Poly(methyl methacrylate) (PMMA)

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General

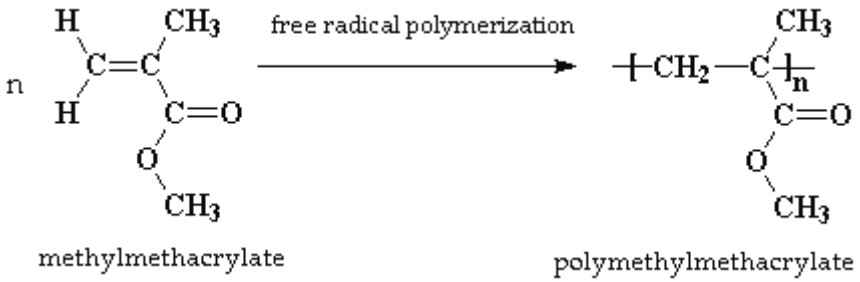
General Poly(methacrylates) are polymers of the esters of methacrylic acids. The most commonly used among them is poly(methyl methacrylate) (PMMA).

Poly(methyl methacrylate) or poly (methyl 2-methylpropenoate) is the polymer of methyl methacrylate, with chemical formula $C_5H_8O_2)_n$. It is a clear, colourless polymer available on the market in both pellet and sheet form under the names Plexiglas, Acrylite, Perspex, Plazcryl, Acrylplast, Altuglas, Lucite etc. It is commonly called acrylic glass or simply acrylic.

Another polymer, poly(methyl acrylate) (PMA) is a rubbery material, similar to poly(methyl methacrylate), but softer than it, because its long polymer chains are thinner and smoother and can more easily slide past each other.

Structure

Poly(methyl methacrylate) is produced by free-radical polymerization of methylmethacrylate in mass (when it is in sheet form) or suspension polymerization according to the following chart:



methylmethacrylate polymethylmethacrylate

Properties

Physical and mechanical properties

PMMA is a linear thermoplastic polymer. PMA has a lack of methyl groups on the backbone carbon chain - its long polymer chains are thinner and smoother and can slide past each other more easily, so the material becomes softer.

Main physical characteristics of PMMA are shown in table 1.

PMMA has high mechanical strength, high Young's modulus and low elongation at break. It does not shatter on rupture. It is one of the hardest thermoplastics and is also highly scratch resistant. It exhibits low moisture and water absorbing capacity, due to which products made have good dimensional stability. Both of these characteristics increase as the temperature rises. Table 2 shows some of mechanical characteristics of PMMA.

Table 1. Typical physical properties of Poly(methyl methacrylate)

Physical Properties	Value
Density	1.15 - 1.19 g/cm^3
Water Absorption	0.3 – 2 %
Moisture Absorption at Equilibrium	0.3 - 0.33 %
Linear Mould Shrinkage	0.003 - 0.0065 cm/cm
Melt Flow	0.9 – 27 g/10 min

Its strength properties during injection moulding differ significantly in longitudinal and transverse direction as a result of the orientation effect. As in the case with other thermoplastics, the mechanical properties of PMMA vary as the temperature changes. This material tends to creep. It is not suitable for operation under multiple dynamic loads.

PMMA is one of the polymers that is most resistant to direct sunshine exposure. Its strength characteristics exhibit fairly small variations under the effect of UV-radiation, as well as in the presence of ozone. These properties of PMMA make it suitable for products intended for long open-air operation.

Table 2. Mechanical characteristics of Polymethyl methacrylate

Mechanical Properties	Value
Hardness, Rockwell M	63 - 97
Tensile Strength, Ultimate	47 - 79 MPa
Elongation at Break	1 - 30 %
Tensile Modulus	2.2 - 3.8 GPa
Flexural Modulus	3 - 3.5 GPa
Izod Impact, Notched	1.2 – 20k J/m^2
Izod Impact, Unnotched	11kJ/m^2
Tensile Creep Modulus, 1 h	1800 - 2700 MPa
Tensile Creep Modulus, 1000 h	1200 - 1800 MPa

Electrical characteristics

The low water absorption capacity of PMMA makes it very suitable for electrical engineering purposes. Its dielectric properties are very good, but polystyrene and LDPE are superior to it. Its resistivity depends on the ambient temperature and relative humidity. The dielectric constant, as well as the loss tangent, depends on the temperature, the relative humidity of air and the frequency.

Table 3. Electrical properties of Poly(methyl methacrylate)

Electrical Properties	Value
Electrical Resistivity	10^{14} - 10^{15} Ω.cm
Surface Resistance	10^{14} - 10^{16} Ω
Loss factor, 20°C, 1000 Hz, 60% humidity	0.04
Dielectric Constant	2.8 - 4
Dielectric Constant, Low Frequency	3 - 4
Dielectric Strength	17.7 - 60 kV/mm
Dissipation Factor	0.03 - 0.55
Arc Resistance	100 - 180 s

Thermal properties

The thermal stability of standard PMMA is only 65°C. Heat-stabilised types can withstand temperatures of up to 100°C. PMMA can withstand temperatures as low as -70°C. Its resistance to temperature changes is very good.

