Plastics

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Committed to improve the Quality of Life

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Plastics

Plastics are used in many products and components like compression packings, gaskets, seals, bearings, liners, etc. Instead of giving detail information about them in articles about these products, useful information about them is given in this article. Information about plastics and commonly used plastics like HDPE, UHMWPE, PTFE and nylon is given in this article.

What is Plastic?

Plastic is the general common term for a wide range of synthetic or semi-synthetic materials used in a huge, and growing, range of applications.

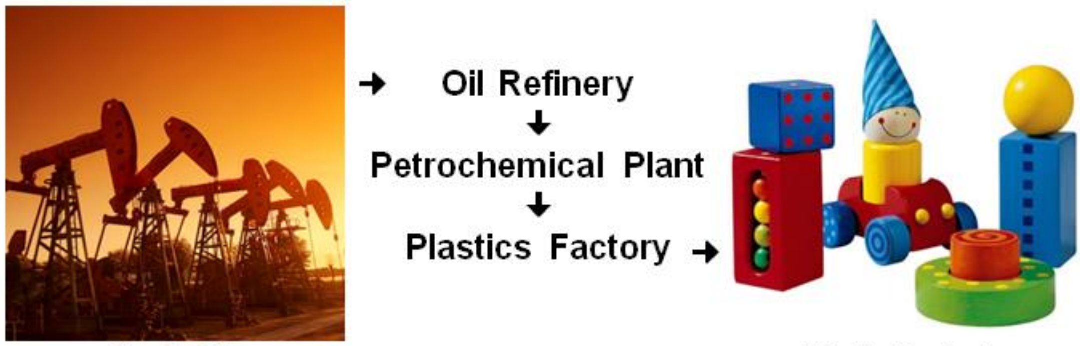
All plastics were soft and moldable during their production - that's why they're called plastics. The Greek word plasticós means "to mold."

Plastics are organic, the same as wood, paper or wool. The raw materials for plastics production are organic compounds. The most common sources are oil (petroleum) and natural gas.

How to Make Plastic

Plastics are synthetic materials, which means that they are artificial, or manufactured. Synthesis means that "something is put together," and synthetic materials are made of building blocks that are put together in factories.

The building blocks for making plastics are small organic molecules - molecules that contain carbon along with other substances. They generally come from oil (petroleum) or natural gas, but they can also come from other organic materials such as wood fibers, corn, or banana peels! Each of these small molecules is known as a **monomer** ("one part") because it's capable of joining with other monomers to form very long molecule chains called **polymers** ("many parts") during a chemical reaction called **polymerization**. To visualize this, think of a single paper clip as a monomer, and all the paper clips in a box chained together as a polymer.



Crude Oil

Plastic Products

Crude Oil to Plastic Products

Crude oil, the unprocessed oil that comes out of the ground, contains hundreds of different hydrocarbons, as well as small amounts of other materials. The job of an oil refinery is to separate these materials and also to break down (or "crack") large hydrocarbons into smaller ones.

A petrochemical plant receives refined oil containing the small monomers they need and creates polymers through chemical reactions.

A plastics factory buys the end products of a petrochemical plant - polymers in the form of resins - introduces additives to modify or obtain desirable properties, then molds or otherwise forms the final plastic products.

The two major processes used to produce plastics are called **polymerization** (also called addition polymerization) and **polycondensation** (condensation polymerization), and they both require specific catalysts.

We call the process a polymerization (addition polymerization) if the entire monomer molecule becomes part of the polymer. For example, when ethylene is polymerized to make polyethylene, every atom of the ethylene molecule becomes part of the polymer. The monomer is added to the polymer outright. Whereas we call a polymerization a polycondensation (condensation polymerization) if part of the monomer molecule is kicked out when the monomer becomes part of the polymer. The part that gets kicked out is usually a small molecule like water, or HCl gas. Because there is less mass in the polymer than in the original monomers, we say that the polymer is condensed with regard to the monomers. The byproduct, whether it's HCl gas, water, or any other thing, is called a condensate. For example, when nylon is made from adipoyl chloride and hexamethylene diamine, the chlorine atoms from the adipoyl chloride, each along with one of the amine hydrogen atoms are expelled in the form of HCl gas.

