERIC MATERIALS

A number of new polymers having unique and desirable combinations of properties have been developed over the past several years; many have found niches in new technologies and/or have satisfactorily replaced other materials. Some of these include ultrahigh molecular weight polyethylene, liquid crystal polymers, and thermoplastic elastomers. Each of these will now be discussed.

Ultrahigh Molecular Weight Polyethylene

ultrahigh molecular weight polyethylene (UHMWPE)

Ultrahigh molecular weight polyethylene (*UHMWPE*) is a linear polyethylene that has an extremely high molecular weight. Its typical $\overline{M}_w$ is approximately 4×10^6 g/mol, which is an order of magnitude (i.e., factor of ten) greater than that of high-density polyethylene. In fiber form, UHMWPE is highly aligned and has the trade name Spectra™. Some of the extraordinary characteristics of this material are as follows:

1. An extremely high impact resistance
2. Outstanding resistance to wear and abrasion
3. A very low coefficient of friction
4. A self-lubricating and nonstick surface
5. Very good chemical resistance to normally encountered solvents
6. Excellent low-temperature properties
7. Outstanding sound damping and energy absorption characteristics
8. Electrically insulating and excellent dielectric properties

However, since this material has a relatively low melting temperature, its mechanical properties diminish rapidly with increasing temperature.

This unusual combination of properties leads to numerous and diverse applications for this material, including bullet-proof vests, composite military helmets, fishing line, ski-bottom surfaces, golf ball cores, bowling alley and ice skating rink surfaces, biomedical prostheses (Section 22.12), blood filters, marking pen nibs, bulk material handling equipment (for coal, grain, cement, gravel, etc.), bushings, pump impellers, and valve gaskets.

Liquid Crystal Polymers

liquid crystal polymer

The **liquid crystal polymers** (*LCPs*) are a group of chemically complex and structurally distinct materials that have unique properties and are utilized in diverse applications. Discussion of the chemistry of these materials is beyond the scope of this book. Suffice it to say that LCPs are composed of extended, rod-shaped, and rigid molecules. In terms of molecular arrangement, these materials do not fall within any of conventional liquid, amorphous, crystalline, or semicrystalline classifications, but may be considered as a new state of matter—the liquid crystalline state, being neither crystalline nor liquid. In the melt (or liquid) condition, whereas other polymer molecules are randomly oriented, LCP molecules can become aligned in highly ordered configurations. As solids, this molecular alignment remains, and, in addition, the molecules form in domain structures having characteristic intermolecular spacings. A schematic comparison of liquid crystals, amorphous polymers, and semicrystalline polymers in both melt and solid states is illustrated in Figure 15.20. Furthermore, there are three types of liquid crystals, based on orientation and positional ordering—smectic, nematic, and cholesteric; distinctions among these types are also beyond the scope of this discussion.

The principal use of liquid crystal polymers is in *liquid crystal displays* (*LCDs*) on digital watches, flat-panel computer monitors and televisions, and other digital displays. Here cholesteric types of LCPs are employed which, at room temperature, are fluid liquids, transparent, and optically anisotropic. The displays are composed of two sheets of glass between which is sandwiched the liquid crystal material. The outer face of each glass sheet is coated with a transparent and

