# Polymer Properties

## Introduction

Plastic products are made from polymers. The term ***plastic*** means that a material is soft and can be ***shaped*** and ***moulded***. The materials that we call plastics, e.g. acrylic, polythene and nylon, have at some point been soft and have been shaped and moulded.

The term ***polymer*** comes from the Greek words "***poly***" meaning many and "***mer***" meaning units. Polymers are made up of lots of units of molecules (**monomers**) strung together in a tangled mass. Variations in the properties of a polymer are made by varying the polymerisation process and by changing the composition of the polymer, e.g. by the use of additives and by alloying, i.e. mixing with one or more other polymers.

New polymers are being developed all the time. The MatWeb Material Property database has records of 55,468 polymers. Some polymers have lots of variations, e.g. there are 2274 types of ABS polymer and 4086 types of polycarbonate polymer listed in the MatWeb Material Property database. Each variation of a polymer is intended to make it suitable for a particular purpose or to improve the production process, e.g.

- general purpose, moulded
- high flow, moulded
- extruded
- impact modified, moulded
- impact modified sheet
- cast
- heat resistant, moulded
- UV stabilized, moulded
- optical grade, moulded
- optical sheet

Polymers are also mixed (alloyed) with other polymers e.g.

- acrylic/polycarbonate alloy
- acrylic/polycarbonate alloy, glass fibre filler
- acrylic/polycarbonate alloy, carbon fibre filler
- styrene/methyl methacrylate copolymer (SMMA) (Acrylic)
- PVC/acrylic alloy (acrylic)
- acrylonitrile-methyl acrylate copolymer.

## Describing polymer properties

The properties of polymers are measured and described in a number of ways, including the polymer:

- Hardness
    - Rockwell hardness test
    - Shore/Durometer hardness test
    - Barcol hardness test
- Specific gravity
- Tensile strength
- Tensile elongation
- Compressive strength
- Shear strength
- Vicat softening point
- Flammability
- Brittleness temperature
- Permanent effect of heat
- Deflection temperature
- Deformation under load
- Water absorption
- Effect of weathering

## Density and specific gravity

**Density** of a polymer = Mass of polymer ÷ Volume of polymer, expressed as grams per cubic centimetre (g/cc).

The **specific gravity** of a polymer is equal to its density divided by the density of water. Specific gravity is expressed as a number.

As the density of water at 4°C is 0.9999 g/cc and at 30°C is 0.9956 g/cc, it is so close to 1 through a range of temperatures that for practical purposes, it may be counted as 1.

Therefore the specific gravity of a polymer = density of polymer ÷ 1

i.e. the specific gravity of a polymer = density of polymer.

## Hardness

Several tests are used to determine the hardness of polymers including:

- **Barcol hardness test.** The Barcol hardness test is used on soft materials and measures the hardness of a material based on the depth of indentation of a sharp point with a flat tip. A scale of 1 - 100 is used, with each division equivalent to a depth of 0.0076 mm. The higher the number, the softer the material.
- **Rockwell E, Rockwell M, Rockwell R hardness tests**. These tests measure the resistance of a plastic to indentation. A hardened steel ball is pressed into the polymer and the depth of the indentation is measured and compared to the applied load.
- **Shore (durometer) hardness tests.** The Shore hardness test is used mainly on softer plastics and rubbers/elastomers. The main scales used are the Shore A and the Shore D scales. Shore A is used with soft rubbers and elastomers. Shore D scale is used for harder rubbers and elastomers. Shore hardness is measured using a Durometer, so the result of the test is also known as the Durometer hardness. The hardness of a polymer sample is determined by the penetration of the Durometer indenter foot into the sample. The result is sometimes shown as a hardness number with an indentation time, because the depth of indentations often changes over time due to the rubbery nature of the material.

## Ultimate tensile strength

The ultimate tensile strength of a plastic (or any other material) is the tensile (tension) force required to break it. The tensile force is measured in either pounds per square inch (psi) or megapascals (MPa).

## Ultimate tensile elongation (elongation at break)

The ultimate tensile elongation of a plastic is the percentage increase in its length before it breaks under tension. A tough material has high ultimate tensile strength together with high tensile elongation.

