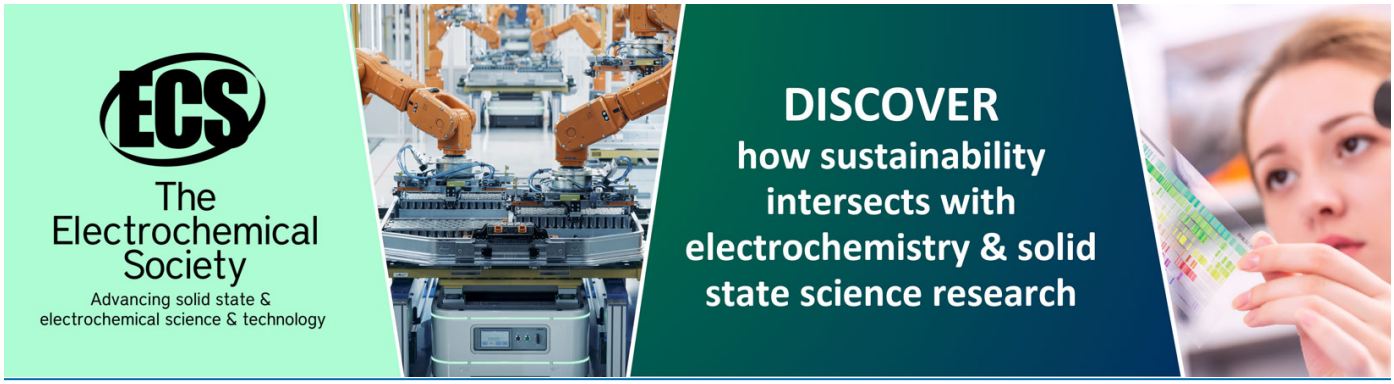
Thermoplastic polymers in product design



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Thermoplastic polymers in product design

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Abstract. It is known that a special chapter in product design is dedicated to the materials from which these products are going to be manufactured**.** Plastics (thermoplastic polymers, thermo-reactive polymers and elastomers) along with classical materials or composite materials are the basis for designing and making products. They are found in all sectors of industrial activity. Products are required to meet certain minimum resistance conditions for the requirements they will be subjected to, throughout their use, low manufacturing costs, etc.[1]. The better the material properties of a product are known, the better the design and manufacture of products respond to market requirements. The paper highlights the most important properties and areas of use of the currently most used thermoplastic polymers in designing and manufacturing of industrial products (polyvinyl chloride, polyethylene, polypropylene, polystyrene, methyl polymethacrylate, polyamides, polycarbonates, cellulose acetate, polyoxymethylenes and thermoplastic polyurethanes).

1. Introduction

Thermoplastic polymers are materials of reference in the design and manufacture of many products in various fields of activity. Their characteristics and behaviour in various applications have been approached over time by several authors [2,3,4]. This paper aims to present in a rigorous manner the properties and the fields of use of the most known thermoplastic polymers used in the manufacture of industrial products.

2. Thermoplastic polymers. Properties and uses

Considering their behaviour at temperature, plastics are divided into three categories:

- elastomers
- thermo-reactive materials (thermosetting) which, by heating at a certain temperature and by exerting a pressure, take the desired shape, definitively, without the operation being repeatable (phenol formaldehyde resins, urea formaldehyde resins, etc.)
- thermoplastic materials which, by heating at a certain temperature and by exerting a certain pressure, can take the desired form and the operation can be repeated many times without any sensitive changes in the structure of the starting material (polyvinyl chloride, polycarbonates, polyamides, etc.). In the present paper only the properties and areas of use of thermoplastics materials will be analyzed.

2.1. Rigid polyvinyl chloride (rigid PVC)
It is in the form of a translucent, white or variously coloured powder or in the form of translucent or variously coloured granules [4,5].

