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POLYMERS

Polymers include the familiar plastic and rubber materials. Many of them are organic compounds that are chemically based on carbon, hydrogen, and other nonmetallic elements (i.e., O, N, and Si). Furthermore, they have very large molecular structures, often chainlike in nature, that often have a backbone of carbon atoms. Some common and familiar polymers are polyethylene (PE), nylon, poly (vinyl chloride) (PVC), polycarbonate (PC), polystyrene (PS), and silicone rubber. These materials typically have low densities, whereas their mechanical characteristics are generally dissimilar to those of the metallic and ceramic materials they are not as stiff or strong as these other material types. However, on the basis of their low densities, many times their stiffnesses and strengths on a per-mass basis are comparable to those of the metals and ceramics. In addition, many of the polymers are extremely ductile and pliable (i.e., plastic), which means they are easily formed into complex shapes. In general, they are relatively inert chemically and unreactive in a large number of environments.

One major drawback to the polymers is their tendency to soften and/or decompose at modest temperatures, which, in some instances, limits their use. Furthermore, they have low electrical conductivities and are nonmagnetic. Figure 1 shows several articles made of polymers that are familiar to the reader.



Figure 1. Several common objects made of polymeric materials: plastic tableware (spoon, fork, and knife), billiard balls, a bicycle helmet, two dice, a lawn mower wheel (plastic hub and rubber tire), and a plastic milk carton.

There are many different polymeric materials that are familiar to us and find a wide variety of applications. These include plastics, elastomers (or rubbers), fibers, coatings, adhesives, foams, and films. Depending on its properties, a particular polymer may be used in

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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.

a) Plastics

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 generalpurpose 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. Others are flexible, exhibiting both elastic and plastic deformations when stressed and sometimes experiencing considerable deformation before fracture. 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 they must be crosslinked enough to maintain their shape.

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 used as coatings on nonstick cookware, in bearings and bushings, and for high-temperature electronic components.

b) Elastomers

One of the fascinating properties of the elastomeric materials is their rubberlike elasticity. That is, they have the ability to be deformed to quite large deformations, and then elastically spring back to their original form. This behavior was probably first observed in natural rubber; Université de Relizane Faculté des Sciences et Technologie Département de Génie Mécanique



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however, the past few years have brought about the synthesis of a large

number of elastomers with a wide variety of properties. Their moduli of elasticity are quite small and, furthermore, vary with strain since the stress–strain curve is nonlinear. 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.

For many applications (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.

Finally, some mention should be made of the silicone rubbers. For these materials, the backbone carbon chain is replaced by a chain that alternates silicon and oxygen atoms.

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. A further attractive characteristic is that some silicone rubbers vulcanize at room temperature (RTV rubbers).

c) Fibers

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 used in the textile industry, being woven or knit into cloth or fabric. In addition, the aramid fibers are employed in composite materials. 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 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 Université de Relizane Faculté des Sciences et Technologie Département de Génie Mécanique





units. Polar groups in the polymer also improve the fiberforming

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.

- Three advanced polymeric materials were discussed: ultra-high-molecularweight polyethylene, liquid crystal polymers, and thermoplastic elastomers. These materials have unusual properties and are used in a host of high-technology applications.

d) 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.

> Adhesives

An adhesive is a substance used to join together the surfaces of two solid materials (termed "adherends") to produce a joint with a high shear strength. The bonding forces between the adhesive and adherend surfaces are thought to be electrostatic, similar to the secondary bonding forces between the molecular chains in thermoplastic polymers. Even though the inherent strength of the adhesive may be much less than that of the adherend materials, nevertheless, a strong joint may be produced if the adhesive layer is thin and continuous. If a good joint is formed, the adherend material may fracture or rupture before the adhesive.

Polymeric materials that fall within the classifications of thermoplastics, thermosetting resins, elastomeric compounds, and natural adhesives (animal glue, casein, starch, and rosin) may serve adhesive functions. Polymer adhesives may be used to join a large variety of material

Université de Relizane Faculté des Sciences et Technologie Département de Génie Mécanique -2021/2022combinations: metal–metal, metal–plastic, metal–ceramic, and so on. The primary drawback is the service temperature limitation.



Organic polymers maintain their mechanical integrity only at relatively low temperatures, and strength decreases rapidly with increasing temperature.

> Films

Within relatively recent times, polymeric materials have found widespread use in the form of thin films. Films having thicknesses between 0.025 and 0.125 mm 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. Some of the polymers that meet these criteria and are manufactured in film form are polyethylene, polypropylene, cellophane, and cellulose acetate.

> Foams

Foams are plastic materials that contain a relatively high volume percent of small pores. Both thermoplastic and thermosetting materials are used as foams; these include polyurethane, rubber, polystyrene, and polyvinyl chloride. Foams are commonly used as cushions in automobiles and furniture as well as in packaging and thermal insulation. The foaming process is 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 as pores upon cooling and give rise to a spongelike structure. The same effect is produced by bubbling an inert gas through a material while it is in a molten state.