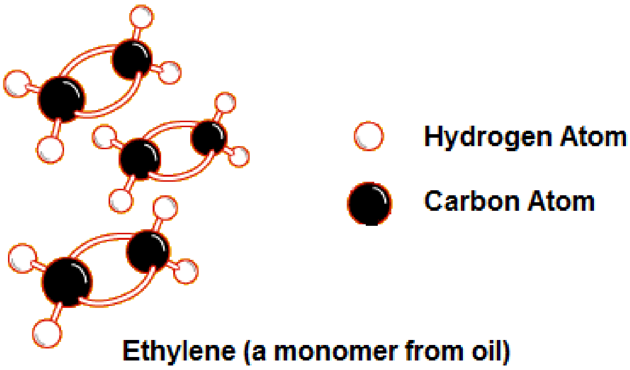
There are two types (categories) of polymerization reactions - Chain Growth Polymerizations and Step Growth Polymerizations. In a chain growth polymerization, only monomers react with growing chains whereas in a step growth polymerization, even growing chains join (react) together.

In a polymerization reactor, monomers like ethylene and propylene are linked together to form long polymers chains. Each polymer has its own properties, structure and size depending on the various types of basic monomers used.

Polymerization in Detail

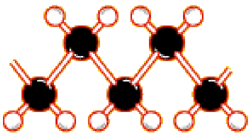
Polymerization is often started by combining the monomers through the use of a **catalyst** - a substance that aids a chemical reaction without undergoing any permanent chemical change itself. During the chemical reaction, hundreds or thousands of monomers combine to form a polymer chain, and millions of polymer chains are formed at the same time. The mass of polymers that results is known as a **resin**. Resins are sold to plastics factories, usually in the form of powder, tiny granules, or pellets. The plastics manufacturer adds coloring agents and other additives that modify the properties of the material for the intended product. Finally, the resin is formed into plastic products. The process is explained by an example of polyethylene.

Polyethylene is probably the polymer you see most in daily life. Polyethylene is the most popular plastic in the world. This is the polymer that makes grocery bags, shampoo bottles, children's toys, and even bullet proof vests. For such a versatile material, it has a very simple structure, the simplest of all commercial polymers. As shown in the following figure, ethylene is a small hydrocarbon consisting of four hydrogen atoms and two carbon atoms.



Ethylene (a monomer from oil)

When you polymerize ethylene, you get a polyethylene resin. A molecule of polyethylene is nothing more than a long chain of carbon atoms, with two hydrogen atoms attached to each carbon atom. That's what the following figure shows.

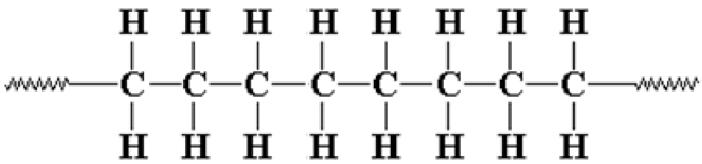


Polyethylene (Molecular Level)

Polyethylene (Pellets or Resins)

Polyethylene

But it might be easier to draw it as shown in the following figure, only with the chain of carbon atoms being many thousands of atoms long (structure).



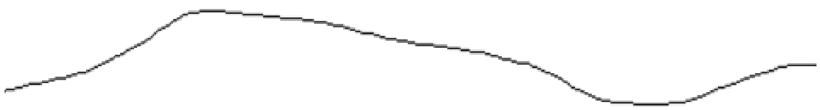
Polyethylene

The polyethylene pellets, or resins, are chains of polymers if you look at them on a molecular level.

There are a number of polyethylene resins families that differ by such properties as density and molecular weight, and they can be made into a huge variety of plastic products.