2.1.1. Properties
Density 1.35 - 1.45 g/cm³ ; exhibits a great rigidity up to near the vitrify temperature, 70-85˚C; is resistant to frazzle friction, does not resist to shocks at low temperatures (-10˚C); products can be operated up to 60-70˚C in the absence of mechanical stress; is a rough plastic, a good isolator; has good resistance to acids, bases, alcohols, gasoline, oil, diesel up to 60˚C; it does not resist to esters, ketones, ethers, carbon tetrachloride; it has a good dimensional stability; current solvents for rigid PVC are: cyclohexanone and tetrahydrofuran; can be welded with hot air at 230˚C, with high frequency energy, with ultrasounds, by friction, etc.

2.1.2. Fields of use (Figure 1)
Constructions - partitions, window profiles, fittings, supports, pipes; electro-technical and electronics industry - sockets, insulating parts, housings; food industry - bottles for mineral water, margarine packaging; photographic industry; chemical industry - products resistant to corrosion; pharmaceutical and cosmetic industry.

Figure 1. Fields of use of rigid polyvinyl chloride.

2.2. Plasticized polyvinyl chloride (plasticized PVC)
岩t is in most cases in the form of a translucent powder or in form of transparent or variously coloured granules, exhibiting a maximum humidity of 0.3%. All of the properties of plasticized vinyl poly-chlorides are dependent of the amount and type of plasticizer used.

2.2.1. Properties
Density 1.3-1.7 g/cm³; the rigidity and hardness of objects decreases as the percentage of plasticizer increases; the fragility of a piece is influenced by the percentage of plasticizer; appears as a flexible and soft material, good electrical isolator; is sensitive to atmospheric factors and sunlight; strongly withstand to the action of weak acids and bases; does not resist to acids and concentrated bases, alcohols, esters, ketones, ethers, benzene, gasoline, carbon tetrachloride.

2.2.2. Fields of use (Figure 2)
Aut*omotive* industry - joints, seals, protection elements, buffer elements, gaskets, electrical cable protection; office equipment, computers - cases, keyboards; electro-technical industry - plugs, various components of telephones and radio equipment, isolating elements; light industry - shoe soles and heels, toy industry - tires, tracksuits, transmissions, belts, various types of sheets that can be thermoform or laminated to obtain various products - tablecloths, raincoats, vacuum products, tarpaulins, extruded products - garden spraying tubes, seat linings; various types of elastic profiles, gaskets used for joining wooden parts, wires and electric wires.

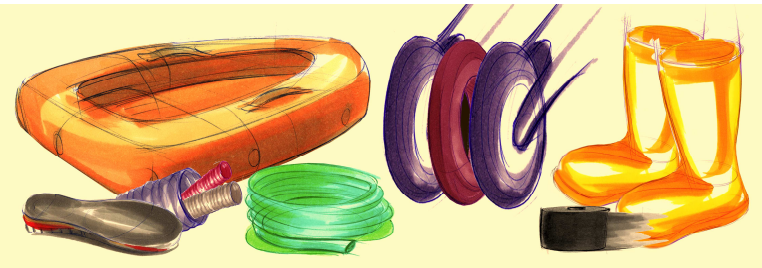

Figure 2. Fields of use of plasticised polyvinyl chloride.

2.3. Low density polyethylene (LDPE)
It is in the form of translucent or colourful granules. Objects made of LDPE can be used up to 60˚C.

2.3.1. Properties
Density 0,915-0,935 g/cm³; exhibits good shock resistance even at low temperatures; great chemical resistance; is an ideal electrical isolator; does not absorb water from the environment; is stable in acids, bases and alcohols; has a partial chemical stability in esters, ketones, ethers and fats; is unstable in petrol, fuels, benzene and carbon tetrachloride.

2.3.2. Fields of use (Figure 3)
Protective foils in agriculture, in packages (heat-shrinkable); industrial storage tanks for chemical solutions, electrical cable isolation, parts in the electrical and electronics industry used as electrical isolators; elastic hoses, toys, cosmetics; household articles - bowls, glasses, vats, basins, buckets, clothes basket; tubing in medical equipment; machine building industry - gaskets, connecting elements.

Figure 3. Fields of use of low density polyethylene.

