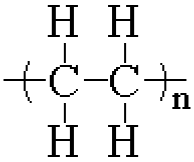
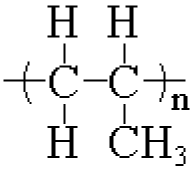
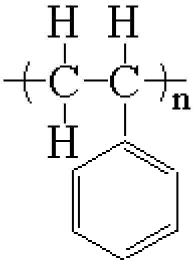
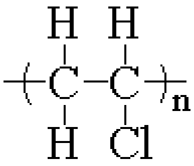
Polymers

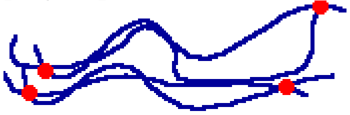
(From various sources, including the Canadian CBD 158/159, text, etc)

About 85% of the world plastics consumption is from just four polymers. These polymers are produced in high volume at very low cost. They are all thermoplastics.

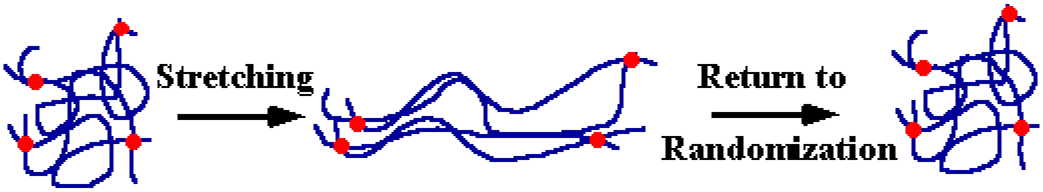
Polymer	Repeat Unit	Applications
Polyethylene (PE)	 $\left(-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}- \right)_n$	electrical wire insulation, flexible tubing, squeeze bottles
Polypropylene (PP)	 $\left(-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{CH_3}{C}}- \right)_n$	carpet fibers, ropes, liquid containers (cups, buckets, tanks), pipes
Polystyrene (PS)		packaging foams, egg cartons, lighting panels, electrical appliance components
Polyvinyl chloride (PVC)	 $\left(-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{Cl}{C}}- \right)_n$	bottles, hoses, pipes, valves, electrical wire insulation, toys, raincoats

Elastomers

Elastomers are long polymer chains above their glass transition temperature. Elastomers are usually lightly crosslinked and are easily deformed. Common elastomers include polybutadiene (used in shoe soles), polyisobutylene (used in automobile tires), and polyisoprene (natural rubber).



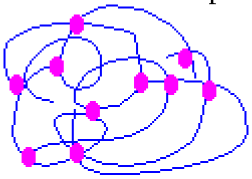
Elastomeric polymer chains can be **crosslinked**, or connected by covalent bonds. This process is sometimes called vulcanization. Crosslinking is initiated by heat, light, or the addition of chemicals.



Crosslinking makes elastomers reversibly stretchable for small deformations. When stretched, the polymer chains become elongated and ordered along the deformation direction. This is entropically unfavorable. When no longer stretched, the chains randomize again. The crosslinks guide the elastomer back to its original shape.

Thermosets

Thermoset polymers have covalent bonds linking the polymer chains in three dimensions. These links prevent the chains from sliding past one another resulting in a higher modulus and improved creep resistance.

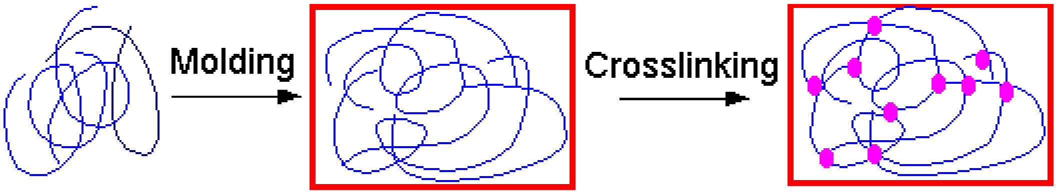


Usually thermosets are more brittle than thermoplastics
Note that thermosets are similar to elastomers. The polymer chains in thermosets are below their glass transition at room temperature, making them glassy. In contrast, the polymer chains in elastomers are above their glass transition at room temperature, making them rubbery.

