Homework

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   - 1.3 What are the difference between them?
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     - 2.3.2 Amorphous
3. *References*
   - 3.1 Introduction to Physical Polymer Science 4th – Sperling 2002
   - 3.2 Principles of Polymerization 4th – Odian 2004
   - 3.3 Materials Science and Engineering-An Introduction – Callister 2007
   - 3.4 Applied Plastics Engineering Handbook-Processing and Materials – Kutz 2011
   - 3.5 Handbook of Vinyl Polymers-Radical Polymerization, Process, and Technology 2nd – Mishra 2009
   - 3.6 Manufacturing Processes for Engineering Materials 5th – Serope Kalpakjian and Steven Schmid 2008
   - 3.7 http://www.solvay.com/en/markets-and-products/featured-products/radel.html

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What are the difference between the semi-crystalline and the amorphous state?

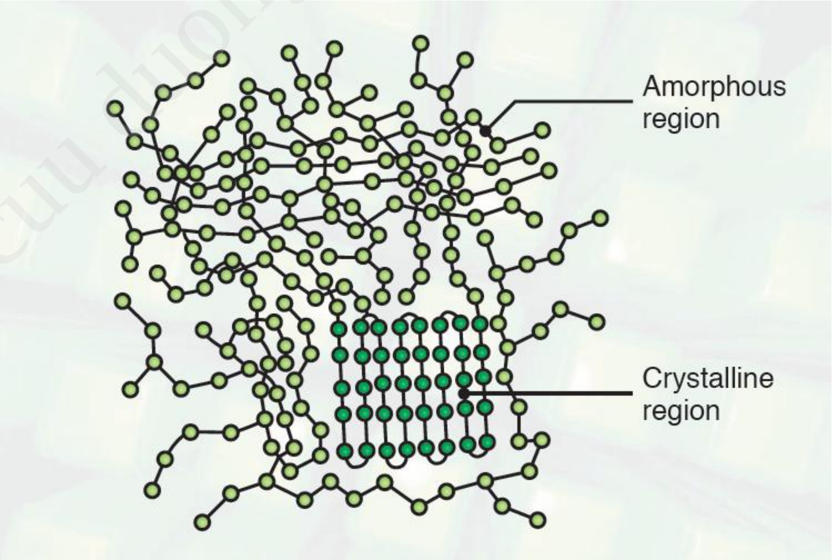


Figure 10.5 Amorphous and crystalline regions in a polymer. Note that the crystalline region (crystallite) has an orderly arrangement of molecules. The higher the crystallinity, the harder, stiffer, and less ductile is the polymer.

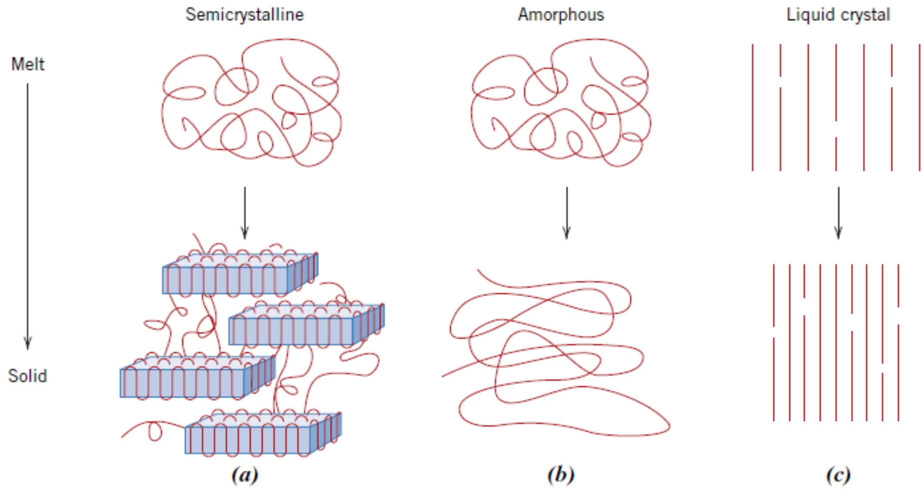


Figure 15.20 Schematic representations of the molecular structures in both melt and solid states for (*a*) semicrystalline, (*b*) amorphous, and (*c*) liquid crystal polymers.
(Adapted from G. W. Calundann and M. Jaffe, "Anisotropic Polymers, Their Synthesis and Properties," Chapter VII in *Proceedings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

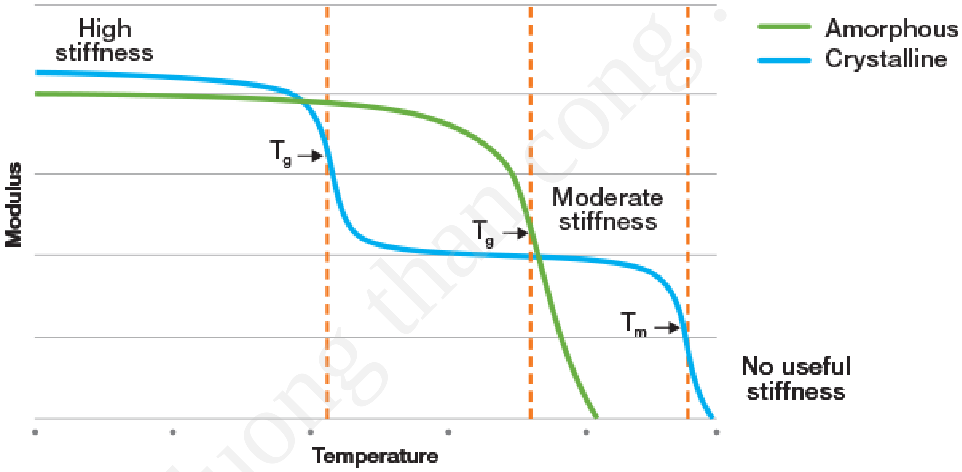


Figure 1 Modulus versus temperature for crystalline and amorphous polymers
(Adapted from http://www.solvay.com/en/markets-and-products/featured-products/udel-psu-faq.html)

