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Division of Building Research, National Research Council Canada

CBD 154

Plastics

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A. Blaga

Please note

This publication is a part of a discontinued series and is archived here as an historical reference. Readers should consult design and regulatory experts for guidance on the applicability of the information to current construction practice.

Although plastics are used increasingly as materials of construction, there is a general lack of understanding of their nature and characteristics. Each plastic has a particular combination of properties, fabrication, and economics that makes it ideal for certain applications, yet unsuitable for others. It is essential, therefore, that users appreciate the nature of these materials in order that they may be used to advantage in appropriate applications.

In a general sense, the term plastic is applied to any material that can be deformed under stress without losing its cohesion yet retain its newly acquired shape. The term is used by the industry to designate materials (raw materials or finished products) that are based on organic, synthetic polymers capable of flow in order that they may be shaped. The current definition of plastic materials is further restricted to those based on organic polymers, which are not considered to be elastomers or fibres. In the engineering sense, a plastic is a mixture containing polymer and various ingredients (for example, plasticizers, stabilizers, fillers, etc.) that are fabricated into a finished product. This Digest will describe the terminology and general nature of plastic materials before fabrication into finished articles or structures.

Organic Polymers

In order to understand the nature of plastic materials it is necessary to consider the materials upon which plastics are based, the organic polymers. These are substances consisting of large chain-like molecules built up from carbon atoms, occasionally with other atoms interposed. Although organic polymers exist in natural substances such as cellulose and natural rubbers, almost all plastics are based on man-made (or synthetic) polymers. The synthetic organic polymers are made from substances consisting of relatively small molecules that combine under certain conditions to give a pattern of repeated groups of atoms in the structure of the large molecule in much the same way as links make up a chain. The substances from which polymers are made are known as monomers; and the process by which polymers are produced is called polymerization. If only one kind of monomer is used, the resulting polymer is called homopolymer; if two kinds are used, the product is a copolymer. The best illustration of a polymer molecule is provided by the typical simple polyethylene molecule, which can be represented as a long chain of carbon atoms (carbon atom backbone) linked to each other, each carbon atom in turn linked to two hydrogen atoms (Figure 1).

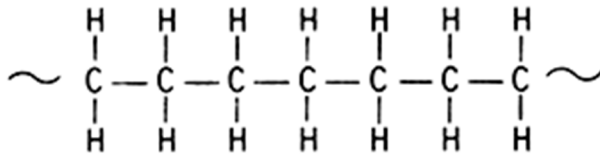


Figure 1. Polyethylene Molecule

Depending on the methods of production and their chemical nature, molecules may be linear and chain-like, with or without appendages called branches, or they may be tri-dimensional network structures resulting from permanent cross-links between the linear chains (Figure 2). The chain-like molecules of a solidified polymeric mass may assume three types of arrangement, giving rise to the amorphous, crystalline, and oriented state. In the amorphous state the molecules are arranged in a completely random manner somewhat like a mass of cooked spaghetti. Familiar amorphous polymers are poly(methyl methacrylate) and polystyrene.



Figure 2. Schematic Representation of Polymer Molecules: (a) Linear (b) Branched (c) Cross-linked

If the polymer molecules have a sufficient degree of regularity (chemical and geometric), the solid mass of a polymeric material may assume an ordered arrangement and is said to be in a crystalline state. Because of the length of the molecules, however, polymers can never have a degree of order equivalent to that of low molecular materials such as ice or common salt. In crystalline polymers, parts of the same molecular chain may participate in a number of ordered arrangements (crystalline structures) while other parts of the same molecule exist in a disordered state, in amorphous regions. The close packing of the molecules causes an increased density; decreased intermolecular distances increase the forces holding the chains together, causing an increase in the values of such properties as tensile strength, modulus of elasticity, softening temperature. There are hundreds of crystalline polymers, the most familiar being polyethylene, polypropylene, polytetrafluoroethylene, and nylon.

When a polymer mass (amorphous or crystalline) is subjected to stress such as tensile stress, the molecular chains become aligned or oriented parallel to the direction of applied stress and the material is said to be in an oriented state. In an oriented material the properties in the direction of molecular alignment (or orientation) differ from those at right angles to the orientation. For example, an oriented polymer sample will be considerably stronger in the direction of orientation than a sample of unoriented material of the same polymer; at right angles to the orientation it will be weaker. Tensile strength can be increased by a factor of 2 or 3 by unidirectional orientation of a sample of amorphous polymer.

When heat is applied to a mass of polymer having linear or branched molecules, the material will soften at a certain temperature and flow because the molecules are free to slide over one another. Polymers having highly cross-linked molecules do not soften with heat or show any significant flow because the individual chain segments are chemically attached to each other and form a rigid structure. As organic materials, polymers decompose with excessive heat, producing smoke and leaving charred residues.