LDPE, HDPE and UHMWPE

In case of polyethylene, sometimes some of the carbons, instead of having hydrogens attached to them, will have long chains of polyethylene attached to them. This is called branched, or low-density polyethylene, or LDPE. When there is no branching, it is called linear polyethylene, or HDPE. Linear polyethylene is much stronger than branched polyethylene, but branched polyethylene is cheaper and easier to make. The following figure shows molecule of a HDPE and LDPE.



A Molecule of Linear Polyethylene or HDPE

A Molecule of Branched Polyethylene or LDPE

Molecule of HDPE and LDPE

Linear polyethylene is normally produced with molecular weights in the range of 200,000 to 500,000, but it can be made even higher. Polyethylene with molecular weights of three to six million is referred to as ultra-high molecular weight polyethylene, or UHMWPE. UHMWPE sheets are extensively used as hopper liners in bulk material handling plants. It is also used to make fibers for use in bullet proof vests.

Thermoplastics and Thermosets

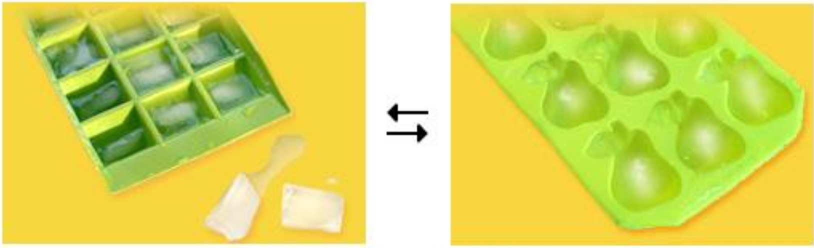
Plastics are classified into two categories/types according to what happens to them when they are heated to high temperatures. **Thermoplastics** keep their plastic properties. They melt when heated and harden again when cooled. **Thermosets**, on the other hand, are permanently "set" once they are initially formed and can't be melted. If they are exposed to enough heat, they will crack or become charred.

80% of the plastics produced are thermoplastics and of these, polyethylene, polypropylene, polystyrene and polyvinylchloride (PVC) are the most commonly used (70%).

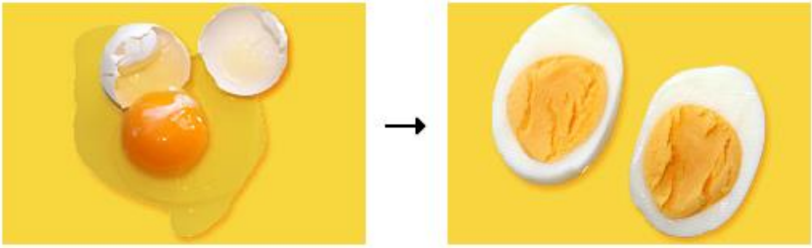
Difference/comparison between them is as under.

Thermoplastics can be reshaped whereas thermosets cannot be reshaped. As shown in the following figure, when ice is heated, it melts. When a thermoplastic object is heated, it melts as well. The melted ice can be formed into a new shape and it will keep that shape when it is cooled. Similarly, a melted thermoplastic object can be formed into a different shape and it will keep that new shape when it is cooled.

Just as a raw egg has the potential to become a boiled egg, a fried egg, and so on, thermosetting polymers have the potential to become all sorts of different objects. However, like an egg which is once boiled, cannot be converted into a fried egg, once a thermosetting plastic object has been formed, it cannot be remade into a different object.



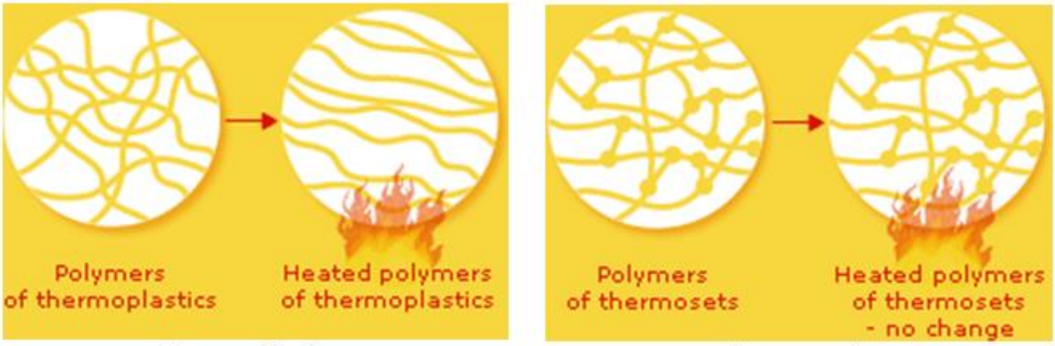
Melted ice can be formed into a new shape.