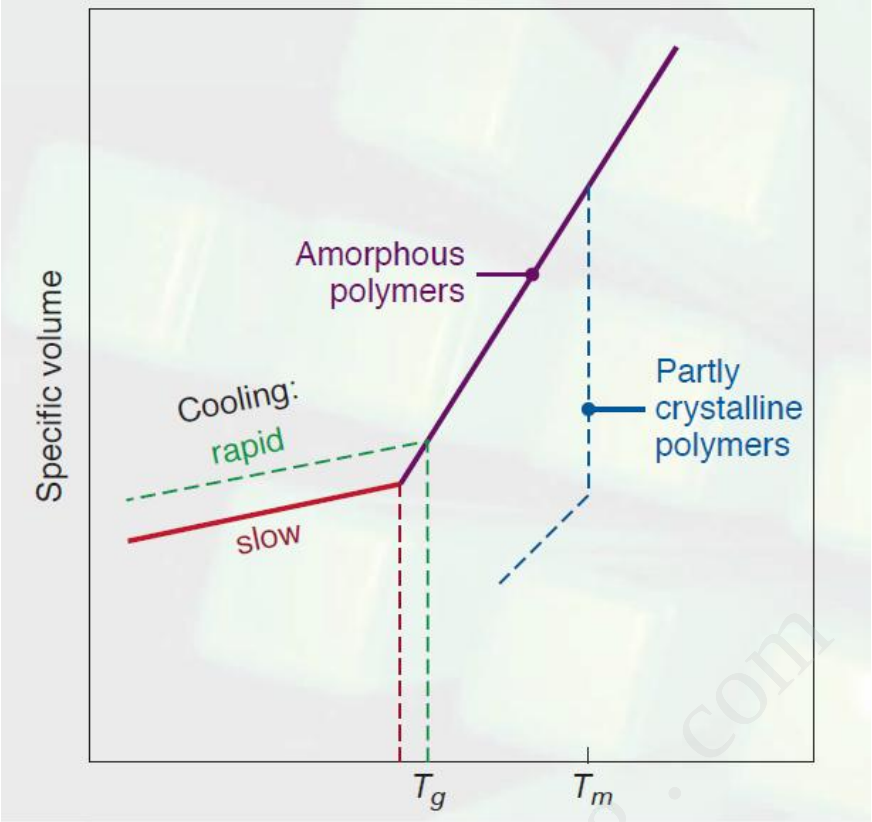


Figure 10.6 Specific volume of polymers as a function of temperature. Amorphous polymers, such as acrylic and polycarbonate, have a glass-transition temperature, T_g, but do not have a specific melting point, T_m. Partly crystalline polymers, such as polyethylene and nylons, contract sharply at their melting points during cooling.

THE AMORPHOUS STATE

The bulk state, sometimes called the condensed or solid state, includes both amorphous and crystalline polymers. Amorphous polymers do not contain any crystalline regions. “Crystalline” polymers generally are only semi-crystalline, containing appreciable amounts of amorphous material. When a crystalline polymer is melted, the melt is amorphous.

Depending on temperature and structure, amorphous polymers exhibit widely different physical and mechanical behavior patterns.

At low temperature, amorphous polymer are glassy, hard and brittle. As the temperature is raised, they go through the glass-rubber transition.

An amorphous polymer does not exhibit a crystalline X-ray diffraction pattern, and it does not have first-order melting transition.

On the simplest level, the structure of bulk amorphous polymers has been likened to a pot spaghetti, where the spaghetti strands weave randomly in and out among each other.

General properties

Two of the important general properties of the amorphous polymers are the density and the excess free energy due to nonattainment of equilibrium.

For many common polymers the density of the amorphous phase is approximately 0.85 to 0.95 that of the crystalline phase.

Table 5.1 summarized the several experiments designed to obtain information about the organization of polymer chains in the bulk amorphous state, both for short-and long-range order and for the general properties.

Table 5.1 *Selected studies of the amorphous state*

Method	***Information Obtainable***	***Principal Findings***
A. Short-Range Interactions		
Stress-optical coefficient	Orientation of segments in isolated chain	Orientation limited to 5-10 Å
Depolarized light-scattering	Segmental orientation correlation	2-3 —CH_2— units along chain correlated
Magnetic birefringence	Segmental orientation correlation	Orientation correlations very small
Raman scattering	Trans and gauche populations	Little or no modification in chain conformation initiated by intermolecular forces
NMR relaxation	Relaxation times	Small fluctuating bundles in the melt
Small-angle X-ray scattering, SAXS	Density variations	Amorphous polymers highly homogeneous; thermal fluctuations predominate
Birefringence	$n_1 - n_2$	Orientation
B. Long-Range Interactions		
Small-angle neutron scattering	Conformation of single chains	Radius of gyration the same in melt as in θ-solvents
Electron microscopy	Surface inhomogeneities	Nodular structures of 50-200 Å in diameter
Electron diffraction and wide-angle X-ray diffraction	Amorphous halos	Bundles of radial dimension = 25 Å and axial dimension = 50 Å, but order may extend to only one or two adjacent chains
C. General		
Enthalpy relaxation	Deviations from equilibrium state	Changes not related to formation of structure
Density	Packing of chains	Density in the amorphous state is about 0.9 times the density in the crystalline state

The detailed arrangement in space must be determined by other experiments and, it particular, by modeling. The resulting models are important in deriving equations for viscosity, diffusion rubbery elasticity, and mechanical behavior.

In the bulk amorphous state the mers are surrounded entirely by identical mers, and the sum of all interactions is zero. Considering mer-mer contacts, the interaction between two distant mers on the same chain is the same as the interaction between two mers on different chain the same is true for longer chain segment.

The amorphous state is defined as a condensed, noncrystalline of matter.

Concluding remarks

In the amorphous state the position of one chain segment relative to its neighbors is relatively disordered. In the relaxed condition, the polymer chains making up the amorphous state from random coils. The chain are highly entangled with one another, with physical crosslink appearing at about every 600 backbone atom.