2.4. High density polyethylene (HDPE)
It is in the form of colourless, opaque or colourful granules. Objects made of high density polyethylene can be used up to 80-100˚C.

2.4.1. Properties [2,4,6,7,8]
It has a lower density than water, 0.945-0.960 g/cm³; tensile strength is superior to low density polyethylene; elongation to breakage is lower than low density polyethylene; have a higher hardness than low density polyethylene; has a vitrify temperature identical to low density polyethylene; insignificant water absorption, is a good isolator; is not attacked by acids, bases and alcohols; exhibits partial chemical stability in attack of esters, ketones; unstable in gasoline, fuels, carbon tetrachloride.

2.4.2. Fields of use (Figure 4)
Packaging - boxes, various types of containers, detergent containers, bottles, packaging foils; household articles - bowls, glasses, buckets, flower pots, plugs, food boxes; toys, wheels, chassis, etc.; medical equipment, various technical items in electrical engineering and electronics; civil and industrial buildings - containers with large volumes, septic tanks, barrels, large housing.

Figure 4. Fields of use of high density polyethylene.

2.5. Polypropylene (PP)
It is a thermoplastic material from the polyolefin class. It is in the form of transparent, opaque or colourful granules.

2.5.1. Properties [4,9]
Density 0.90-0.91 g/cm³; is similar to high density polyethylene material, but with a tensile strength and temperature greater than this; exhibits a lower shock resistance than PEID; clarity, gloss and light resistance are lower than for PEID; the material can be sterilized, is a good electrical isolator; exhibits good bending properties (fatigue-resistant material); resists to attack of weak acids and bases, resists to attack of concentrated acids, gasoline and carbon tetrachloride; presents partial stability to the attack of alcohols, ketones, esters and oils; does not absorb water from the atmosphere.

2.5.2. Fields of use (Figure 5)
Household articles - bowls, buckets, glasses, pipes for the circulation and transport of water; toys, medical equipment; swimming pool construction; car industry - car bumper, protective bands applied to the sides of the car; articles specific to the electro-technical and electronic industry; cosmetics - brushes, combs, packages for makeup kits; garden products - chairs, loungers, tables, benches, pots, etc.; textile industry - spools, coils, wear parts, laces; packaging industry - packaging for food, packaging for storage and transport of liquids; sporting goods industry - boots, tents, roller skates, etc.

Figure 5. Fields of use of polypropylene.

2.6. Polymethyl Methacrylate (PMMA)
Methyl polymethacrylate is recognized primarily because of the exceptional optical properties it presents. It is an amorphous polymer and due to its main properties (transparency and shock resistance), it is used mainly in the automotive, aeronautical and machine building industry [4,7,9]. It is in the form of transparent or colourful granules and pearls.

2.6.1.Properties
Density 1.18 g/cm³; (approximately 92% light transmission through 2 cm thick plates), the total reflection angle on an inner surface is 41-42° (which allows the realization of light conductors, optical fibers), the index (for λ = 587.6 nm helium) is 1.491, making it an ideal material for use in the optical industry; resistant to UV radiation; is an amorphous polymer with a vitrify temperature of 110-135°C,

which makes it a hard and rigid material at ambient temperature, absorbs a maximum of 0.3% humidity, good resistance to aging and action of the atmospheric agents; it does not taste and smell, and can therefore be used in the manufacture of food contact products; good mechanical properties; gently absorbs dust from the air; is resistant to diluted organic and mineral acids in weak bases, benzols, oils and fats, limited stability to alcohols; is attacked by acids and concentrated bases, fuel airplanes, gasoline, liquid ammonia, ethyl alcohol, acetone, chloroform, cyclohexane, hydrogen peroxide min. 40%, hydrocarbons, methanol, nitrobenzene, petrol, phenol, carbon tetrachloride

2.6.2. Fields of use (Figure 6)
Aeronautics industry; glass-imitation plates, showcases; shuttles on ships and naval craft; optical and photo apparatus - lenses, magnifiers, precision parts, watches; automotive industry - indicator dial, position lamp, windscreen, dashboard, signaling lamps; various technical parts in machine building industry, medicine; office equipment - linear, sequential; mobile phone display, electronic industry; modern furniture, household items, bathroom accessories, cosmetic packaging.