Thermoset formation

Thermosets are formed from thermoplastic polymer chains which are then covalently bonded to each other in a process known as crosslinking.

The thermoplastic polymer flows easily and can be molded into the desired shape, like the box below.



Once the precursor is cast into the desired shape the polymer is crosslinked, creating the thermoset material.

Crosslinking is initiated by heat, light, or the addition of other chemicals. It is not a reversible process resulting in materials which cannot be recycled.

Once shaped into a permanent form, usually with heat and pressure, a thermosetting plastic cannot be remelted or reshaped because the basic polymeric component has undergone an irreversible chemical change. The operation by which the raw material is converted to a hard, insoluble and infusible product is referred to as cure (or curing) and corresponds to the final step of the polymerization reaction.

A thermosetting material may be cured by the use of heat, radiation, catalysts or a combination of these. The polymer component consists of molecules with permanent cross-links between linear chains that form a rigid three-dimensional network structure which cannot flow. The tightly cross-linked structure of thermosetting polymers immobilizes the molecules, providing hardness, strength at relatively high temperature, insolubility, good heat and chemical resistance, and resistance to creep.

Table I. Typical Range of Mechanical Properties of Thermosetting Plastics (Filled or Reinforced)[1]

Thermosetting Materials	Tensile Strength, psi (ASTM D-638)	Elongation, % (ASTM D-638)	Tensile Modulus, 10^5 psi (ASTM D-638)	Compressive Strength, psi, (ASTM D-695)	Flexural Yield Strength, psi, (ASTM D-790)	Hardness[**]
Epoxy (moulding compounds)[*]	10,000-30,000	4.0	30.4	25,000-40,000	10,000-60,000	M100-M110
Unsat'd Polyester	4,000-50,000	0.5-5.0	8.0-45	15,000-50,000	10,000-80,000	M70-M120, 60-80
Phenolics (cast-resin)	4,000-9,000	-	18.8	10,500-34,000	5,000-12,000	M85-M120, R110
Urea-formadlehyde (moulding compounds)	5,500-13,000	0.5-1.0	10.0-15.0	25,000-45,000	10,000-18,000	M110-M120
Melamine-formaldehyde (moulding compounds)	5,000-13,000	0.3-0.9	11.0-24.0	20,000-45,000	9,000-23,000	M110-M125
Alkyds	3,000-9,500	-	5.0-30.0	12,000-38,000	6,000-20,000	55-80 M95-M99, E76-E98

[*] Glass fibre filled
[**] Figures preceded by E,M or R (hardness scale symbols) represent values obtained by a Rockwell tester (ASTM D-785); the figures without letters were obtained with a Barcol tester (ASTM D-2583)

Table II. General Properties of Commercial Thermosetting Plastics (Filled or Reinforced)[1]

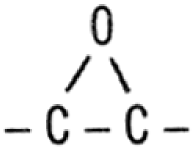
Thermosetting Material	Burning Rate (Flammability), in./min., (ASTM D-635)	Coeff of Therm Exp. 10^{05}/°F	Resistance to Heat (continuous), °F	Water Absorption, % (ASTM D-570)	Chemical Resistance* (room temperature)
Epoxy (moulding compounds)	Self-ext	0.6-2.8	300-500	0.05-.020	Resistant to weak acid and in general to weak alkalis, attacked by some strong acids, and slightly by strong alkalis.
Polyester	0.7-2.0	0.7-2.8	300-350	0.01-1.00	Resistant to some weak acids, but attacked by strong acids, alkalis, and by oxidizing agents.
Phenollics (cast resins)	Negotiable	1.8-4.2	160-300	0.12-0.36	May resist or undergo slight attack by weak acids; are attacked by strong agents oxidizing agents and strong alkalis, undergoing decomposition.
Urea-formaldehyde (mould compounds)	Self-text	1.2-2.0	170	0.40-0.80	Fairly resistant t weak acids, but ay undergo surface attack and decomposition in strong acids. Moderately attacked by weak alkalis, decomposes in strong alkalis.
Melamine-formaldehyde	Very slow burning, self-ext or nonburning	0.8-2.5	210-400	0.08-0.80	May resist or undergo slight attack by weak acids and alkalis but decomposes in strong acids and alkalis.
Alkyds	Slow burning, self-ext to nonburning	0.8-3.1	300-450	0.05-050	May undergo slight attack by weak acids and weak alkalis and more severe attack by strong acids and strong alkalis (with decomposition).