THE CRYSTALLINE STATE

The crystalline state is defined as one that diffracts X-rays and exhibits the first-order transition known as melting.

A first-order transition normally has discontinuity in the volume-temperature dependence, as well as a heat of transition, ΔH_f, also called the enthalpy of fusion or melting. The most important second-order transition is the glass transition.

Polymers crystallized in the bulk, however, are never totally crystalline, a consequence of their long-chain nature and subsequent entanglements.

The development of crystallinity in polymers depends on the regularity of structure in the polymers. Thus, isotactic and synditactic polymers usually crystallize, whereas atatic polymers, with a few exceptions (where the side groups are small or highly polar), do not. Regular structures also appear in the polyamides (nylons), polyesters, and so on, and these polymers make excellent fibers.

Methods of determining crystal structure

1. X-ray methods
2. Electron diffraction of singe crystals
3. Infrared absorption
4. Raman spectra

Percent crystallinity in polymers

Most crystallizing polymers are semicrystalline, that is, a certain fraction of the material is amorphous, while the remainder is crystalline. The reason why polymers fail to attain 100% crystallinity is kinetic, resulting from the inability of the polymer chains to completely disentangle and line up properly in a finite period of cooling or annealing.

Methods of determining the percent crystallinity

- DSC: the first involves the determination of the heat of fusion of the whole sample by calorimetric methods. The heat of fusion per mole of crystalline material can be estimated independently by melting point depression experiments.

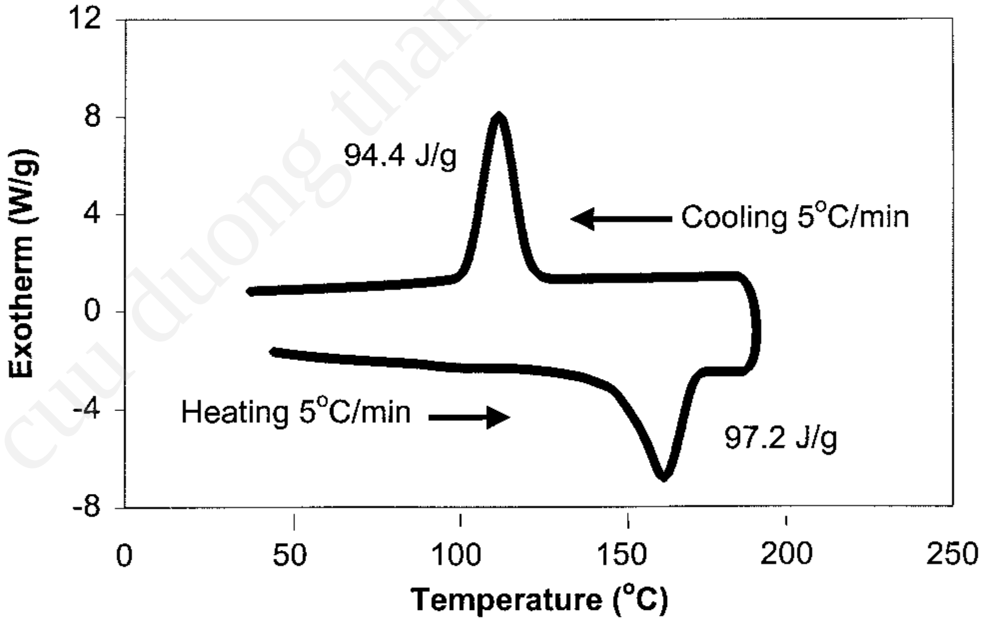


Figure 6.3 Differential scanning calorimetry of a commercial isotactic polypropylene sample, generously provided by Dr. S. J. Han of the Exxon Research and Engineering Company. Note the supercooling effect on crystallization, but the equal and opposite heats of melting and crystallization. Experiment by S. D. Kim.

- X-ray analysis of the crystal structure, and determining the theoretical density of a 100% crystalline material. The density of the amorphous material can be determined from an extrapolation of the density from the melt to the temperature of interest.

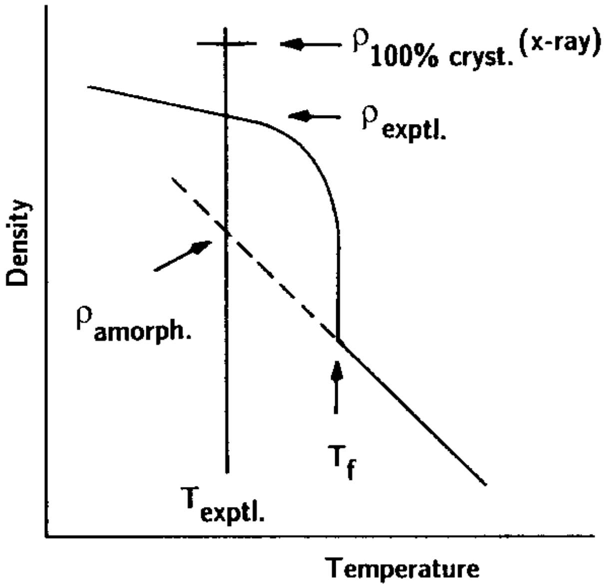


Figure 6.24 The experimental determination of the extent of polymer crystallinity using the density method.
Then the percent crystallinity is given by

$$\%\ \text{Crystallinity} = \left[\frac{\rho_{\text{exptl}} - \rho_{\text{amorph}}}{\rho_{100\%\ \text{cryst}} - \rho_{\text{amorph}}}\right] \times 100$$

where ρ_{exptl} represents the experimental density, and ρ_{amorph} and $\rho_{100\%\text{cryst}}$ are the densities of the amorphous and crystalline portions, respectively.

- WAXS: wide-angle X-ray scattering. A third method stems from the fact that the intensity of X-ray diffraction depends on the number of electrons involved and is thus proportional to the density. Besides Bragg diffraction lines for the crystalline portion, there is an amorphous halo caused by the amorphous portion of the polymer. This last occurs at a slightly smaller angle than the corresponding crystalline peak, because the atomic spacings are larger. The amorphous halo is broader than the corresponding crystalline peak, because of the molecular disorder.