PMMA is a combustible material, which continues burning even after the flame is removed – the products separated in the process of thermal destruction have an intoxicating effect.

Table 4. Thermal properties of Poly(methyl methacrylate)

Thermal Properties	Value
CTE, linear 20°C	60 - 130 µm/m.°C
CTE, linear 20°C Transverse to Flow	70 - 90 µm/m.°C
Specific Heat Capacity	1.46 - 1.47 J/g.°C
Thermal Conductivity	0.19 - 0.24 W/m.K
Maximum Service Temperature, Air	41 - 103 °C
Melting Point	130°C
Vicat Softening Point	47 - 117 °C
Glass Temperature	100 - 105 °C

Optical properties

PMMA exhibits very good optical properties – it transmits more light (up to 93% of visible light) than glass. Combined with its good degree of compatibility with human tissue, it can be used for replacement intraocular lenses or for contact lenses. Unlike glass, PMMA does not filter ultraviolet light. It transmits UV light down to 300 nm and allows infrared light of up to 2800 nm to pass.

Table 5. Optical properties of Poly(methyl methacrylate)

Optical Properties	Value
Haze	1 - 96 %
Transmission, Visible	80 - 93 %
Refractive Index	1.49 - 1.498

Chemical resistance

Acrylics are unaffected by aqueous solutions of most laboratory chemicals, by detergents, cleaners, dilute inorganic acids, alkalis, and aliphatic hydrocarbons – however, acrylics are not recommended for use with chlorinated or aromatic hydrocarbons, esters, or ketones. It dissolves completely in chloroform, di- and trichlorethane, which is used for production of glues. The chemical resistance will vary with stress level, temperature, reagents and duration of exposure.

PMMA are physiologically harmless. Due to their low moisture absorption capacity they are not attacked by moulds and enzymes.

Processing methods

PMMA is suitable for injection moulding, extrusion, extrusion blow moulding (impact modified acrylics only), thermoforming, casting. The melt flow index of the material varies according to the method of treatment:

- low melt flow index (0.8 – 2.5) – materials intended for extrusion;
- medium melt flow index (2.5 - 10) – general-purpose PMMA;
- high melt flow index (> 10) – PMMA for injection moulding of products having a complex shape.

For injection moulding the mould temperature should be between 40 and 80°C, depending on the type, the material temperature should be between 200 and 250°C. Usually high injection pressures are needed because of poor flow properties. This is particularly important for optical mouldings where visible weld lines will form if the correct parameters are not used. During injection moulding internal stresses often build up, which can be eliminated by heating at a temperature about 80°C (tempering).

Mould's nozzle is an important factor when manufacturing PMMA-product. The size of the nozzle gate varies depending on the shape and the size of the product. Products manufactured from PMMA are mainly clear and transparent and it is important that they do not have any scratches. So that it is recommend to use at least draft angle of 1° (rather 2°). Because PMMA has high viscosity, the gas removing channels can be quite deep, from 0.04 to 0.08 mm.

Misoperation due to higher temperature causes destruction of PMMA, accompanied by release of methylmethacrylate or other low-molecule volatile products. The process also leads to a loss of mass, which makes it undesirable, and a good knowledge of the thermo-physical properties of the polymer is necessary in order to avoid it, especially in the temperature range processing (220-250°C).

Acrylics are easily sawed, drilled, milled, engraved, and finished with sharp carbide-tipped tools. Cut surfaces may be readily sanded and polished. They are also readily bent or thermoformed at low temperature and solvent bonding of properly fitting parts produces a strong, invisible joint. PMMA can be welded by all the plastics welding processes such as hot-blade, hot-gas, ultrasonic or spin welding.

Applications

PMMA is an economical, versatile general-purpose material. It is available in extruded and/or cast material in sheet, rod and tube forms, as well as custom profiles. Various types of acrylics are used in a wide variety of fields and applications, including:

- **Optics:** Dust covers for hi-fi equipment, sunglasses, watch glasses, lenses, magnifying glasses;
- **Vehicles:** Rear lights, indicators, tachometer covers, warning triangles;
- **Electrical engineering:** Lamp covers, switch parts, dials, control buttons;
- **Office equipment**: Writing and drawing instruments, pens;
- **Medicine:** Packaging for tablets, pills, capsules, suppositories, urine containers, sterilisable equipment;
- **Others:** Leaflet dispensers, shatter-resistant glazing, shower cubicles, transparent pipelines, illuminated signs, toys.

Brands

- Lucite®L (Lucite International, Inc, USA)
- Plexiglas® (Altuglas International)
- Acrylite® GP (Piedmont Plastics, CYRO Industries, USA)

** The ranges given in the tables indicate the minimum and the maximum value of the respective property, found experimentally and published for the different brands and types of the polymer.*

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