* Thermosetting materials do not dissolve, and only swell if they interact with solvents. Many thermosetting materials do not swell appreciably in contact with any solvent, but some of the compounding ingredients may be leached out.

Thermosetting materials are usually preferred for structural applications because their strength is generally higher than that of thermoplastics and they do not have a tendency to cold flow (creep) at room temperature. The major families are epoxies, unsaturated polyesters, phenolics, amino resins (urea- and melamine-formaldehyde) and alkyds Typical properties are given in Table I and Table II. (The ranges of these properties are also given for comparison, and may represent only a fraction of the values attainable.) As thermosetting plastics are generally used with fillers or reinforcements, the properties given are for materials containing such ingredients. Other thermosetting plastics include polyurethanes (used in foams and coatings), allyls, and furane resins.

Epoxies

This family of thermosetting plastics derives its name from the epoxy group,



which is present in the monomer as well as in the intermediate polymer before cross-linking. To produce thermosetting plastic articles the intermediate epoxy polymer is compounded with one or more ingredients that may include fillers, reinforcements, pigments, or plasticizers. Curing is effected by adding either hardeners or catalysts, usually in conjunction with heating. Thermoset epoxy plastics can be formulated for almost any application.

Reinforced plastics based on epoxy resins have better mechanical strength, chemical resistance, electrical insulating properties and environmental stability than those made with conventional unsaturated polyesters. Epoxy glass-fibre-reinforced materials are mainly used in printed electrical circuits and in wing and fuselage structural members of jet aircraft where they must maintain their strength over a wide range of temperatures. Other structures fabricated from reinforced epoxy thermosets are pipes, tanks, pressure vessels and tooling jigs and fixtures. Reinforcements and fillers include glass, asbestos, cotton, paper, metal foils, and synthetic fibres. Glass-filament-wound epoxy composites are used in the manufacture of casings of rocket motors for missiles.

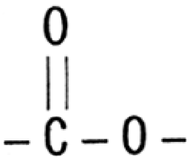
Because of their excellent adhesion and good chemical resistance, epoxies are used in protective coatings and adhesives. Epoxy-based adhesives are compatible with most materials, and some can withstand temperatures as high as 204°C (400°F) without weakening. Epoxy-resin-based materials used as surface coatings combine good chemical resistance, toughness, flexibility and adhesion. Epoxy coatings are used primarily in corrosion- and abrasion-resistant applications, for example, in maintenance paints and finishes; container, pipe and tank linings; heavy-duty floor and wall coatings for masonry, steel, and wood surfaces.

Because of their combination of properties epoxy resins are used in a number of heavy-duty applications in building and construction; for mar and wear-resistant terrazzo, industrial flooring, and for filling potholes and repairing cracks on highways and bridges. Owing to good bonding properties and low shrinkage during curing, epoxies are used in the fabrication of interior and exterior wall panels made with exposed aggregate (for example, with glass chips, marble).

Epoxies are used for making electrical parts by casting, for potting and encapsulating electrical components. Epoxy moulding compounds are also available and may be processed by injection, transfer moulding, etc; applications include packaging of electronic components and pipe fittings.

