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Polymers Used in Everyday Life

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ABSTRACT

From the stone-age to the age of computers, a significant development is self-evident in the materials that make our daily life comfortable. One of these revolutionary materials in the modern world is polymers. Polymers are natural or synthetic substances composed of very large molecules, called macromolecules, which are multiples of simpler chemical units called monomers. These are present in almost every aspect of modern-day lives because of their vast spectrum of properties. Natural polymers like wool, cotton, and silk are present in our society long before the notion itself. In 1869 John Wesley Hyatt invented celluloid, the first synthetic plastic, while searching for an artificial replacement for ivory. It was not until 1907 when polymers entered the industrial sector with the invention of Bakelite, the first fully synthetic plastic, containing zero naturally occurring molecules. These inventions later emerged as a field of macromolecular chemistry, a field closely associated with the name of Herman Staudinger, who received the Nobel Prize in 1953 for first proposing the idea of polymerization (a process of reacting monomer molecules together in a chemical reaction to form polymer chains).

KEYWORDS: *Polymers, monomers, macromolecule, polymerization, daily life, polythene*

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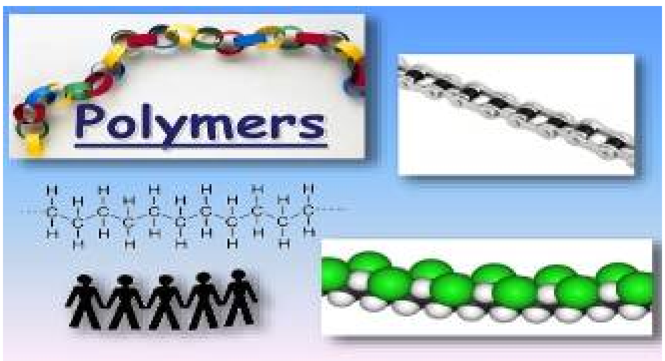
Since then, there have been several developments in the synthesis of various polymers, contributing to six more Nobel prizes associated with the field of polymeric sciences. In this review we will discuss some of the most commonly used polymers in everyday life.



1. INTRODUCTION

Polymer is a natural or synthetic material containing large molecules made by bonding (chemically linking) a series of building blocks called monomers. The term "polymer" derives from the Greek word *polus*, meaning "many and *meros*, meaning "part". The term was coined by Jons Jacob Berzelius in 1833. The modern concept of polymers as covalently bonded macromolecular structures was proposed in 1920 by Hermann Staudinger. Due to their broad spectrum of properties, both synthetic and natural polymers play essential and ubiquitous roles in everyday life. In modern age polymers are being used in many fields viz. fabrics, plastic bottles, paints, home care products, kitchen products, medical filed, computer parts, adhesives, agriculture, carpeting, cosmetics, switch boards and many more to come. Polymers range from familiar synthetic plastics such as polystyrene to natural biopolymers such as DNA and proteins that are fundamental to biological structure and function. Polymers, both natural and synthetic, are created via polymerization of many small molecules, known as monomers. Their consequently large molecular mass, relative to small molecules, produces unique physical properties including toughness, high elasticity, visco-elasticity, and a tendency to form amorphous and semi-crystalline structures rather than crystals. They can also be reused and some of them can even be recycled which has also cut down the damage which was earlier being caused by the non-biodegradable substances. Polymers are studied in the fields of polymer science (which includes polymer chemistry and polymer physics), biophysics and materials science and engineering. Historically, products arising from the linkage of repeating units by covalent chemical bonds have been the primary focus of polymer science. An emerging important area now focuses on supramolecular polymers formed by non-covalent links. Polyisoprene of latex rubber is an example of a natural polymer, and the polystyrene of styrofoam is an example of a synthetic polymer. In biological contexts, essentially all biological macromolecules i.e., proteins (polyamides), nucleic acids (polynucleotides), and polysaccharides are purely polymeric, or are composed in large part of polymeric components.

Fig 1: Polymers used in everyday life

2. Classification of Polymers

Polymers are classified in different types on different basis as in the following enumeration:

2.1. Natural and Synthetic Polymers (Classification based on the source of origin)

Those polymers which are isolated from natural materials such as animals and plants are called natural polymers. e.g. Cotton, Silk, Jute, Leather, Wool, Natural rubber etc.

The polymers obtained by simple chemical treatment of natural fibers to improve their physical properties like lastrus nature, tensile strength are called semi-synthetic polymers. e.g. Cellulose acetate (Rayon), Cupra ammonium silk, Viscous rayon etc.

Those polymers which are synthesized from low molecular weight compounds in laboratory are called synthetic polymers. e.g. Polyethylene, PVC, Nylon, Terylene, Bakelite, Teflon, Orlon, Perlon, synthetic rubber etc.