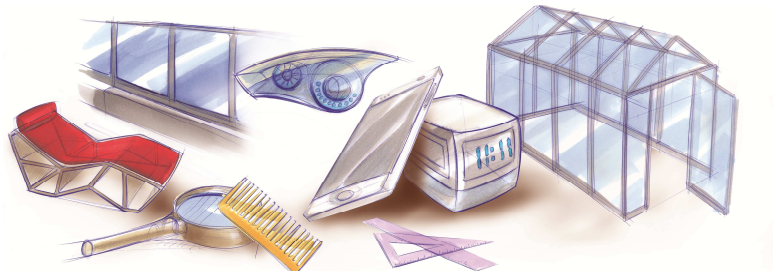

Figure 6. Fields of use of polymethyl methacrylate.

2.7. Shock resistant polystyrene (PS)
In order to eliminate the greatest disadvantage of crystal polystyrene and low shock resistance, PS (anti-shock polystyrene) was designed and manufactured. It is made of polyester modified with elastomer. The usual elastomer is butadiene rubber. The disadvantage of PS is that it is not transparent. It is in the form of opaque or coloured granules.

2.7.1. Properties
Density 1.03-1.04 g/cm^3; shock resistant, withstands better to mechanical stress than crystal polystyrene; is a good electrical isolator; is stable to weak and unstable acids and bases in esters, ketones, ethers and gasoline.

2.7.2. Fields of use (Figure 7)
Electro-technical and electronic industry - computer cases, monitors, TV cases, radios, audio systems; household goods - refrigerators, mixers, coffee makers; packaging, toys; toiletries - brushes, combs.

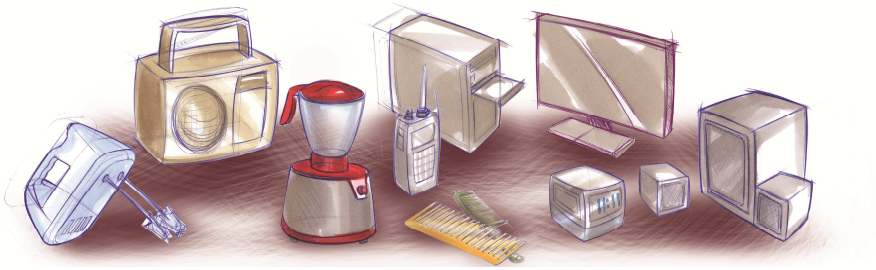

Figure 7. Fields of use of shock resistant polystyrene.

2.8. Polyamides (PA)
The polyamides are in the form of colourful, opaque cylindrical granules. It is also in the form of yarns, fibers and fabrics.

2.8.1. Properties
Density 1.01-1.15 g/cm³; are translucent in the parts injected with thin walls and opaque in the parts injected with thick walls and if obtained in the form of thin sheets, are transparent; are hygroscopic, absorbing the water from the atmosphere to a balance - between 2.5% and 9.5%; mechanical, thermal, electrical properties and dimensional stability are influenced by the percentage of water absorbed; have a high level of stiffness, are hard, shock-resistant, have good stability to dynamic stresses and achieve very good vibration damping; the polyamides have a greasy appearance with good sliding properties and a good use-resistance; by adding glass fibers the polyamides improve their tensile strength, bending strength, coefficient of elasticity and hardness [10]; have a low resistance to the action of UV radiation; are stable to oils, hydrocarbons, lacquers, weak bases, esters, ethers, alcohol and petrol; polyamides are attacked by phenols, formic acid, trichloroacetic acid, floured alcohols and concentrated organic acids.