Unsaturated Polyesters

Polyesters are polymers that contain ester groups,



$$-\overset{O}{\overset{\|}{C}}-O-$$

in the main chain. Conventional, general-purpose, unsaturated polyesters are produced by reaction of polypropylene glycol with a mixture of maleic and phthalic anhydrides. The molecule of the resulting polymer contains double bonds, (C=C), also called unsaturated bonds, from which the name unsaturated polyester has been derived. various unsaturated vinyl-type monomers can be added as cross-linking agents to convert the unsaturated polyester to a thermosetting material. Styrene is most frequently used because of its low cost, availability, and the physical properties of the resulting product; and methyl methacrylate (acrylic modified polyester) used in conjunction with styrene will improve weatherability.

The most important advantages of unsaturated polyester resin systems include ease of handling, rapid curing with no volatile by-products, light colour, dimensional stability, and generally good physical and electrical properties. Applications of unsaturated polyester-based thermosetting plastics are many and include building and construction components, transportation applications, fabrication of electrical parts, consumer products and anti-corrosive materials.

In building construction, corrugated and flat sheets made from glass-fibre-reinforced polyester (GRP) are used for roofs, awnings, skylight domes, partitions, wall siding, decorative fixtures, fences, bathroom accessories, surfacing of concrete floors. Transportation applications include passenger car parts and bodies, truck cabs, and tank trucks.

Unsaturated polyester thermosets are, in general, good insulating materials for electrical applications and are often used with glass fibre as reinforcement. Consumer products include diverse articles such as luggage, chairs, fishing rods, cafeteria trays, pipes and ducts, and boat hulls. GRP is also used in fabricating pipes, tanks, ducts, grids and baffles for corrosive environments.

Articles and structures based on general-purpose unsaturated polyester resin have only limited resistance to chemical degradation. By modification of the basic resin and proper formulation, chemical resistance can be dramatically improved. Unsaturated polyester resin can also be successfully formulated to yield good fire-retardant materials. The performance of articles (or structures) made for outdoor application from general-purpose GRP by present-day technology is fair. Compounds, formulations and techniques are available for making materials with better, even excellent, weathering resistance, but these materials are very expensive.

Phenolics

Most important among the phenolic plastics are those based on polymers produced by the reaction of phenol with formaldehyde. Basically, phenolic plastics are compositions of resol or novolac resins, various fillers, colouring agents, lubricants and plasticizers designed either for general use or for specific applications. The general purpose grades are usually filled with wood flour and other low-priced fillers to reduce cost and provide a balance of good insulation and strength. The finished article can have high gloss, but colours are limited by the tendency of phenolics to darken with age and exposure. Applications include appliance parts, wiring devices, switchboards and automotive parts.

Heat-resistant phenolic compounds contain mineral fillers such as diatomaceous earth, mica and asbestos. Some can withstand intermittent exposure to temperatures up to 260°C (500°F) without impairment of the finish or physical properties. Typical applications include handles on kitchen utensils, parts for appliances and ovens, and electrical switch gear. Impact-resistant compounds contain fibrous reinforcing materials such as cotton, glass, synthetic flock, and special grades of asbestos.

Phenolics are particularly suitable for electrical applications because of their good dielectric properties, dimensional stability and resistance to moisture. Phenolic-based compounds are used in laminating applications, for example, for decorative laminates for counter tops and wall coverings. A number of industrial applications, including heat setting adhesives, abrasive wheels, and sandpaper, are possible owing to their good adhesive properties and bonding strength. Phenolics are also used in varnishes and protective coatings.

Urea-Formaldehydes (Ureas) and Melamine-Formaldehydes (Melamines)

These thermosetting plastics, also called amino resins because they are produced by the reaction of amines, or compounds bearing the amino group (-NH2), with formaldehyde, are clear and colourless, a distinct advantage over the phenolics. They also have better hardness and tensile strength than phenolics, but their impact strength and moisture resistance are lower. Ureas have lower hardness, heat resistance and moisture resistance than melamines.

Amino resins are used in the fabrication of industrial and decorative laminates, adhesives, protective coatings, paper manufacture, and moulding compounds. Melamine is one of the thermosetting plastics that can be made in unlimited colours. Articles fabricated from melamines are rigid and have one of the hardest surface finishes of any plastic material. Because of this they are widely used for the production of decorative laminates, which are usually assembled from a core of phenolic resin-impregnated paper and a melamine impregnated overlay sheet. The system is cured with hot pressing to produce such items as counter, cabinet or table tops.