## Processing temperature

The processing temperature of a polymer is the temperature range between which a polymer softens and melts and can be bent, twisted, stretched, moulded, extruded, etc without the polymer overheating, degrading or burning. One polymer may have different processing temperatures for each manufacturing process, e.g. the optimal processing temperature for line bending a thermoplastic polymer will be different to the optimal processing temperature for extruding or injection moulding it.

## Vicat softening point

The Vicat softening test determines the temperature at which a needle with a 1 mm diameter flat end or 1 mm square flat end penetrates a polymer specimen to a depth of 1 mm.

| Polymer | Density g/cc | Hardness | Tensile Strength (Ultimate) | Elongation at break | Processing Temp. | Application |
|---|---|---|---|---|---|---|
| Acrylonitrile Butadiene Styrene (ABS), *(Moulded)* | 0.35 - 1.26 | Rockwell R 90 - 121 | 27.6 - 65 MPa | 2.40 - 110 % | 160 - 274°C | Telephone handsets, suitcases, kitchen appliance, housings, handles, computer cases. |
| Acrylic (PMMA) *(General Purpose)* | 0.98 - 1.2 | Rockwell M 18 - 99 Rockwell R 69 - 95 | 19.3 - 80 MPa | 1 - 85 % | 177 - 265°C | Alternative to glass, used as windows, screens, vehicle signal lights, lenses, light fittings, signs, adhesives. Resin casting. |
| Acrylic (PMMA) *(Cast)* | 1.18 - 1.19 | Rockwell M 94 - 102 | 62 - 84 MPa | 4 - 5.5 % | 80 - 193°C | |
| Polybutene-1 (PB-1) | 0.91 | N/A | 27 - 34MPa | >=350% | Melting temp. 116 -123°C | Seal-peel or easy-open packaging, e.g. cereal packaging and packs for cold meats, cheeses. |
| Polyamides (PA) *(Nylon 6)* | 1 - 1.49 | Rockwell M 81 - 88 Rockwell R 78 - 122 | 12 - 100 MPa | 3.2 - 500% | 40 - 371°C | Injection moulding. Nylon fibres are used in textiles, fishing lines, carpets, upholstery fabrics, seat belts, toothbrush bristles and ropes. Nylon films are used for food packaging. |
| Polycarbonate (PC) *(Moulded)* | 0.95 - 1.54 | Rockwell M 65 - 122 Rockwell R 70 - 123 | 37 - 630 MPa | 1.5 - 233% | 227 - 343°C | Motor vehicle bumpers, CDs, computer housings, power tool casings, safety helmets, sheeting material in the construction industries, e.g. polycarbonate roofs, sky lights, vandal proof windows. |
| Polyethylene Terephthalate (PET) | 1.25 - 1.91 | Rockwell M 80 - 95 Rockwell R 105 - 120 | 22 - 207 MPa | 1.5 - 600 % | 120 - 295°C | Automobile parts, household products, PET fibres are widely used in textile, |
| Styrene Acrylonitrile (SAN) | 0.9 - 1.2 | Rockwell M 75 - 93 Rockwell R 83 - 124 | 45 - 80 MPa | 1.5 - 16% | 220 - 260°C | Kitchen ware, business machine casings, drinks cups, packaging, toys, toothbrush handles. |
| Acrylonitrile Styrene Acrylate (ASA) | 1 - 1.2 | Rockwell R 86.0 - 119 | 25 - 48 MPa | 5.00 - 230% | 220 - 280°C | Aerospace components, automobile parts, recreational equipment components, outdoor structural parts. |