Two important characteristic temperatures associated with polymers are glass-transition temperature (T_g) and melt temperature (T_m). The glass-transition temperature is the temperature below which a polymer mass has many of the properties of an inorganic glass, including hardness, stiffness, and transparency. Above this temperature the material has plastic or elastic properties and is said to be in a rubbery state. The position of the glass-transition temperature with respect to room temperature will determine the type of application

or the usefulness of the polymeric material. For example, polymers such as polystyrene and poly(methyl methacrylate), with glass-transition well above room temperature (100 and 110°C, respectively), are normally used in the glassy state in plastics with the same name. Polymers having glass-transitions well below room temperature. for example, polyisoprene (-83°C) and polyisobutylene (-65°C), are used in rubbers. If the glass-transition lies near room temperature, the polymers are generally not very useful because they are rubbery in the summer and glassy in the winter.

The melt temperature (T_m) is also called flow temperature for amorphous polymers and crystalline melting point for crystalline polymers. At the melt temperature (usually a range) solid elements of the polymers are in equilibrium with the molten state, and thus the polymer mass is practically a viscous liquid. Highly cross-linked polymers have neither glass-transition nor melting temperature.

From Polymers to Plastics

The word polymer refers to either the pure chemical substance or the material produced as a direct result of the polymerization process. Commercially produced high polymers contain pure polymer and traces of such impurities as unreacted monomer, catalysts and solvent that are uneconomical to remove. They are essentially, however, one chemical entity. Normally, impurities impair the properties of pure polymers, diminishing resistance to oxygen, heat and solar radiation.

Although the great variety of polymers provides a wide spectrum of properties, this is not enough to meet the demands of the various applications. To extend the range and reduce deterioration during fabrication and use and to facilitate processing, polymers are generally mixed with various materials. It is usually this physical mixture of polymers and additives that constitutes the plastic, so that it is important to distinguish between a polymer and a plastic. Although the terms are often used synonymously, they refer to different materials.

It is also relevant to comment on the word resin, originally applied to certain natural products. When the polymeric nature of this natural material was recognized, synthetic polymers began to be called "synthetic resins," and later in the U.S.A. simply "resins." Today, the terms resin and base resin are often used to designate a commercial polymer, i.e., polymer material containing no deliberately added ingredients.

Plastic Compound

The physical mixture of polymer and additives is called a plastic compound, the precise nature and amount of material to be added depending on the polymer, the processing method used to convert the plastic into a finished article, and the properties required in the finished article. The selection of additives and the operation of mixing them with the polymer constituent is known as compounding. The proportions of the various ingredients of a plastic compound constitute its formulation. The base resin in a compound may be homopolymer or copolymer, or it may be a mixture of the two.

The term additive may be applied to any substance that is incorporated, generally in small concentrations (there are exceptions), in plastic compounds to alter the properties of the resin, the ultimate purpose being either to facilitate processing or to change physical, chemical or electrical properties of end products. The main classes of the various additives used in the manufacture of plastic products will be discussed briefly.

Lubricants

Lubricants are incorporated in plastic compounds to provide external and internal lubrication. They eliminate external friction between the polymer and the metal surface of the processing equipment; and they improve the internal flow characteristics of the polymer, adding to the wetting properties of the compounding ingredients. Many lubricant systems used in plastic compounds perform both functions. At present the most common lubricants are synthetic and natural waxes, low molecular weight polyethylene, and metallic stearates. A major application

for internal lubrication is in rigid PVC where it is necessary to eliminate the high shear rate that develops in the melt during processing. Absence of lubrication will cause degradation during processing and shorten long-term durability or impair adequate service performance of the plastic product. Other plastics requiring internal lubrication are polyolefins, polystyrenes, phenolics, melamines, cellulose acetate, acrylonitrile - butadiene - styrene polymer (ABS), nylon, unsaturated polyesters and many rubber compounds.

Stabilizers

Stabilizers provide protection against degradation caused by heat, oxidation, and solar radiation. Thus, when used in plastic compositions they may be classified as heat (or thermal) stabilizers, antioxidants and UV light stabilizers.

It is the role of heat stabilizers to prevent the polymer from degrading during the short period of high temperature (150 to 300°C) processing and to protect the finished plastic article against slow aging over longer periods at service temperatures.

Antioxidants inhibit or retard oxidative degradation (**CBD 117, CBD 122**) at normal or elevated temperatures during processing, storage or service. Most polymers undergo some oxidative degradation, but hydrocarbon polymers are specially susceptible. Antioxidants, therefore, are generally added in small quantities.