Naturally these methods will not yield the same answer for a given sample, but surprisingly good agreement is obtained. For many semicrystalline polymers the crystallinity is in the range of 40% to 75%. Polymers such as polytetrafluoroethylene achieve 90% crystallinity, while poly(vinyl chloride) is often down around 15% crystallinity. The latter polymer is largely atactic, but short syndiotactic segments contribute greatly to its crystallinity. Of course, annealing usually increases crystallinity, as does orienting the polymer in fiber or film formation.

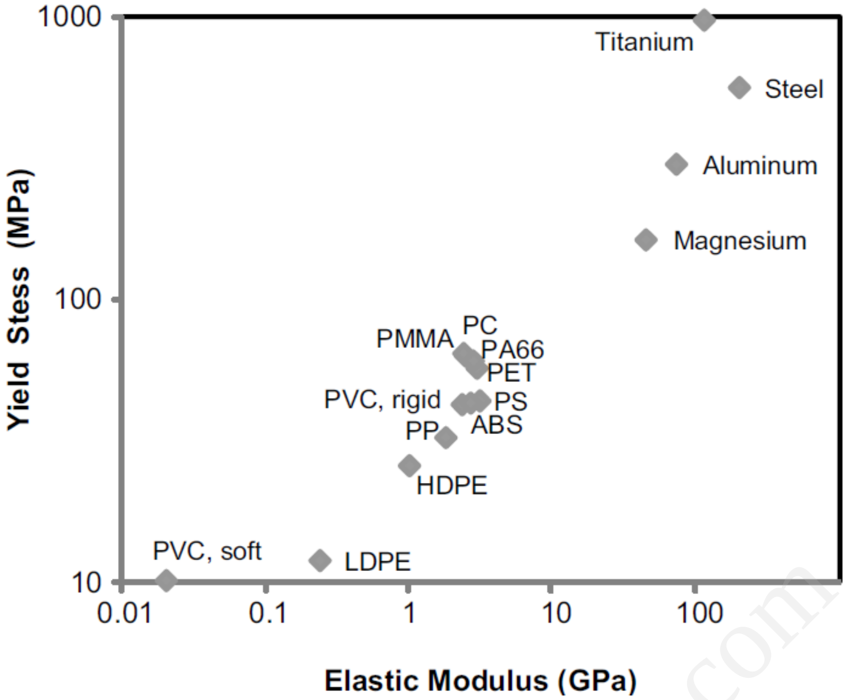


Figure 31.2 Comparison of yield stress and elastic modulus.

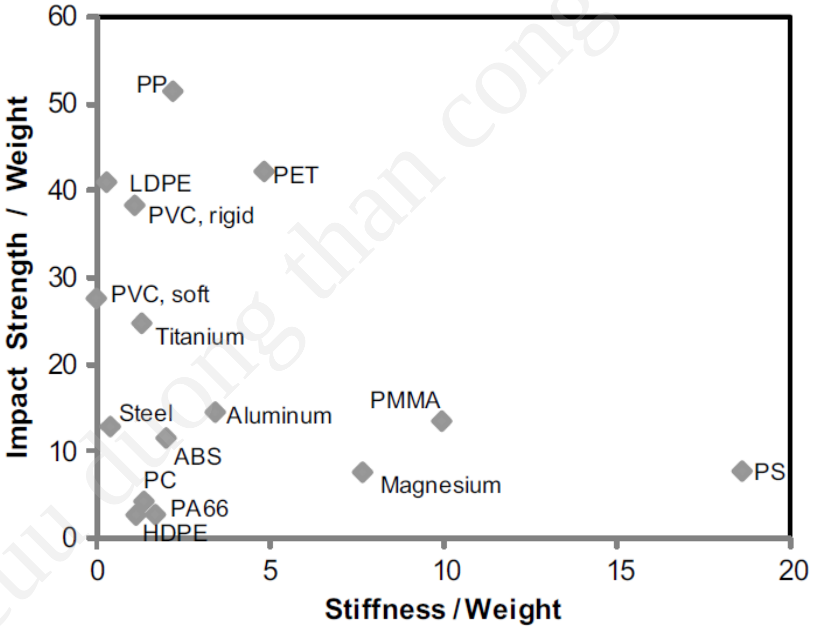


Figure 31.3 Comparison of impact strength and stiffness per unit weight.

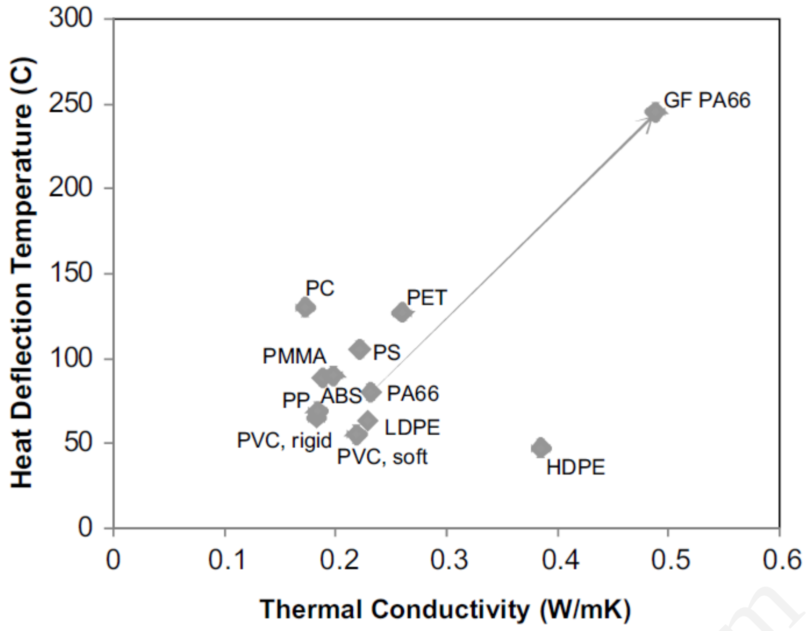


Figure 31.4 Thermal properties of plastic materials.