Egg once boiled, cannot be changed to other egg item.

Analogy between Ice and Egg

The reaction for above behavior is as under.



Thermoplastics Thermosets

Effect of Heat on Thermoplastics and Thermosets

Thermoplastics have long, linear polymer chains that are only weakly chemically bonded, or connected, to each other. As shown in above figure, when a thermoplastic object is heated, these bonds are easily broken, which makes the polymers able to glide past each other like strands of freshly cooked spaghetti. That is why thermoplastics can readily be remolded. The weak bonds between the polymers reform when the plastic object is cooled, which enable it to keep its new shape.

In a thermoset, the linear chains are crosslinked - strongly chemically bonded. This prevents a thermoset object from being melted and reformed.

The most common method for making plastics is molding. However, the difference between forming (manufacturing) objects from the two types is as under.

To make a thermoplastic object, plastic granules (resin) are forced into a mold under high heat and pressure. When the material has cooled down, the mold is opened and the plastic object is complete. When making plastic fibers, the molten resin is sprayed through a strainer with tiny holes.

To make a thermoplastic object, the linear polymers are forced into a mold where "curing" takes place. This may involve heating, pressure, and the addition of catalysts. During this process, a cross-linked or networked structure forms, creating a permanently hard object that is no longer meltable or moldable.

The difference in recycling these types is as under.

Thermoplastics are easy to recycle since they can be melted and reshaped into other products. For example, a plastic bottle that contained a soft drink could be reformed into the fibres of a fleece jacket.

Thermosets are hard to recycle, but today there are methods of crushing the objects into a fine powder form for use as fillers in reinforced thermosets.

Better Catalysts Improve Plastics

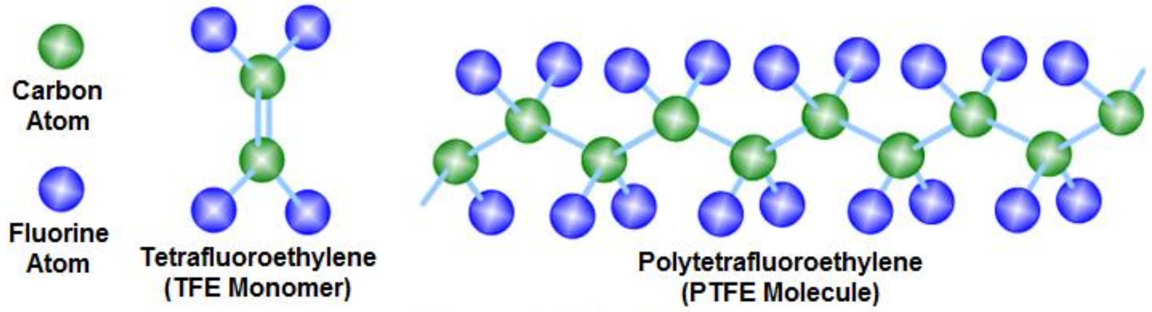
For most applications, the ideal polymer is a long, straight chain with a highly regular molecular structure. Early synthetic polymers, however, often exhibited odd little branches and other irregularities. In the 1950s, German chemist Karl Ziegler (1898-1973) discovered that an entirely different type of catalyst - a combination of aluminum compounds with other metallic compounds - could solve some of these annoying problems and increase the length of a polymer chain, producing superior plastics. For his innovative work in the polymerization of plastics, Karl Ziegler and Giulio Natta shared the Nobel Prize in Chemistry in 1963. Ziegler became a wealthy man as a result of patents for plastics such as high density polyethylene (HDPE), which is used to manufacture a variety of products such as bottles or pipe.

