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Please note

Thermoplastics constitute an important class of synthetic material used increasingly in a variety of applications. For example, in building and construction they perform various functions as light structural and decorative components or as auxiliaries to other materials and components. As only brief reference has been made to them in previous Digests, they will now be discussed in greater detail and their general characteristics and major families described.

Characteristics

Thermoplastics are based on linear or slightly branched polymers in which the molecular chains flow over each other when heated and solidify into new shapes when cooled. The process of softening with heating and hardening with cooling can be repeated as often as may be required; for thermoplastics, unlike thermosetting materials, do not undergo any chemical changes. Indeed, thermoplastic scrap can usually be reclaimed and reprocessed. Articles made from thermoplastics range from small pins and sensors to large items such as water storage tanks and to complex forms such as coatings, adhesives, foams, reinforced plastics, and materials capable of withstanding high temperatures.

Major Types of Thermoplastics

The major families of commercially available thermoplastics are polyethylene, polypropylene, poly (vinyl chloride), polystyrene, acrylics, nylons and cellulosics. With the exception of nylons and cellulosics, the principal member of each family is based on polymers that have an entirely carbon-carbon backbone chain. This can be represented by the general formula of Figure 1; groups designated R and R^1 are given in Table I. Nylons and cellulosics are based on polymers that also have atoms other than carbon in the main chain. Typical properties of commercial thermoplastics are given in Table II and Table III, although the values of some properties represent only a fraction of the total range attainable and should be used for comparative purposes only.

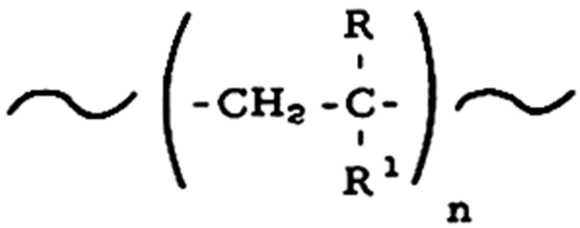

Figure 1. General formula of thermoplastic polymers having a C-C backbone chain.

Table I. Thermoplastic Polymers with a C-C Backbone Chain

R	**R^1**	**Name of Polymer**	**Abbreviation**
H	H	Polyethylene	PE
H	CH_3	Polypropylene	PP
H	Cl	Poly(vinyl chloride)	PVC
H	C_6H_5	Polystyrene	PS
H	COOCH	Poly(methyl acrylate)	PMA
CH	COOCH	Poly(methyl methacrylate)	PMMA

Polyethylene Plastics.
These are the most widely used of all plastics. Although they sometimes consist solely of polyethylene (PE) polymer, which is produced by polymerization of ethylene (a gas), more often they contain small proportions of one or more additives such as fillers, pigments, stabilizers, antistatic agents, and flame retardants. Commercially available polyethylenes are sub-divided into two major classes, low-density polyethylene (LDPE) and high-density polyethylene (HDPE). HDPE materials exhibit greater rigidity and physical strength and have a higher melting point, but they have lower resistance to environmental stress cracking than has LDPE.

Table II. Typical Range of Mechanical Properties of Commercial Thermoplastics (Unfilled, Unreinforced) [1]

Name of Thermoplastic	Tensile Strength, psi (ASTM D-638)	Elongation, per cent (ASTM D-638)	Tensile Modulus, 10^5 psi (ASTM D-638)	Compressive Strength, psi (ASTM D-695)	Flexural Yield Strength, psi (STM D-790)	Hardness**
Ployethylene						
low density	600-3,500	50- 800	0.14-0.55	-	4,800-7,000	41-60 (Shore D), R10-R15
high density	3,100-5,500	20-1,000	0.6-1.8	2,200-3,600	-	60-70 (Shore D)
Polypropylene	4,300-5,500	200- 700	1.60-2.25	5,500-8,000	6,000-8,000	R85-R11
Rigid poly(vinyl	5,000-9,000	2- 40	3.5-6.0	8,000-13,000	10,000-16,000	65-85 (Shore

chloride)						D)***
Flexible poly(vinyl chloride) (unfilled)	1,500-3,500	200- 450	-	900- 1,700	-	50-100 (Shore A)***
Polystyrene*	5,000-12,000	1- 2.5	4.0-6.0	11,500-16,000	8,700-14,000	M65-M80
Poly(methyl methacrylate)	7,000-12,500	2- 10	3.5-4.8	11,000-21,000	12,000-19,000	M61-M105
Nylon 66	9,000-12,000	60- 300	1.75-4.15	6,700-12,500	No break	R108-R120
Cellulose acetate	1,900-9,00	6- 70	0.7-6.0	2,000-36,000	2,000-16,000	R34-R125