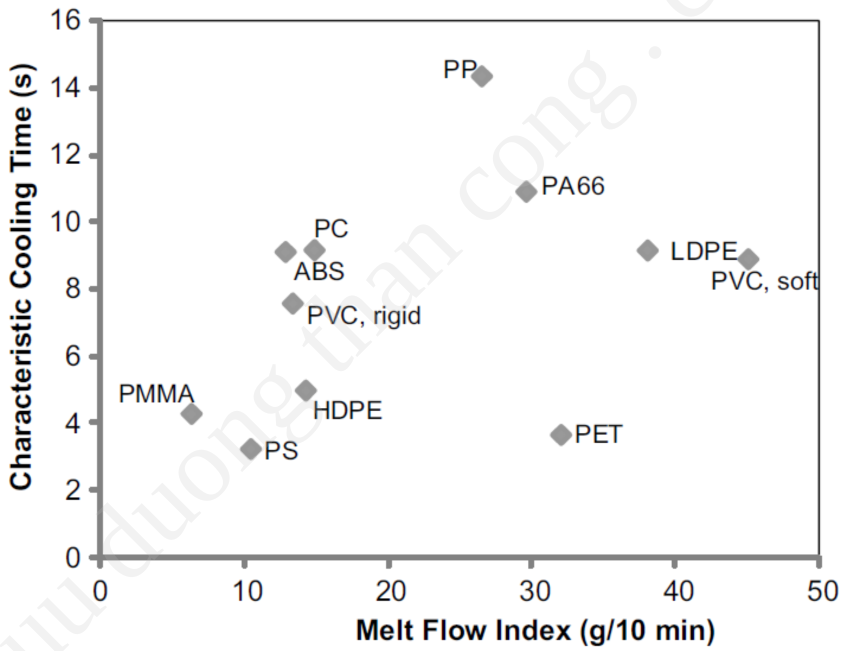


Figure 31.5 Processing properties of plastic materials.

High-density polyethylene

Polyethylene

$$-\!\!\left[CH_2 - CH_2 \right]\!\!-_n$$

Monomer	***Polymerization***	***Major Uses***
Ethylene	LDPE: free-radical-initiated chain polymerization	film and sheet (55%), housewares and toys (16%), wire and cable coating (5%)
	HDPE: Ziegler-Natta or metal-oxide catalyzed chain polymerization	bottles (40%), housewares, containers, toys (35%), pipe and fittings (10%), film and sheet (5%)

Polyethylene is the most widely used thermoplastic material and is composed of ethylene. The two main types are LDPE and high-density polyethylene (HDPE).

Polyethylene is partially amorphous and partially crystalline. Linearity of polymer chains affords more efficient packing of molecules and hence a higher degree of crystallinity. On the other hand, side-chain branching reduces the degree of crystallinity. Increasing crystallinity increases density, stiffness, hardness, tensile strength, heat and chemical resistance, creep resistance, barrier properties, and opacity, but it reduces stress-crack resistance, permeability, and impact strength. Table 1.1 shows a comparison of three types of polyethylene.

Table 1.1 Types of Polyethylene

Material	***Chain Structure***	***Density (g/cm^3)***	***Crystallinity (%)***	***Process***
LDPE	Branched	0.912-0.94	50	High pressure
LLDPE	Linear/less branched	0.92-0.94	50	Low pressure
HDPE	Linear	0.958	90	Low pressure

Table 35.1 Permeation factor of common packaging materials

	Oxygen	Carbon	Dioxide
PET amorphous	10.4		
PET heat set bottle	5.5	20	2.5
PET double blow bottles	4.3	9.0	1.2
PVC	8-15	20-40	2-3
LDPE	480	1500	1.5
HDPE	95	580	0.3
PP	150	450	0.5
PS	416	1250	13
PC	225	550	14
ANS (Barex)	1.1	3.1	6.1

Note: Permeability rates at 25^0C (cm^3)(mil)/(24 hour)(100 in.^{2})(bar) ASTM D1434. Water vapor transmission at 38^0C 50-100% RH (g)(mil)(24 hour)(100 in.^{2}) ASTM E-96. The data in the table is based on Barrier Polymers and other information provided by Morris Salame and elsewhere.

HDPE is used for many packaging applications because it provides excellent moisture barrier properties and chemical resistance. However, HDPE, similar to all types of PE, is limited to those food-packaging applications that do not require an oxygen or CO_2 barrier. In film form, HDPE is used in snack food packages and cereal box liners; in blow-molded bottle form, for milk and non-carbonated beverage bottles; and in injection-molded tub form, for packaging margarine, whipped toppings, and deli foods. Because HDPE has good chemical resistance, it is used for packaging many household as well as industrial chemicals such as detergents, bleach, and acids.

General uses of HDPE include injection-molded beverage cases, bread trays, as well as films for grocery sacks and bottles for beverages and household chemicals.

HDPE is also widely used in fireworks. In tubes of varying length (depending on the size of the ordnance), HDPE is used as a replacement for the supplied cardboard mortar for two primary reasons: it is much safer than the supplied cardboard tubes, and because if a shell were to malfunction and explode inside an HDPE tube, the tube will not shatter.

High-Molecular-Weight High-Density Polyethylene

High-molecular-weight high-density polyethylene (HMW-HDPE) is defined as a linear homopolymers or copolymer with a weight-average molecular weight in the range of approximately 200,000-500,000. HMW-HDPE resins are manufactured using predominantly two basic catalyst systems: Ziegler-type catalysts and chromium oxide-based catalysts. These catalysts produce linear polymers which can be either homopolymers when higher-density products are required or copolymers with lower density. Typical comonomers used in the latter type of products are butene, hexane, and octenes.

The principal applications of HMW-HDPE are in film, pressure pipe, large blow-molded articles, and extruded sheet. HMW-HDPE film now finds application in T-shirt grocery sacks (with 0.6-0.9-mil thick sacks capable of carrying 30 lb of produce), trash bags, industrial liners, and specialty roll stock. Sheets 20-100 mils thick and 18-20 ft. wide are available that can be welded in situ for pond and tank liners.