2.8.2. Fields of use (Figure 8)
Automotive industry [11] - cases, fans, complicated construction, gas tanks, bushings, pivots, flexible harnesses connecting the trailer truck cabin, carburettor floats, brake fluid reservoirs; electro-technical industry - connectors, holes for drilling machines; machines construction - wheel banding, friction parts, gear wheels; household goods - fruit juicer, kitchen robot, furniture, cutlery handles, hammer heads, etc.; toys, zippers; sports and tourism materials industry - boots, skates, tents, mountaineering and caving ropes, helmets used in climbing, caving, motorcycle, etc.; cycling - bicycle chain derailment system [12]; soles for sports shoes.

Figure 8. Fields of use of polyamides.

2.9. Polycarbonates (PC)
It is in the form of cylindrical granules, transparent or variously coloured. Polycarbonates are recognized for their outstanding transparency and for unaltered properties in a wide range of temperatures.

2.9.1. Properties [13]
Density 1.2 g/cm³; polycarbonates are polymers of amorphous structure and very good transparency; due to the high vitrify temperature (150˚C), polycarbonates retain their rigidity over a wide range of temperatures; exhibits very good traction and pressure resistance; have high mechanical strengths at high and low temperatures; between -80˚C and 150˚C, remain elastic, malleable, ductile, which explains their good shock resistance; resists shocks at low temperatures up to -80˚C; polycarbonates are soluble in halogenated hydrocarbons, are attacked by strong bases (ammonia), are partially soluble in aromatic hydrocarbons; polycarbonates are resistant to dilute mineral and organic acids, to alcohols, ethers and aliphatic hydrocarbons.

2.9.2. Fields of use (Figure 9)
Lighting equipment - headlights; urban furniture anti-vandalism, safety glass; sterilizable sanitary materials - syringes, dishes, dialysis devices, blood filters; transparent protective materials - helmets, visors, windscreens, windows in alpine shelters; shields, roofs, domes on buildings, sports halls, swimming pools, greenhouses; optical devices - cameras, binoculars, lenses, eyeglasses, sunglasses; electromechanical equipment - power outlets, electrical relays; household appliances - cases, coffee filters, hair dryers, mixers, dishes; toys, packaging, musical instruments.

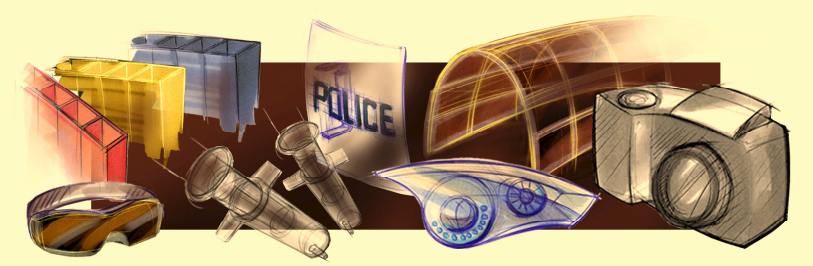

Figure 9. Fields of use of polycarbonates.

2.10. Polyoxymethylenes (POM)
2.10.1. Properties [4,14,15,16]
Have a density of 1.4-1.42 g / cm³, polyoxymethylenes are opaque; they have an assembly of mechanical properties that make them ultra-performing, often replacing metals; bear very well with cyclical stress (fatigue); exhibits good friction and frazzle resistance properties; (aldehydes, esters, ethers, herbicides, insecticides, fertilizers) have a good resistance, without dimensional modifications, to many organic chemical agents. They are sensitive to oxidizing acids (or very concentrated pH <4) and to strong bases (pH> 9).

2.10.2. Fields of use (Figure 10)
Machine building industry - toothed wheels, racks, valves, chains elements, conveyor belt parts, screws, discs, cams, gaiters, gears; automotive industry - toothed wheels, cases, guides, active organs of oil or diesel pumps, float level indicators, taps, ice screen cleaners; electrical machines - various types of cases for vacuum cleaners, mixers, coffee machines, connections for pneumatic systems; photographic industry - camcorders of cameras; optical industry - buttons, drums; audio industry - potentiometers, pointers; medical industry - various types of medical instruments, valves, accessories; sporting industry - various items for roller skates, toothed gears for bicycle gears, ski bindings.