* General purpose and heat-resistant grade
** Figure preceded by M or R (hardness scale symbols) represent values obtained by Rockwell tester (ASTM D-785)
*** The letters A and D designate the type of durometer tester (ASTM D-2240)

PE plastics have an excellent combination of good physical and electrical properties, resistance to water and chemicals, toughness, light weight, flexibility, easy processing, and low cost. They are used in a variety of ways, for example, in wire and cable coating, films for packaging, vapour barrier films, drums, cold water tanks, storage tanks and other large containers, drainage pipes, tubing, and sheeting. Their deficiencies are poor stress-crack resistance and cold flow (creep at room temperature) on loading. Outdoor aging resistance is also poor, since PE is affected by ultraviolet light and oxygen. This results in loss of strength, elongation and decreased tear resistance. Although stabilizers can retard deterioration, few are compatible with the polymer. The weathering of carbon-black-pigmented material is quite good.

Table III. General Properties of Commercial Thermoplastics (Unfilled, Unreinforced) (1)

Name of Thermoplastic	Burning Rate (Flammability), in./min (ASTM D-635)	Deflection Temp. °F at 264 psi (ASTM D-648)	Coefficient of Thermal Expansion, 10^{-5}/°F (ASTM D-696)	Water Absorption (in 24 hr), per cent (ASTM D-570)	Effect of Organic Solvents (STM D-790)	Effect of Sunlight (Weathering)
Ployethylene						
low density	Very Slow (1.00-1.04)	90-120	5.6-11.1	<0.02	Resistant (below 140°F	Require protection
high density	Very Slow (1.00-1.04)	110-130	6.1-7.2	<0.01	Resistant (below 176L)	Weather-resistant grades available in all colours.
Polypropylene	Slow	125-140	3.2-5.7	<0.01	Resistant (below 176°F	
Rigid poly(vinyl chloride)*	Self-extinguishing	-	2.8-10.3	0.15-0.75	Soluble or swells in ketones and esters	-

Flexible poly*(vinyl chloride)	Slow to self-extinguishing	-	3.9-13.9	0.15-0.75	Soluble or swells in ketones and esters	-
Polystyrene**	Slow	220 max	3.3-4.4	0.03-0.01	Sol. in aromatic and chlorinated hydrocarbons	Yellows and crazes
Poly(methyl methacrylate)	Non-burning to slow (0.6-1.3)	155-215	2.8-5.0	0.1-0.4	Sol. in ketones, esters, aromatic and chlorinated hydrocarbons	Nil
Nylon 66	Self-extinguishing	150-220	4.4	1.5	Resistant to common solvents	Discolors slightly
Cellulose acetate	Slow to self-extinguishing	111-195	4.4-10.0	1.7-7.0	Soluble in most common solvents	Slight

* Vinyl chloride polymer and vinyl chloride-vinyl acetate copolymer based plastic
** General purpose and heat-resistant grade

Polypropylene Plastics.
Polypropylene (PP) is related structurally to PE and is made by polymerization of propylene (a gas). Plastics made from polypropylene polymer have an unusual combination of properties. They have excellent resistance to stress or flex cracking, very low specific gravity, good mechanical properties, including excellent impact strengths, yet are hard and have scratch-resistant surfaces. Further, PP plastics have good dielectric characteristics, are chemically inert, and are insoluble at room temperature. Other interesting properties include rot and mildew resistance, and good heat resistance up to 116°C (240°F). Polypropylene formulations may contain additives such as pigments, carbon black, rubbers, antioxidants, and UV stabilizer for outdoor applications. Current applications are in pipe and fittings, automotive parts, housewares and furniture, film and sheeting, filament for synthetic residential and industrial carpeting, cordage, ribbon, upholstery and drapery fabrics.

Poly(vinyl chloride) and Related Plastics.
By virtue of its great variation in properties, poly(vinyl chloride) (PVC) is the most versatile of all plastics. It is also known as vinyl. Regardless of end use or method of fabrication, compounding ingredients must be added to PVC resins, particularly to prevent degradation during processing and service. Because PVC polymer resin is relatively vulnerable to heat and light, stabilizers are invariably used. Other compounding ingredients include plasticizers, lubricants, impact modifiers, or processing aids. Materials such as colour pigments, dyes, flame retardants, fillers and fungicides can be added for specific requirements.

PVC plastics based on the homopolymer (made from one monomer) are of two basic types, rigid or flexible. "Rigid" usually refers to unplasticized PVC, normally containing only polymer, stabilizer, lubricant and, sometimes, impact modifiers. This term, however, is occasionally extended to include slightly plasticized (up to 20 parts per hundred) products, although these materials should more properly be called "semi-rigid." Other polymers are often added to PVC to improve impact resistance or processing. Products made from rigid PVC compound are hard, tough, and difficult to process, but they have fairly good outdoor stability, superior electrical properties, excellent resistance to moisture and chemicals, and excellent dimensional stability. They are self-extinguishing.