| Polymer | Density g/cc | Hardness | Tensile Strength (Ultimate) | Elongation at break | Processing Temp. | Application |
|---|---|---|---|---|---|---|
| Polyvinyl Chloride (PVC) *(Flexible grade)* | 1.11 - 1.89 | Shore A 35 - 95 Shore D 33 - 78 | 0.75 - 29.7 MPa | 50 - 520 % | 150 -220°C | Fashion and footwear, packaging, cling film, credit cards and synthetic leather, wire insulation, floor covering, roofing membranes, shower curtains, table covers, stationary, automotive seat coverings, upholstery sheets, wall covering, garden hoses, handbags, inflatable boats and toys, rainwear, tubes, automotive pedals & trim, calendered sheet. |
| Polyvinyl Chloride (PVC) *(uPVC)* *(Sheet grade)* | 1.27 - 1.55 | Rockwell R 76 - 112 Shore D 74 - 83 | 46 - 52 MPa | 15.0 - 100 % | 182 - 210°C | Window frames, doors, drain pipe, water pipe, pipe fittings, automotive interiors, ladder feet. |
| Expanded Polypropylene (EPP) | 0.1 | N/A | 0.27 - 1.9 MPa | 7 - 21% | 130 - 171°C | Seating, car bumper and door components, packaging, furniture, sporting goods, electrical applications. |
| Polypropylene (PP) *(Moulded)* | 0.88 - 1.7 | Rockwell R 20 - 117 Rockwell R | 9 - 80 MPa | 3 - 900% | 88 - 320°C | Packaging, motor vehicle bumpers, panels and trims, crates, luggage, bags, fibres used in tapes, strapping and ropes. LIVING HINGES |
| Cellulose Acetate Butyrate (CAB) *(16% plasticised)* | 1.16 | N/A | 23 MPa | >= 50% | Melt temp. 205 - 215°C | Spectacle frames, buttons, pen barrels, toothbrushes, helmets, tool handles, hot melt adhesives, safety goggles, steering wheels, blister packaging, transparent wrapping. |
| Cellulose Acetate Propionate (CAP) *(15% plasticised)* | 1.19 | N/A | 28 MPa | 34% | Melt temp. 210 - 220°C | Used in printing inks, nail care products, pen barrels, pipes, tubing, tooth brushes, telephones. |

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| Ethylene Vinyl Acetate (EVA) *(Adhesive/sealant)* | 0.92 - 0.98 | Shore A 40 - 85 Shore D 15 27 | 1.5 - 27 MPa | 50 - 1300% | 175 - 275°C | Adhesive, sealants. |
| Ethylene Vinyl Acetate (EVA) *(Moulded / Extruded)* | 0.92 - 1.05 | Shore A 53 - 98 Shore D 15 - 26 | 1.9 - 27 MPa | 50 - 1300% | 121 - 204°C | Handle grips, flexible tubing, vacuum, cleaner hoses, squeeze toys, stretch films, gaskets. |
| Polytetrafluoroethylene (PTFE) *(Extruded)* (Dupont Teflon®) | 2 - 2.3 | Shore D 50 - 65 | 18 - 34 MPa | 200 - 500 % | Melt temp. 325 - 327°C | Very resistant to chemical attack, very low coefficient of friction, used for gaskets, rings, bearings, bottles, syringes, pipes, containers, thread seal tape, non-stick coatings. |
| Fluorinated Ethylene Propylene (FEP) | 1.3 - 2.17 | Shore D 56 | 19 - 27 MPa | 250 - 340% | Melt temp. 245 - 275°C | Gaskets, bearings, seals, tubing, electrical wire and cable insulation. |
| High Density Polyethylene (HDPE)*(Sheet grade*) | 0.9 - 1.06 | Rockwell R 60 - 70 Shore D 65 - 69 | 21.4 - 30.3 MPa | 500 - 2800% | Vicat softening point 122 - 134°C | Blow moulded bottles for milk, non-carbonated drinks, detergents, bleach, acids, drums, fuel tanks, toys, household goods. Injection moulded crates, containers, caps, household goods, toys. Extruded pipes for water, gas, corrugated pipes and conduit for electrical cables, wire and cable insulation. |
| High Density Polyethylene (HDPE) *(Injection moulded*) | 0.92 - 1.05 | Rockwell R 33 - 52 Shore D 55 - 76 | 10 - 43 MPa | 3.2 - 2080 % | 82 - 280°C | |
| High Density Polyethylene (HDPE) *(Film grade*) | 0.92 - 0.96 | Shore D 28 - 69 | 29 - 45 MPa | 250 - 1350 % | 60 - 240°C | Snack food packages, cereal box liners, wrapping, refuse sacks, carrier bags, industrial liners freezer bags, water pipes. |
| Low Density Polyethylene (LLDPE & LDPE) *(Film grade)* | 0.91 - 0.93 | Shore D 42 - 60 | 7.8 - 34.5 MPa | 50 - 1000% | 143 - 260°C | Sandwich bags, films, sheets, cling wrap, car covers, squeeze bottles, toys, house ware, carrier bags, rubbish sacks, packaging, gas and water pipes, liners for tanks and ponds, moisture barriers, in construction, cable and wire insulation, used for rotational moulding. |