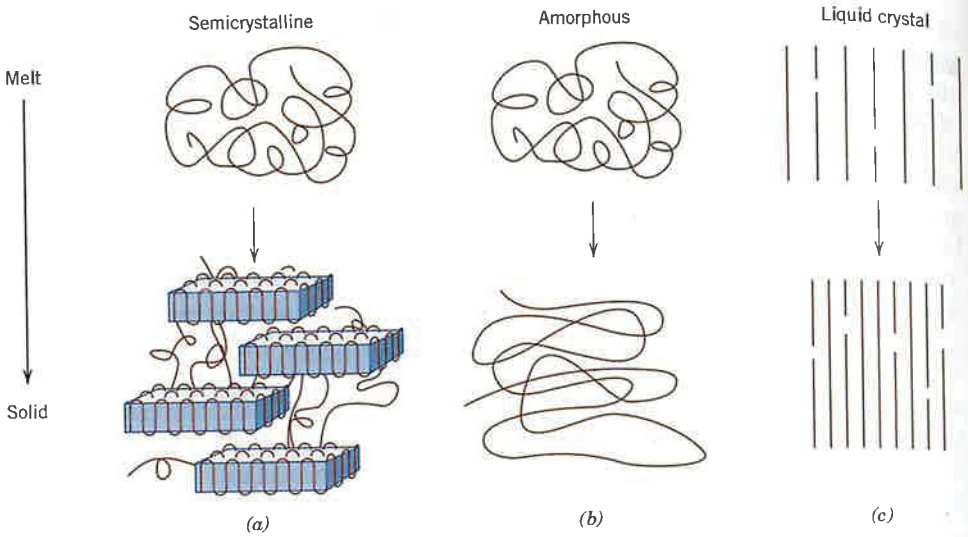


Figure 15.20 Schematic representations of the molecular structures in both melt and solid states for (*a*) semicrystalline, (*b*) amorphous, and (*c*) liquid crystal polymers. (Adapted from G. W. Calundann and M. Jaffe, "Anisotropic Polymers, Their Synthesis and Properties," Chapter VII in *Proceedings of the Robert A. Welch Foundation Conferences on Polymer Research,* 26th Conference, Synthetic Polymers, Nov. 1982.)

electrically conductive film; in addition, the character-forming number/letter elements are etched into this film on the side that is to be viewed. A voltage applied through the conductive films (and thus between these two glass sheets) over one of these character-forming regions causes a disruption of the orientation of the LCP molecules in this region, a darkening of this LCP material, and, in turn, the formation of a visible character.

Some of the nematic type of liquid crystal polymers are rigid solids at room temperature and, on the basis of an outstanding combination of properties and processing characteristics, have found widespread use in a variety of commercial applications. For example, these materials exhibit the following behaviors:

1. Excellent thermal stability; they may be used to temperatures as high as 230°C (450°F).
2. Stiff and strong; their tensile moduli range between 10 and 24 GPa (1.4×10^6 and 3.5×10^6 psi), while tensile strengths are from 125 to 255 MPa (18,000 to 37,000 psi).
3. High impact strengths, which are retained upon cooling to relatively low temperatures.
4. Chemical inertness to a wide variety of acids, solvents, bleaches, etc.
5. Inherent flame resistance and combustion products that are relatively nontoxic.

The thermal stability and chemical inertness of these materials are explained by extremely high intermolecular interactions.

The following may be said about their processing and fabrication characteristics:

1. All conventional processing techniques available for thermoplastic materials may be used.
2. Extremely low shrinkage and warpage take place during molding.

3. Exceptional dimensional repeatability from part to part.
4. Low melt viscosity, which permits molding of thin sections and/or complex shapes.
5. Low heats of fusion; this results in rapid melting and subsequent cooling, which shortens molding cycle times.
6. Anisotropic finished-part properties; molecular orientation effects are produced from melt flow during molding.

These materials are used extensively by the electronics industry (interconnect devices, relay and capacitor housings, brackets, etc.), by the medical equipment industry (in components to be repeatedly sterilized), and in photocopiers and fiber-optic components.

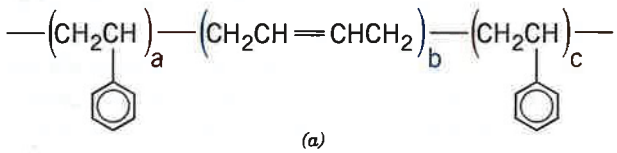
Thermoplastic Elastomers

thermoplastic elastomer

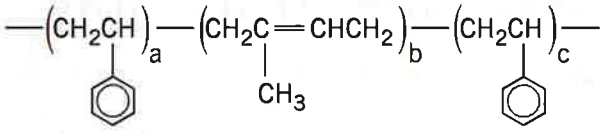
The **thermoplastic elastomers** (*TPE*s or *TE*s) are a type of polymeric material that, at ambient conditions, exhibits elastomeric (or rubbery) behavior, yet is thermoplastic in nature (Section 14.9). By way of contrast, most elastomers heretofore discussed are thermosets, because they are crosslinked during vulcanization. Of the several varieties of TPEs, one of the best known and widely used is a block copolymer consisting of block segments of a hard and rigid thermoplastic (commonly styrene [S]), that alternate with block segments of a soft and flexible elastic material (often butadiene [B] or isoprene [I]). For a common TPE, hard polymerized segments are located at chain ends, whereas each soft central region consists of polymerized butadiene or isoprene units. These TPEs are frequently termed *styrenic block copolymers,* and chain chemistries for the two (S-B-S and S-I-S) types are shown in Figure 15.21