HMW-HDPE piping is used extensively in gas distribution, water collection and supply, irrigation pipe, industrial effluent discharge, and cable conduit. The availability of pipe materials with significantly higher hydrostatic design stress (800 psi compared with 630 psi of the original HDPE resins) has given added impetus to their use. Large-diameter HMW-HDPE piping has found increasing use in sewer relining.

Large-blow-molded articles, such as 55-gal shipping containers, are produced. Equipment is now available to blow mold very large containers, such as 200- and 500-gal capacity industrial trash receptacles and 250-gal vessels to transport hazardous chemicals.

Ultrahigh-Molecular-Weight Polyethylene

Ultrahigh-molecular-weight polyethylene (UHMWPE) is defined by ASTM as “polyethylene with molecular weight over three million (weight average).” The resin is made by a special Ziegler-type polymerization. Being chemically similar to HDPE, UHMWPE shows the typical polyethylene characteristics of chemical inertness, lubricity, and electrical resistance, while its very long substantially linear chains provide greater impact strength, abrasion resistance, toughness, and freedom from stress cracking.

However, this very high molecular weight also makes it difficult to process the polymer by standard molding and extrusion techniques. Compression molding of sheets and ram extrusion of profiles are the normal manufacturing techniques.

UHMWPE was first used in the textile machinery field picker blocks and throw sticks, for example. Wear strips, timing wheels, and gears made of the UHMW polymer are used in material handling, assembly, and packaging lines. Chemical resistance and lubricity of the polymer are important in its applications in chemical, food, beverage, mining, mineral processing, and paper industries. All sorts of self-unloading containers use UHMWPE liners to reduce wear, prevent sticking, and speed up the unloading cycles. The polymer provides slippery surfaces that facilitate unloading even when the product is wet or frozen.

Because of its outstanding toughness, cut, wear, and excellent chemical resistance, UHWMPE is used in a wide diversity of applications. These include can- and bottle-handling machine parts, moving parts on weaving machines, bearings, gears, artificial joints, edge protection on ice rinks, and butchers’ chopping boards. It has even replaced Kevlar in new bulletproof vests.

Extrusion blow molding is the largest process user of high-density polyethylene (HDPE). The extrusion blow molding markets for HDPE that are growing at a greater pace than the bottle market, in general, are for large holding tanks, 55 gallon drums, and automotive fuel tanks. Approximately 40% of the HDPE produced goes into the blow molding market, making it the workhorse process of the HDPE industry.

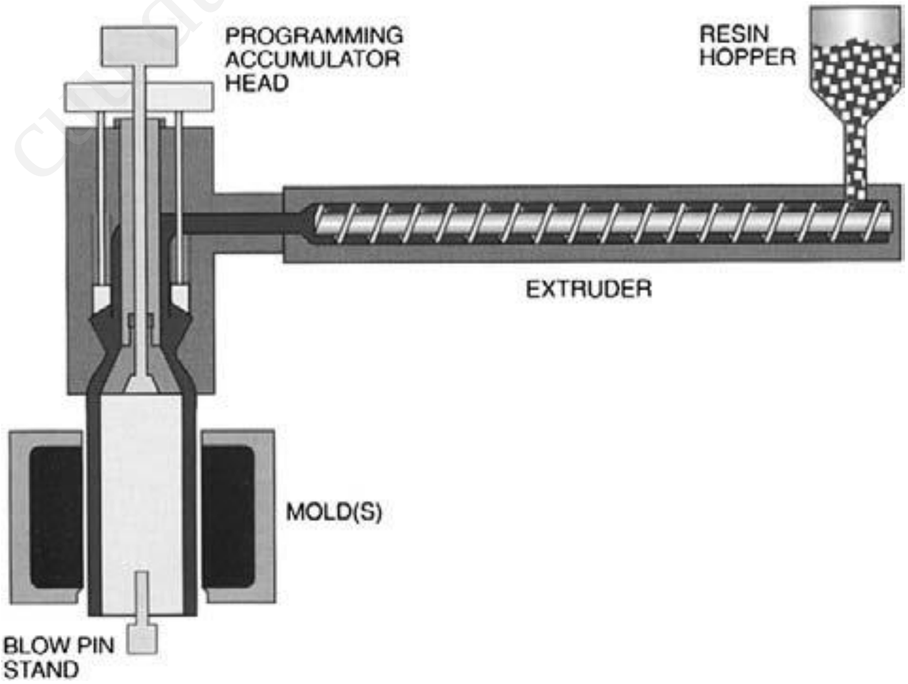
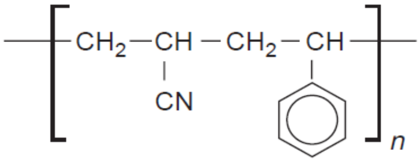


Figure 16.1 The extrusion blow molding process.

When blow molding HDPE, the cooling time controls the cycle. This mold cooling is critical.

Styrene-Acrylonitrile Copolymer



Monomer	***Polymerization***	***Major Uses***
Acrylonitrile, styrene	Free-radical-initiated chain polymerization	Components of domestic appliances, electrical equipment and car equipment, picnic ware, housewares

Because of the polar nature of the acrylonitrile molecule, styrene-acrylonitrile (SAN) copolymers have better resistance to hydrocarbons, oils, and greases than polystyrene. These copolymers have a higher softening point, a much better resistance to stress cracking and crazing, and a higher impact strength than the homopolymer polystyrene, yet they retain the transparency of the latter. The toughness and chemical resistance of the copolymer increases with the acrylonitrile content but so do the difficulty in molding and the yellowness of the resin. Commercially available SAN copolymers have 20-30% acrylonitrile content. They are produced by emulsion, suspension, or continuous polymerization.