Plastics have contributed to our quality of life in countless ways. Many products would be much more expensive - or wouldn't exist - if it weren't for plastics. Information about commonly used plastics for engineering applications is given in following sections.

Polytetrafluoroethylene (PTFE)

Most plastics are chains of carbon atoms with hydrogen or other atoms attached to them. In fluoropolymers, fluorine atoms replace some or all of the hydrogen atoms. Substitution of fluorine for hydrogen creates a high binding energy among atoms within the plastic molecules, making the plastics highly stable and giving them unique and valuable properties. Fluoropolymers are in general more resistant to heat and chemical attack than other materials. Different fluoropolymers have different properties. The best known member of this family is Polytetrafluoroethylene (PTFE).

PTFE is the original fluoropolymer resin discovered by DuPont in 1938. As shown in the following figure, PTFE is a polymer consisting of long linear polymer chains, each one of them is made of a carbon chain surrounded by fluorine atoms forming a repeating structure -CF_2-CF_2-CF_2-. It is produced from the monomer tetrafluoroethylene (TFE), having the structure $F_2C{=}CF_2$. TFE is made in several steps from common salt (sodium chloride, NaCl), methane and an ore called fluorspar.



Structure of TFE and PTFE

The fluorine atoms covering the carbon chain protect it from chemical activity. They also repeal other PTFE molecules and molecules of other substances resulting in high chemical resistance and exceptional non-sticking properties of polytetrafluoroethylene.

PTFE resin is supplied as granular powders and aqueous dispersions. Shapes and parts are formed by specialized processing technologies, typically compression molding and sintering followed by machining. Tubing is made by ram extrusion. Linings are formed by isostatic molding and sintering or applied as sheets. Surfaces are coated by applying dispersion and then baking. Processing has a much stronger effect on performance of PTFE parts than for most other polymers.

Properties

The outstanding properties of PTFE are as under.

- Nonstick
- Nonwetting
- Low coefficient of friction
- Chemical resistance
- Heat resistance
- Non-flammability
- Cryogenic stability
- Unique electrical properties

Very few solid substances will permanently adhere to a PTFE. Although tacky materials may show some adhesion, almost all substances release easily.

Since surfaces coated with PTFE are both oleophobic and hydrophobic, they are not readily wetted. Cleanup is easier and more thorough. In many cases, surfaces are self-cleaning.

The coefficient of friction of PTFE is generally in the range of 0.05 to 0.20.

PTFE are normally unaffected by chemical environments.

PTFE can operate continuously at temperatures up to 260°C/500°F.

PTFE resist ignition and do not promote flame spread. When ignited by flame from other sources, they will stop burning ("self-extinguish") once the supporting flame is removed.

PTFE can withstand severe temperature extremes without loss of physical properties. They may be used at temperatures as low as -240°C/-400°F.

Over a wide range of frequencies, PTFE has high dielectric strength, low dissipation factor, and very high surface resistivity. By special techniques, it can even be made electroconductive enough to be used as an anti-static coating.

Applications of PTFE

While best known for its use as a coating in nonstick cookware, PTFE is also the preferred fluoropolymer for a host of other applications.

It is widely used in such industries as automotive, chemical processing, semiconductor manufacturing, cabling materials, chemical handling, data communication, aerospace, electronics, building and renewable energy.

PTFE is extensively used as gaskets, compression packings, seals, bearings, pump parts, hopper liners, thread seal tape, etc.

Teflon® is a registered trademark of DuPont for its brand of fluoropolymer resins, which can only be licensed by DuPont for use in approved applications.

Teflon® PTFE fluoropolymer resin Grade 8 is a free-flowing white powder composed of relatively large particles for compression molding. Its important properties are as under.