At ambient temperatures, the soft, amorphous, central (butadiene or isoprene) segments impart the rubbery, elastomeric behavior to the material. Furthermore, for temperatures below the T_m of the hard (styrene) component, hard chain-end segments from numerous adjacent chains aggregate together to form rigid crystalline domain regions. These domains are "physical crosslinks" that act as anchor points so as to restrict soft-chain segment motions; they function in much the same way as "chemical crosslinks" for the thermoset elastomers. A schematic illustration for the structure of this TPE type is presented in Figure 15.22.

The tensile modulus of this TPE material is subject to alteration; increasing the number of soft-component blocks per chain will lead to a decrease in modulus and, therefore, a diminishment of stiffness. Furthermore, the useful temperature range lies between T_g of the soft and flexible component and T_m of the hard, rigid one.



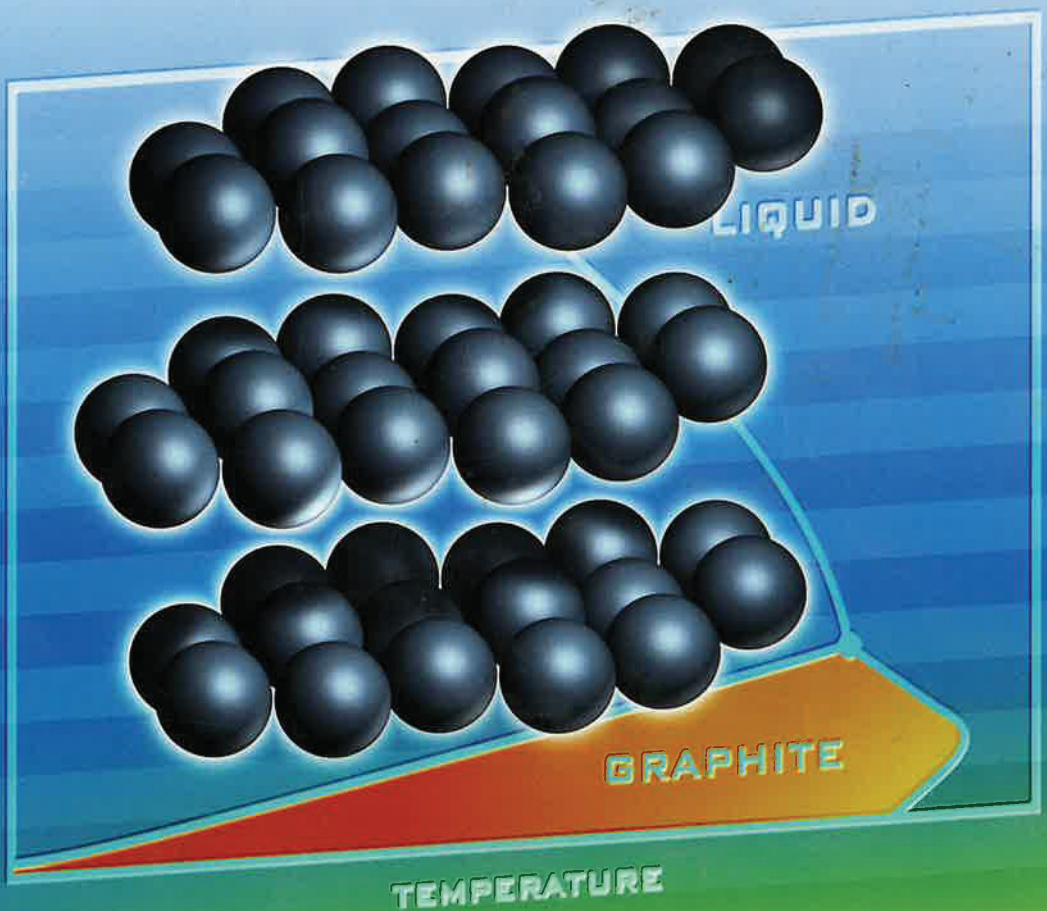
(a)



(b)

Figure 15.21 Representations of the chain chemistries for (*a*) styrene-butadiene-styrene (S-B-S), and (*b*) styrene-isoprene-styrene (S-I-S) thermoplastic elastomers.

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