Most plastics exhibit varying degrees of degradation upon prolonged outdoor exposure (**CBD 117, CBD 122**). Polypropylene, poly(vinyl chloride), polyethylene, polyesters, crystalline and high impact polystyrenes, and ABS are particularly sensitive. Other plastics, particularly poly(methyl methacrylate) and the fluorocarbons, are much more resistant. To arrest or retard polymer degradation caused by the ultraviolet portion of solar radiation, plastic formulations contain UV absorbers. These are compounds such as substituted benzophenones, benzotriazoles and acrylonitriles that selectively absorb harmful radiation and convert it to heat energy.

Pigments such as titanium dioxide and zinc oxide are also used to protect plastics against the harmful effect of ultraviolet radiation. They function by absorbing some UV radiation, but their ability to reflect radiation (heat as well as light) accounts for much of their effectiveness. In applications where colour is not a requirement, carbon black, which absorbs UV light, is widely used as a very effective stabilizer (e.g., in black polyethylene).

Plasticizers

Plasticizers are substances added to plastic formulations to improve processing and reduce brittleness of the end product. They lower the glass transition temperature below room temperature, so that the properties of a material change from hard, brittle, and glass-like to soft, flexible and tough. Plasticizers are medium molecular weight, relatively high-boiling, colourless liquids, normally non-polymeric. They are added in amounts varying from 5 to 50 per cent. Some have additional beneficial effects, for example, epoxy plasticizers enhance heat and UV light stabilization, phosphates improve flame resistance. Plasticizers are used with some thermoplastic materials, the principal one being PVC. Without plasticizer PVC is hard and brittle; with plasticizer it is softer, more flexible, and easier to process.

Fillers

Fillers are relatively inert materials that are added to some plastics in amounts ranging from 5 to 60 percent to improve hardness, abrasion resistance, impact strength, solvent resistance and to modify electrical characteristics. Some are added to plastic materials primarily to lower cost. The most common fillers are carbon black, calcium carbonate, calcium sulphate, talc, diatomaceous earth, silica, alumina, bentonite, clay, iron oxide, wood flour and metallic powders.

Reinforcements

In some respects reinforcements may be regarded as fillers, but they are added mainly to improve the tensile and flexural strength properties of the plastic material. Most are in fibrous form. Typical reinforcing materials available as fibres are glass, asbestos, boron, carbon, ceramic, cotton flock, jute and sisal. Recently, synthetic fibres of nylon, polyethylene terephthalate, poly(vinyl alcohol), poly(vinyl chloride) and acrylonitrile have also been used.

Fire Retardants

Plastic compounds may also contain components that improve the fire resistance of the end product. The most commonly used fire retardants are compounds containing halogen, derivatives of antimony, phosphorous, boron, and nitrogen. Fire resistance in the base polymer resin may be achieved by copolymerizing halogenated monomers with normally flammable monomers.

Colorants

Colorants are added to enhance the aesthetic qualities of plastic materials, and may be dyes or pigments. Usually dyes are employed for brilliant transparent effects in clear plastics such as polystyrene, acrylics and cellulose. Sometimes they are used in conjunction with a pigment. Carbon blacks are an important group of pigments that also function as fillers and are good UV light stabilizers.

Thermoplastics and Thermosetting Plastics

On the basis of how they react to heat, plastics are divided into two main types: thermoplastics and thermosetting plastics (or "thermosets"). Thermoplastics are based on linear or branched polymers and are capable of repeated softening by heat and hardening by cooling. In this respect, they may be compared to wax or iron. Typical of the thermoplastic family are materials based on polyethylene, polypropylene, poly(vinyl chloride), polystyrene polymers and copolymers, acrylics, cellulose, nylons and the various fluorocarbons.

Thermosetting plastics are materials based on polymers that have undergone a chemical reaction (induced by the action of heat, catalysts or ultraviolet light) that results in a relatively infusible, intractable and insoluble product. The polymeric component of the product is in a cross-linked state. Thermosetting plastics thus behave like concrete: once set (or cured) they cannot be melted and shaped again. Typical plastics of the thermosetting family are epoxies, phenolics, alkyds, polyurethanes, melamine- and urea-formaldehydes.

Summary

Plastics are man-made materials based on organic polymers. Plastic articles and structures are made from raw materials called plastic compounds, mixtures containing one or more polymers and various ingredients such as lubricants, stabilizers, plasticizers, fillers, colorants, etc. These are incorporated to improve processing or to change the physical, chemical or electrical properties of the end products.

According to the way they react to heat, plastic materials may be classified as thermoplastics and thermosetting plastics. Articles and structures made from thermoplastic compounds can be repeatedly softened by heat and hardened by cooling, and are based on linear or branched polymers. Thermosetting plastic compounds are based on polymers that undergo a chemical reaction during fabrication to form a cross-linked or tridimensional structure that results in a relatively infusible, intractable and insoluble material. Thermosetting materials cannot be reshaped.