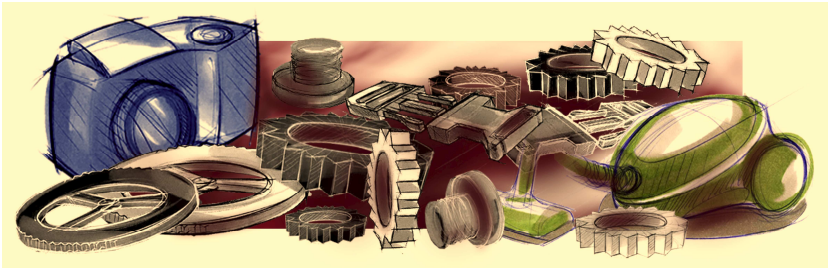

Figure 10. Fields of use of polyoxymethylenes.

2.11. Cellulose acetate (CA)
It is in the form of cylindrical, transparent or variously coloured granules. It is a shiny, pleasing to touch material.

2.11.1.Properties
Density 1.26 g/cm³; is an amorphous and transparent material; exhibits good dimensional stability even in wet environments; material with high mechanical strength; very poorly sensitive to dust, has a remarkable acoustic inertia; soluble in acetone and acetic acid; resistant to petrol, oil, water, salt water, alcohols.

2.11.2. Fields of use (Figure 11)
In the automotive industry - steering wheels, decorative buttons [3,5,17]; tool kits - handles for pliers, screwdrivers; transparent packaging, household articles - cutlery handles, scissors; electrical and electronic apparatus - cases for televisions, radio, telephone accessories; office equipment - compass kits, pens; toys, optical industry - spectacle frames, lenses; furniture industry - chairs, door handles, drawers; cosmetic articles - toothbrushes, combs, lipsticks, brush handles.

Figure 11. Fields of use of cellulose acetate.

2.12. Thermoplastic polyurethanes (TPU)
2.12.1. Properties
High frazzle and abrasion resistance; good tensile strength and remarkable resistance to rupture propagation; very good flexibility at low temperatures; resistant to damp environments, resistant to oils, fats, oxygen and ozone; attacked by concentrated acids and alkaline solutions, resistant to dilute acids and weak bases.

2.12.2. Fields of use (Figure 12)
Extruded profiles resistant to the action of chemical agents; automotive industry: car face mask, sealing rings, vibration-resistant, radiator grille, shifting lever protections, body sills made of glass fiber reinforced thermoplastic polyurethane, connecting bells between metal parts - cooling systems with air, resistant and flexible, snow chains, safety rings at the bar, oil and vaseline resistant, protective bumpers; electro-technical industry: electrical cable protection, telephone cable protection, seismic recording cable protection, frazzle and shock resistant, wiring and drainage hoses obtained of reinforced polyurethane, flexible and resistant to the transport of abrasive materials, hose for vacuum cleaner, irrigation hoses, pneumatic hoses, electric drill housings, transmission belts, cases for bearings, various types of trolleys; sports and leisure: ski boots [18], mountain biking boots low

Figure 12. Fields of use of thermoplastic polyurethanes.

temperature and humidity resistant, roller skates, golf carts, snowboard bindings, binocular covers, soles of shoes sportswear, shoe protectors fixed to the skis, snowboard boots.

3. Conclusion

The paper presents in a rigorous manner the properties and the fields of use of the main thermoplastic polymers (polyvinyl chloride, polyethylene, polypropylene, polystyrene, methyl polymetacrylate, polyamides, polycarbonates, cellulose acetate, polyoxymethylenes and thermoplastic polyurethanes). Knowing the properties of materials makes it possible to choose and develop the correct product specifications for product design and manufacture. Due to their characteristics and performance, thermoplastic polymers are used in many fields: automotive, electrical and electronics industry, sports equipment industry, toys, home appliance industry, packaging industry, pharmaceutical and cosmetics industry, garden furniture, medicine, optics, and so on.

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