Due to their rigidity, transparency, and thermal stability, SAN resins have found applications for dials, knobs, and covers for domestic appliances, electrical equipment, car equipment, dishwasher-safe housewares, such as refrigerator meat and vegetable drawers, blender bowls, vacuum cleaner parts, humidifier parts, plus other industrial and domestic applications with requirements more stringent than can be met by polystyrene.

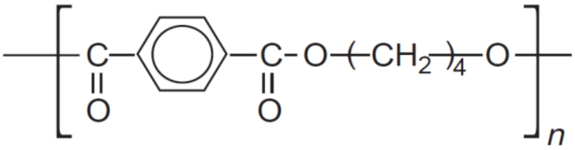
SAN resins are also reinforced with glass to make dashboard components and battery cases. Over 35% of the total SAN production is used in the manufacture of ABS blends.

The two most important ways of producing ABS polymers are (1) blends of styrene-acrylonitrile copolymers with butadiene-acrylonitrile rubber, and (2) interpolymers of polybutadiene with styrene and acrylonitrile, which is now the most important type. A typical blend would consist of 70 parts styrene-acrylonitrile (70:30) copolymer and 40 parts butadiene-acrylonitrile (65:35) rubber.

Interpolymers are produced by copolymerizing styrene and acrylonitrile in the presence of polybutadiene rubber (latex) by using batch or continuous emulsion polymerization. The resultant materials are a mixture of polybutadiene, SAN copolymer, and polybutadiene grafted with styrene and acrylonitrile. The mixture is made up of three phases: a continuous matrix of SAN, a dispersed phase of polybutadiene, and a boundary layer of SAN graft.

Disposable medical products such as syringes, test tubes, petridishes, dialysis products, and drainage devices are proving to be high-volume markets for transparent plastics such as rigid PVC, polystyrene, styrene acrylonitrile (SAN) copolymer, acrylic resins, and polycarbonate. The possibility of mass production is an important consideration in these applications.

Poly(Butylene Terephthalate)



Monomers	***Polymerization***	***Major Uses***
Dimethyl terephthalate or terephthalic acid, butanediol	Bulk polycondensaiton	Machine parts, electrical applications, small appliances

Poly(butylenes terephthalate), often abbreviated to PBT or PBTP, is manufactured by condensation polymerization of dimethyl terephthalate and butane-1,4-diol in the presence of tetrabutyl titanate. The polymer is also known as poly(tetramethylene terephthalate), PTMT in short. Some trade names for this engineering thermoplastic are Tenite PTMT (Eastman Kodak), Valox (General Electric), Celanex (Celanese) in America and Arnite PBTP (Akzo), Ultradur (BASF), Pocan (Bayer), and Crastin (Ciba- Geigy) in Europe.

Because of the longer sequence of methylene groups in the repeating unit poly(butylenes terephthalate) chains are both more flexible and less polar than poly(ethylene terephthalate). This leads to lower values for melting point (about 224^0C) and glass transition temperature (22-43^0C). The low glass transition temperature facilitates rapid crystallization when cooling in the mold, and this allows short injection-molding cycles and high injection speeds.

PBT finds use as an engineering material due to its dimensional stability, particularly in water, and its resistance to hydrocarbon oils without showing stress cracking. PBT also has high mechanical strength and excellent electrical properties but a relatively low heat-deflection temperature 54^0C at 264 psi (1.8 MPa). The low water absorption of PBT-less than 0.1% after 24-h immersion-is outstanding.

Both dimensional stability and electrical properties are retained under conditions of high humidity. The lubricity of the resin results in outstanding wear resistance.

Typical applications of PBT include pump housings, impellers, bearing bushings, gear wheels, automotive exterior and under-the-hood parts, and electrical parts such as connectors and fuse cases.

Industrial Polyblends

The automotive sector is an important area for polymer blends. Alloys of polycarbonate (PC) and poly (butylenes terephthalate) (PBT), which combine the high impact strength of PC with the resistance of gasoline and oil and processing ease of PBT, are being increasingly used in car bumpers.

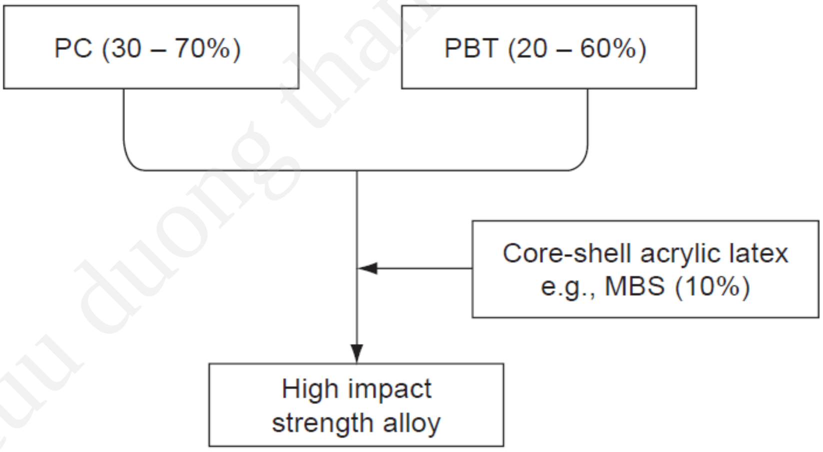
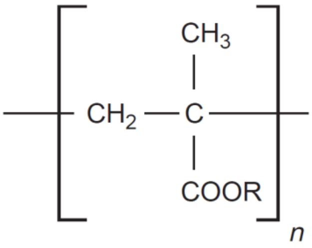


Figure 1.41 Schematic of preparation of polycarbonate/poly(butylenes terephthalate) blend. (After Utracki, L. A. 1989. Polymer Alloys and Blends. Hanser Publishers, Munich, Germany.)



$$\left[-CH_2-C(CH_3)(COOR)- \right]_n$$

A large number of alkyl methacrylates, which may be considered as esters of poly(methacrylic acid), have been prepared. By far the most important of these polymers is poly(methyl methacrylate), which is an established major plastics material. As with other linear polymers, the mechanical and thermal properties of polymethacrylates are largely determined by the intermolecular attraction, spatial symmetry, and chain stiffness.