Rigid PVC compounds are used in piping for drains, waste and vent systems, water distribution and irrigation systems, and various building products including house sidings, window sash, building panels, rain gutters, downspouts, flashing, and wall tile.

Flexible PVC contains significant amounts of plasticizers (from 20 to 50 parts per hundred or more) to make it flexible and easy to process. It has lower strength, lower heat resistance, and poorer weathering properties than has rigid PVC. Flexible compounds are used in cable and wire insulation, floor and wall coverings, pipe, packaging film, shower curtains, corrugated sheeting, weatherstripping, window frames and decorative wallboard laminates. Flexible PVC is also used increasingly in the automotive industry.

Polystyrene and Related Plastics.
The family of plastics based on styrene-derived polymers includes polystyrene (PS), copolymers of styrene with vinyl monomers (monosubstituted ethylenes), and blends of polystyrene and styrene containing copolymers with elastomers. PS-based plastics are relatively economical, easily moulded, and readily coloured; they have low moisture absorption, good dimensional stability, good insulation properties, and reasonable chemical resistance.

There are three grades of PS plastic: general purpose, high molecular, and heat resistant. The general purpose grade is lowest in cost and is used for applications requiring good optical clarity and rigidity, for example, for toys, packaging, containers and throw-away dishes. The high molecular grades are sometimes used where improved impact strength is required without the loss of clarity that occurs with toughened PS. Because of its low heat conductivity PS is used as thermal insulation in polystyrene foam where the polymer constitutes the solid matrix.

The principal limitations of PS plastics are their brittleness, low deflection temperatures (82 to 88°C), and poor resistance to organic solvents, including dry-cleaning agents. Further, PS resins have inherently poor outdoor weathering resistance; they turn yellow and craze on exposure. Many of these defects can be overcome by proper formulation, however, by copolymerization of styrene with vinyl monomers or by blending with other polymers.

The most important of all the copolymers of styrene in terms of volume are styrene-butadiene synthetic rubber and the styrene-butadiene copolymer, used in latex paint. The copolymer of styrene with acrylonitrile is also of major interest. ABS resins are two-phase systems consisting of styrene-butadiene rubber in a continuous glassy matrix of styrene-acrylonitrile copolymer. ABS plastics have higher temperature stability and better solvent resistance than high-impact PS, and are particularly well suited to heavy duty applications. ABS is used in drain, waste and vent piping, sliding door and window tracks, weather seals, concrete forms, and appliance housings.

Acrylic Plastics.
This family of plastics includes a range of polyacrylates, poly(methyl methacrylate) (PMMA) and the important fibre-forming polymer, polyacrylonitrile. The most important acrylic plastics are based on PMMA, which is amorphous. Outstanding properties of PMMA are optical clarity, lack of colour and unusually good resistance to outdoor weathering. The three basic types available are cast sheet (used in glazing), standard moulding powder (used for making lenses and dials), and high-impact powder, which gives less transparency but will take higher shock loads.

Nylons.
Nylons are formed from reactions between molecules possessing amino ($-NH_2$) and carboxylic acid (-COOH) groups. They have nitrogen atoms in their backbone chain (Figure 2). Nylons are characterized by high strength, outstanding toughness, wear-resistance, good chemical resistance, and very low coefficient of friction. Parts made from nylon, however, have poor dimensional stability owing to moisture sensitivity and because they undergo cold flow. Nylons were first used in the form of fibre and films, but recent improvements in materials and processing techniques have made them suitable for various light engineering applications: for

gears, bearings, bushes, cams and other mechanical parts, in rollers and tracks for cabinets, domestic appliance housings, slides, wire coverings, and car components.

$$\sim NH\text{-}(CH_2)_x\text{-}CO\text{-}NH\text{-}(CH_2)_y\text{-}CO \sim$$

Figure 2. Polyamide molecule.

Cellulosics.

These plastics are produced by chemical modification of cellulose, a natural polymer found in wood and cotton, etc. The best known plastic of this class is cellulose acetate. Its outstanding properties are its toughness, high impact strength, good electrical properties, and light weight. Its greatest disadvantages are low heat distortion temperature and high water absorption characteristics. Cellulose acetate is used to make tool handles, housings, toys, light fixtures, shades, and in protective coatings and lacquers for wood and metals.

Reference

1. Guide to Plastics, by the Editors of Modern Plastics Encyclopedia, McGraw-Hill, Inc., New York, 1970.