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| Low Density Polyethylene (LLDPE & LDPE) *(Film grade)* | 0.91 - 0.93 | Shore D 42 - 60 | 7.8 - 34.5 MPa | 50 - 1000% | 143 - 260°C | Sandwich bags, films, sheets, cling wrap, car covers, squeeze bottles, toys, house ware, carrier bags, rubbish sacks, packaging, gas and water pipes, liners for tanks and ponds, moisture barriers, in construction, cable and wire insulation, used for rotational moulding. |
| General Purpose Polystyrene (GPPS) | 1.40 | Rockwell M 77 | 48 MPa | 2% | Melt temp 180 - 260°C | Toys, rigid packaging, refrigerator trays, costume jewellery, lighting diffusers, cassette and CD cases, storm windows, disposable medical ware. |
| High Impact Polystyrene (HIPS) | 1.04 | Rockwell R 65 - 100 | 21 - 27.5 MPa | 55% | Vicat softening point 102°C | Cosmetic packaging, cups, shower surrounds, point of sale displays, thin-wall injection moulding and thermoforming, radio and TV cabinets, instrument control knobs, yoghurt pots, vending cups, toys. |
| Expanded Polystyrene (EPS) | 0.008 - 0.1 | N/A | N/A | N/A | Melt point 240°C | Thermal insulation materials, packaging, impact protection and cushioning, drinks cups, food trays, clamshell packaging. |
| Unsaturated Polyester Resins (UP Resins) (Styrene content 23 - 44 %) | 0.6 - 2 | Barcol 37 - 68 | 10 - 123 MPa | N/A | 135 - 280°C | Bowling balls, buttons, resin component of GRP, used for boat hulls, canoes, car and lorry body panels, embedding/encapsulating, coating. |
| Polyester Moulding Compound *(Thermoset)* | 2 | N/A | 24 - 48 MPa | N/A | 135 - 165°C | Dough and bulk moulding compounds for compression moulding, also widely used for powder coating and as reinforcement tapes and roving in composites. |

| Polymer | Density g/cc | Hardness | Tensile Strength (Ultimate) | Elongation at break | Processing Temp. | Application |
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| Epoxy Resin (EP) *(Thermoset)* | 0.86 - 2.6 | Shore D 50 - 95 | 5.1 - 58.6 MPa | 0 - 50% | 25 - 170°C | Coatings, encapsulation, electrical components moulds, laminates, castings, used in composites, two part epoxy paints. |
| Epoxy Resin (EP) *(Thermoset adhesive)* | 0.46 - 4.8 | Shore D 50 - 95 Shore D 13 - 92 | 1.38 - 69.6 MPa | 0 - 200% | 4.4 - 260°C | Adhesive. |
| Urea Formaldehyde (UF) (Powders and moulding compounds) | N/A | N/A | N/A | N/A | N/A | Used mostly as wood adhesives for the bonding of plywood and particleboards, concerns about the release of formaldehyde into the atmosphere have led to it being substituted by other adhesives, e.g. phenolics. |
| Melamine Formaldehyde (MF) | 1.5 - 1.8 | Ball indentation hardness 250 - 300 MPa | N/A | N/A | 100 - 115°C | Decorative laminates, laminating resins, surface coatings buttons, dinner ware, tanning of leathers |
| Melamine-Phenolic Copolymer moulding compound | 1.67 | Rockwell E 74 | 59 MPa | 0.81% | N/A | Bottle caps, lighting, tableware, electrical equipment |
| Phenolic Formaldehyde resin (PF) | 1.37 | N/A | N/A | N/A | Melt temp. 80 - 100°C | Lamp holders, bottle caps, saucepan handles, electrical plugs, switches, electrical iron parts, abrasives, adhesives, varnishes. |
| Polyurethane cast elastomers (EP) | N/A | Shore A 70 | Yield 26.2 MPa | 900% | 82.2°C | Solid tyres, wheels, shoe heels, automobile bumpers. |
| Vinyl Ester SMC | 1.03 - 1.95 | Barcol 35.0 - 70.0 | 30.3 - 827 MPa | 1.2 - 7.9% | 93 - 160°C | Chemical tanks, piping. |

Polymer properties data from:

http://www.matweb.com
http://www.prospector.ides.com
http://www.indianplasticportal.com