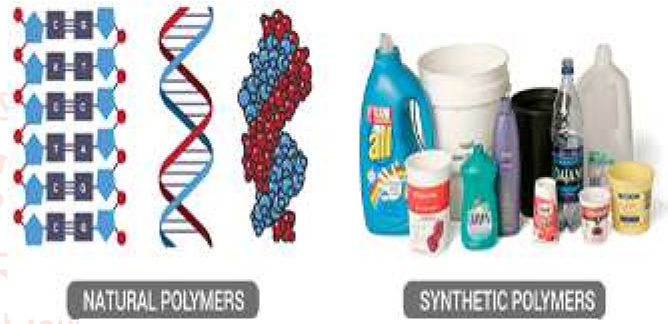


Fig 2: Natural and synthetic polymers

2.2. Organic and Inorganic Polymers (Classification based on the backbone)

Those polymers whose backbone chain is made of carbon atoms is termed as organic polymer. e.g. Polypropylene, PVA, PMMA etc.

Those polymers which contain no carbon atom in their backbone chain are termed as inorganic polymers. e.g. Glass, Silicon rubber etc.

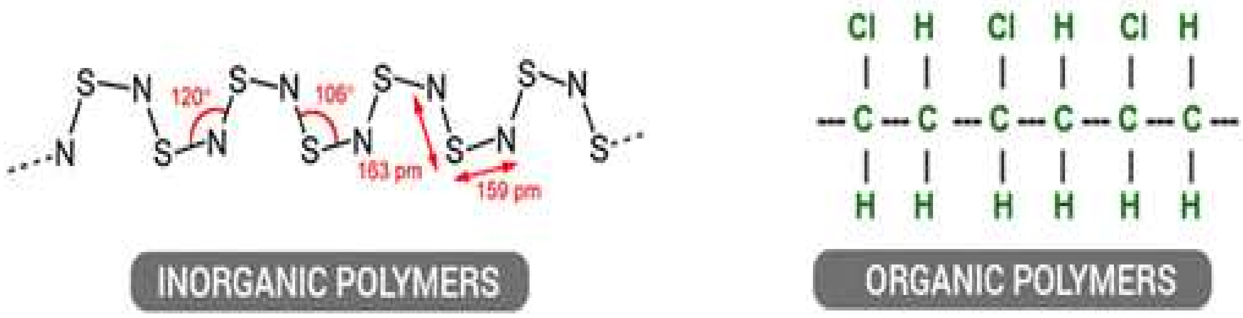


Fig 3: Organic and inorganic polymers

2.3. Elastomers, Fibres, Thermoplastic and Thermosetting Polymers (Classification based on the molecular forces)

The polymers in which polymer chains are held up by weakest attractive forces are Elastomers. They contains randomly coiled molecular chains having few cross links. As the stain is applied polymer get stretched and as the force is released polymer regain its original position. Since these polymers are elastic and called Elastomers. e.g. Neoprene and vulcanized rubber.

The polymers which have high intermolecular attractive force like H-bonding and can be drawn into long filament like material then it is called Fibres. They have high tensile strength and used in textile industries. e.g. Nylon-6, Nylon-66 and Terylene.

Those polymers which can be soften on heating and can be converted into any shape that they can retain on cooling are called Thermoplastic polymers. e.g. Polyethylene, PVC, Nylon, Sealing wax etc.

Those polymers which undergo some chemical changes on heating and convert themselves into an infusible mass are called Thermosetting polymers. These are not soft on heating under pressure and they are not remolded. These are cross linked polymers and are not reused. e.g. Phenol formaldehyde resin, polyesters etc.

Those polymers which are used as adhesive, potting compounds, sealants, etc in a liquid form are called as Liquid resins. e.g. Polysulphide, Melamine formaldehyde etc.

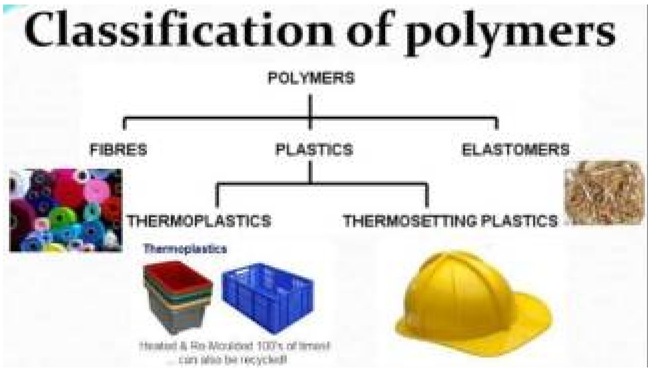


Fig 4: Elastomers, fibres, thermoplastic and thermosetting polymers

2.4. Addition polymers and Condensation polymers (Classification based on the polymerization process)
The polymers formed by the addition of monomers repeatedly without removal of by products are called addition polymers. These polymers contain all the atoms of monomers hence they are integral multiple of monomer unit. e.g. Orlon, Teflon, Polyethene, Polypropylene, PVC. The monomeric units are generally alkenes and its derivatives.

The polymers formed by the combination of two monomers by removal of small molecules like water, alcohol or ammonia are called condensation polymers. They have ester and amide linkage in their molecules. Their molecular mass is not the integral multiple of monomer units, e g. Polyamides (Nylons), Polyesters, Polyurethanes.