Poly(methyl methacrylate)

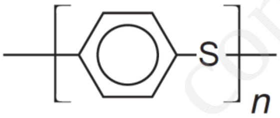
Monomers	***Polymerization***	***Major Uses***
Methyl methacrylate	Solution, suspension and emulsion processes	Lenses, transparent aircaft enclosures, drafting equipment, outdoor signs

PMMA is by far the predominant polymethacrylate used in rigid applications *because it has crystal clear transparency*, excellent weatherability (better than most other plastics), and a useful combination of stiffness, density, and moderate toughness. The glass transition temperature of the polymer is 105^{0}C, and the heat deflection temperatures range from 75 to 100^{0}C. The mechanical properties of PMMA can be further improved by orientation of heat-cast sheets.

PMMA is widely used for signs, glazing, lighting, fixtures, sanitary wares, solar panels, and automotive tail and stoplight lenses. The low index of refraction (1.49) and high degree of uniformity make PMMA an excellent lens material for optical applications.

Methyl methacrylate has been copolymerized with a wide variety of other monomers, such as acrylates, acrylonitrile, styrene, and butadiene. Copolymerization with styrene gives a material with improved melt-flow characteristics. Copolymerization with either butadiene or acrylonitrile, or blending PMMA with SBR, improves impact resistance. Butadiene-methyl methacrylate copolymer has been used in paper and board finishes.

Poly(Phenylene Sulfide)



Monomers	***Polymerization***	***Major Uses***
p-Dichlorobenzene, sodium sulfide	Polycondensation	Electrical components, mechanical parts

Poly(phenylene sulfide) (PPS) is the thio analogue of poly(phenylene oxide) (PPO). The first commercial grades were introduced by Phillips Petroleum in 1968 under the trade name Ryton.

PPS is an engineering plastic. The thermoplastic grades of PPS are outstanding in heat resistance, flame resistance, chemical resistance, and electrical insulation characteristics. The linear polymers are highly crystalline with melting point in the range of 285-295^{0}C and T_g of 193-204^{0}C.

The material is soluble only above 200^{0}C in aromatic and chlorinated aromatic solvents. It has the ability to cross-link by air-oxidation at elevated temperatures, thereby providing an irreversible cure. Thermogravimetric analysis shows no weight loss below 5008C in air but demonstrates complete decomposition by 700^{0}C. It is found to retain its properties after four months at 233^{0}C in air.

Significant increases in mechanical properties can be achieved with glass-fiber reinforcement. In the unfilled form the tensile strength of the material is 64-77 MPa at 21^{0}C, 33 MPa at 204^{0}C, and the flexural modulus is 4200 MPa at 21^{0}C. The corresponding values for PPS-glass fiber (60:40) composites are 150, 33, and 15,500 MPa.

Although rigidity and tensile strength are similar to those of other engineering plastics, PPS does not possess the toughness of amorphous materials, such as the polycarbonates and the polysulfones (described later), and are somewhat brittle. On the other hand, PPS does show a high level of resistance to environmental stress cracking.

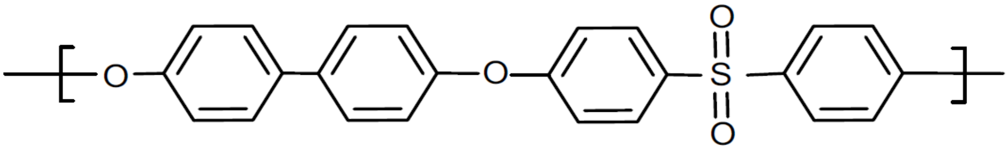
Being one of the most expensive commercial moldable thermoplastics, the use of PPS is heavily dependent on its particular combination of properties. Good electrical insulation characteristics, including good arcing and arc-tracking resistance has led to PPS replacing some of the older thermosets in electrical parts. These include connectors, terminal blocks, relay components, brush holders, and switch components.

PPS is used in chemical process plants for gear pumps. It has found application in the automotive sector, in such specific uses as carburetor parts, ignition plates, flow control values for heating systems, and exhaust-gas return valves to control pollution. The material also finds uses in sterilizable medical, dental, and general laboratory equipment, cooking appliance, and hair dryer components.

Injection-molded products of PPS include high-temperature lamp holders and reflectors, pump parts, valve, and, especially when filled for example with PTFE or graphite, bearings. Processing temperatures are 300-350^{0}C with mold temperatures of up to 200^{0}C. PPS is also used for encapulation of electronic components and as a high temperature surface coating material.

PPS is resistant to neutron and gamma radiation. In nuclear installations, its flexural strength and modulus are essentially unchanged when it is exposed to gamma radiation of 5x10^9 rad and neutron radiation of 1x10^9 rad.

Polyphenylsulfone



Monomers	*Polymerization*	*Major Uses*
4,4'-biphenol and bis(p-chlorophenyl) sulfone.	Nucleophilic aromatic substitution between aromatic dihalides and bisphenolate salts	Plumbing, food services, medical, aerospace, wire and cable

Polysulfones are typically synthesized from aromatic dichlorides in a polar aprotic solvent such as 1-methyl-2-pyrrolidinone (NMP) or dimethyl sulfoxide.

Also known as PPSF, PPSU is part of Sulfone polymers, which are high performance polymer exhibiting very attractive properties such as high temperature performance, good chemical resistance, outstanding toughness, excellent colorability and very good dimensional stability. As the other sulfone polymers, PPSU is an amorphous polymer and displays therefore very good creep resistance, isotropic thermal and mechanical properties (if non reinforced) and transparency properties.

Key features	*Typical applications*
High HDT of 207°C	Sterilization cases and trays
Superior toughness and impact strength	Dental and surgical instruments
Exceptional long-term hydrolytic stability	Medical devices
Better chemical resistance than PSU and PEI	Aircraft interiors
Withstands over 1,000 cycles of steam sterilization without any significant loss of properties	Airline catering trolleys
Inherently flame retardant	Hot water fittings
Transparent	Plumbing manifolds
Colorable	Food service trays