Alkyds

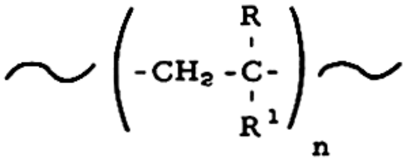
The name of this family of thermosets is derived somewhat freely from the monomers used to produce the basic resin, the "al" from alcohol and the "cid" from acid. Currently, there are many commercial alkyd resins modified with epoxy resin, phenolic resin, rosin, fatty acids derived from mineral and vegetable oils, etc. A combination of interesting properties and moderate cost makes alkyd thermosetting resins and their modifications very attractive for certain applications, especially in coatings and moulding applications (in the automotive, electrical and electronic industries, for example). Their properties include durability, flexibility, gloss retention, reasonable heat resistance, good colourability and dimensional stability and good electrical properties.

Thermoplastics

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 the tables below, although the values of some properties represent only a fraction of the total range attainable and should be used for comparative purposes only.



$$\sim\left(-CH_2-\overset{R}{\underset{R^1}{C}}-\right)_n\sim$$

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

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

R Abbreviation	R^1	Name of Polymer	
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.

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-	2- 40	3.5-6.0	8,000-	10,000-	65-85 (Shore

chloride)	9,000			13,000	16,000	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

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[*] 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.

Typical Properties of Commercial Thermoplastics (Unfilled, Unreinforced)

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
Polypropylene	Slow	125-140	3.2-5.7	<0.01	Resistant (below 176°F	

						all colours.
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

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[*] 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.

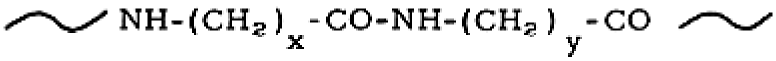
The most important of all the copolymers of styrene in terms of volume are styrene-butadiene synthetic rubber and the styrene-butadiene copolymer, used in latex paint. The copolymer of styrene with acrylonitrile is also of major interest. ABS resins are two-phase systems consisting of styrene-butadiene 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.

Glass Transition Temperature

Some plastics are hard, and some that are soft. For example, the plastic keys on your keyboard are hard, while the plastic around the cables of the same computer is soft. This is because all plastics have a certain temperature above which they are soft and pliable, and below which they are hard and brittle. This is called the glass transition temperature, or Tg. The Tg is different for each plastic and is an important characteristic of all polymers. At room temperature, some plastics are below their Tg, and so they are hard. Other plastics are above their Tg at room temperature, and these plastics are soft.

Sometimes additives are added to a plastic to make it softer and more pliable. These additives are called plasticizers. PVC is generally stiff, but adding plasticizers causes it to be flexible. The smell of a new shower curtain or new car is the result of plasticizers off-gassing. Some of these products have negative health effects.

Polymer Processing

Polymers are formed by many low temperature processes.

Extrusion. The polymer is heated to the liquid state and forced through a die under pressure resulting in an endless product of constant cross section. 60% of polymers are prepared in this way. Examples include: tubing, pipes, window frames, sheet, insulated wire.

Film Blowing. Using the same method as extrusion the material coming out of the die is blown into a film. An example is plastic wrap.

Injection molding. Similar to extrusion, the polymer is heated to the liquid state, but it is prepared in metered amounts, and the melt is forced into a mold to create the part. It is not a continous process. Many toys are made by injection molding.

Blow molding. The melted polymer is put into a mold, then compressed air is used to spread the polymer into the mold. It is used to make many containers such as plastic soda containers and milk jugs.

Compression molding. Solid polymer is placed in a mold, the mold is heated and puts pressure on the polymer to form the part.

Reaction injection molding. Liquid monomers are placed in the mold avoiding the need to use temperature to melt the polymer or pressure to inject it. The monomers polymerize in the mold forming the part.