Average Bulk Density: 725 g/L
Average Particle Size: 600 µm
Standard Specific Gravity: 2.16
Melting, Peak Temperature Initial: 342 ±10 °C (648 ±18 °F)
Melting, Second: 327 ±10°C (621 ±18 °F)
Tensile Strength: 27.6 MPa (4,000 psi)
Elongation at Break: 300%

Filled PTFE

As the need for more demanding engineering uses emerge, it is possible to add a variety of fillers to pure unfilled PTFE which improve its physical properties. The addition of these fillers can tailor PTFE to suit mechanical applications which would normally be outside the scope of virgin material. Fillers are not used to make it cheaper. The most common fillers are 25% glass, 25% carbon and 60% bronze.

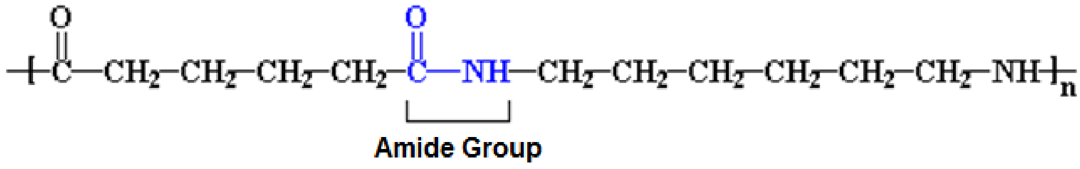
Filler enhances properties of PTFE as under.

- Improvement in resistance to cold flow / creep
- Reduction in wear
- Increases in stiffness and hardness
- Improved dimensional stability

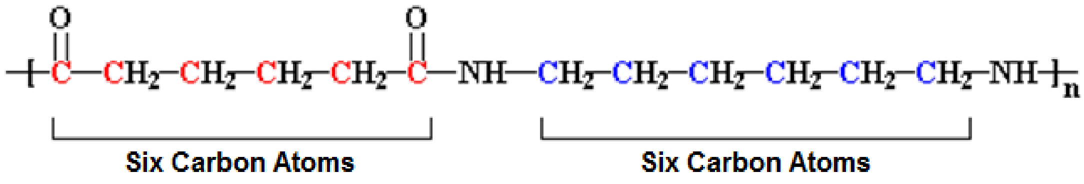
Nylon

The name "nylons" refers to the group of plastics known as **polyamides (PA)**. Polyamides were discovered in 1931. Commercial production of nylon 6,6 began in 1938. Polyamides were first introduced as fibre forming polymers. Its first commercial application was the Bristles on Dr West's Miracle Tuft toothbrush. Commercial production of nylon moulding powders began in 1941.

Nylons are called polyamides because of the characteristic amide groups in the backbone chain as shown in the following figure.



They are typified by amide groups (CONH) and encompass a range of material types (e.g. Nylon 6,6; Nylon 6,12; Nylon 6; Nylon 12 etc.), providing broad range of properties. The two most common for textile and plastics industries are nylon 6,6 and nylon 6.

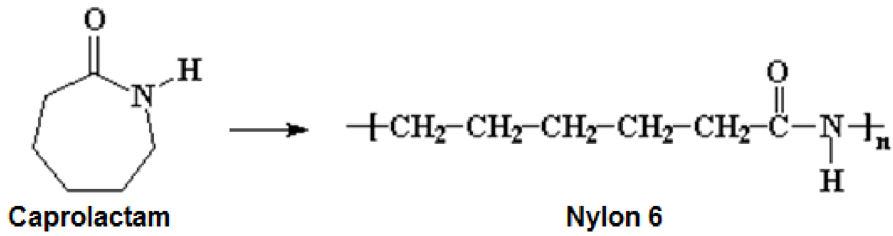


Nylon 6,6

The nylon structure shown in above figure is called **nylon 6,6** because each repeat unit of the polymer chain has two stretches of carbon atoms, each being six carbon atoms long. The polymer is made by reaction between adipic acid and hexamethylene diamine.

Nylon 6 or **polycaprolactam** is a polymer developed by Paul Schlack at IG Farben to reproduce the properties of nylon 6,6 without violating the patent on its production by DuPont.

However, nylon 6 is not made by a condensation polymerization like nylon 6,6. As shown in the following figure, it is made by ring-opening polymerization from the monomer caprolactam.



Making Nylon 6 by Ring-opening Polymerization

It is called nylon 6 because each repeat unit of the polymer chain has only one kind of carbon chain, six carbon atoms long.

Properties

The majority of nylons tends to be semi-crystalline and are generally very tough materials with good thermal and chemical resistance. The different types give a wide range of properties with specific gravity, melting point and moisture content tending to reduce as the nylon number increases.

Nylons tend to absorb moisture from their surroundings. This absorption continues until equilibrium is reached and can have a negative effect on dimensional stability. In general, the impact resistance and flexibility of nylon tends to increase with moisture content. Though this lowers tensile strength.

Nylons may also be blended with other engineering plastics to improve certain aspects of performance.

Applications

Nylon fibres are used in textiles, carpets, fishing line, ropes, conveyor belts and hoses. Nylon films are used for food packaging, offering toughness and low gas permeability.

Moulding and extrusion compounds find many applications as replacements for metal parts, for instance in car engine components. Intake manifolds in nylon are tough, corrosion resistant, lighter and cheaper than aluminium (once tooling costs are covered) and offer better air flow due to a smooth internal bore instead of a rough cast one. Its self-lubricating properties make it useful for gears and bearings.

Aramid

Aramids are a family of nylons. They are used in the form of fibers. They are heat-resistant and strong fibers. They are used in aerospace and military applications, for ballistic rated body armor fabric, in bicycle tires and as asbestos substitute. They are extensively used as an asbestos substitute in the manufacturing of compression packings and gaskets.

Well known brands Nomex® and Kevlar® from DuPont are aramid. Kevlar® is used to make things like bullet proof vests and puncture resistant bicycle tires. Blends of Nomex® and Kevlar® are used to make fireproof clothing.

Vespel®

Like Teflon, Vespal® is a brand owned by DuPont. The majority of Vespal® products are based on a class of polymers called **polyimides (PI)**, which are rigid and thermally stable enough to allow them to perform well in too severe conditions.

Parts like line shaft bearings and stationary wear rings made from Vespal® are used to decrease risk of pump seizure due to run-dry conditions in refinery and power generation.

Attributes of Vespal® for pump components are as under.

- Low coefficient of friction
- Wide range of temperature capabilities up to 500°F/260°C
- Maintains high load-speed (PV) with no lubrication
- Excellent mechanical strength
- Low coefficient of thermal expansion
- Broad chemical compatibility

Following table shows typical properties of commonly used PTFE and engineering plastics as per Fluorocarbo Company Limited, United Kingdom (www.fluorocarbon.co.uk).

Material	Density g/cm³	Tensile Strength, N/mm² (at 23°C)	Elongation at Break, % (at 23°C)	Shore Hardness, D	Coefficient of Friction	Maximum Continuous Operating Temperature, °C
PTFE Vergin	2.14-2.19	20-40	200-450	55-65	0.05-0.2	260
PTFE 25% Glass	2.24	12-20	200-300	60-70	0.07-0.2	260
PTFE 25% Carbon	2.10	11-16	70-150	60-70	0.1-0.2	260
PTFE 60% Bronze	3.90	10-14	80-160	65-75	0.07-0.2	260
Vespel® SP1	1.35-1.45	45-86	2-8	-	0.2-0.35	300
UHMWPE	0.94	20-40	300-500	60-70	0.15-0.3	80
NYLON 6	1.10-1.15	40-80	80-100	-	0.22-0.26	90
HDPE	0.95-0.96	19-35	300-500	62-69	0.3-0.35	80

More Information

For an overview of the history of plastics, their manufacture and use in product design and some ways to work them, you may see “An Introduction to Plastics” – a textbook for secondary schools. The book may be downloaded from website of The Plastics Historical Society (www.plastiquarian.com). To reach the link, please select (click on) Plastics and Education.