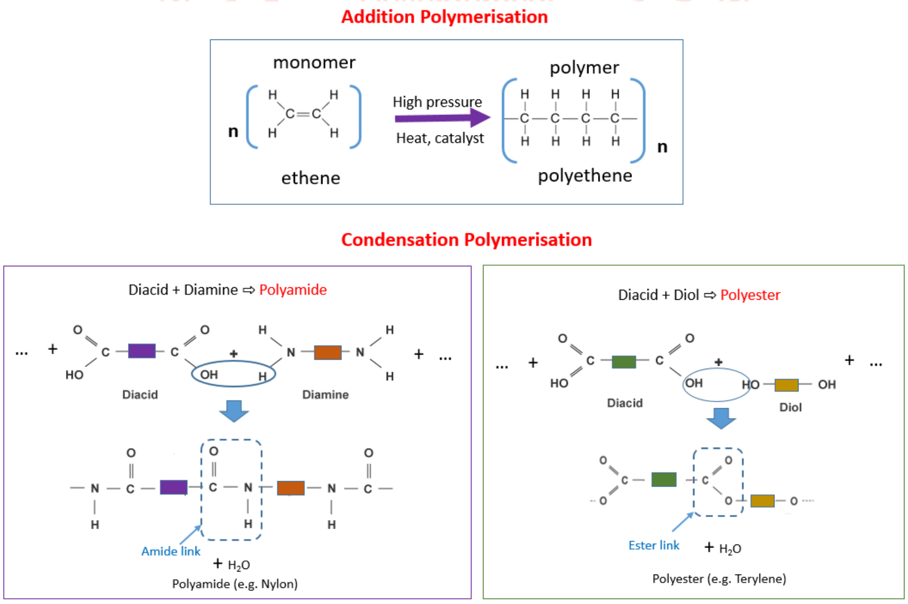


Fig 5: Addition and condensation polymers

2.5. Chain Growth and Step Growth Polymers (Classification based on the mode of formation)
Chain growth polymerization process involves the addition of molecules at the reactive end of the growing chain across the double bond. Many alkenes and its derivatives undergo growth chain polymerization. e.g. Polyethene, PVC, PAN etc.

Step growth polymerization process involves the step wise intermolecular condensation through a series of independent reaction. This process involves loss of simple molecules like NH_3, H_2O and HCl. It is possible when the monomer have more than one functional group. It proceeds through the formation of dimer, trimmer, tetramer, etc. e.g. Dacron, Nylon etc.

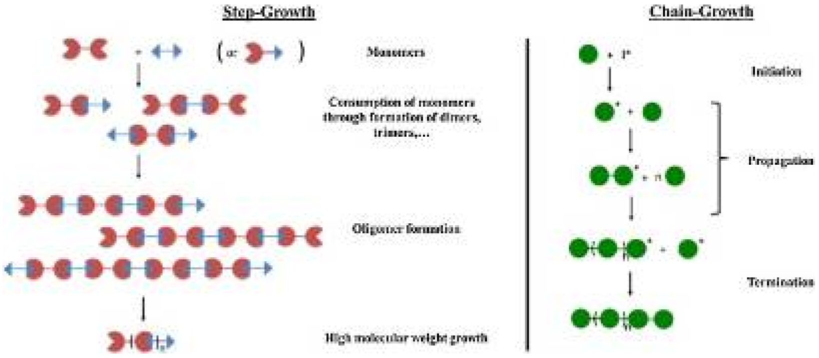


Fig 6: Step growth and chain growth polymers

2.6. Homopolymers and Copolymers (Classification based on the homogeneity of Polymers)

Those polymers which consist of only one type of repeating unit are called homopolymers. e.g. Polyethylene, PVC, PAN, Teflon etc.

Those polymers which consist of more than one type of repeating unit are called copolymers. e.g. Nylon, Dacron etc.

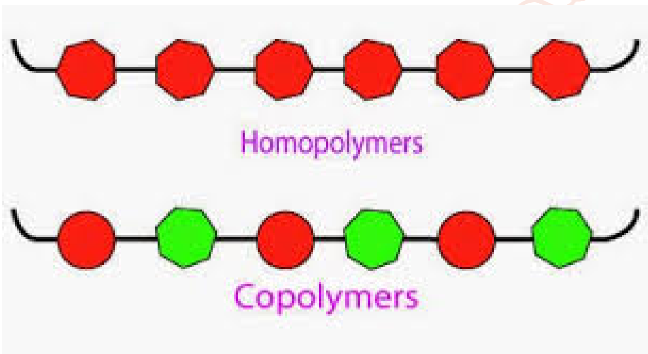


Fig 7: Homopolymers and copolymers

2.7. Linear, Branched and Cross linked Polymers (Classification based on the arrangement of monomeric units)

The polymers in which monomers are linked with each other to form a long straight chains and these chains have no any side chains are termed as linear polymers. Their molecules are closely packed and have high density, tensile strength, and melting point. e.g. Polyethene, PVC, Nylons, polyesters etc.

The polymers which have a straight long chain with different side chains are termed as branched polymers. Their molecules are irregularly packed hence they have low density, tensile strength and melting point. e.g. Polypropylene (side chain -CH3), amylopectin and glycogen.

The polymers in which monomeric units are linked together to constitute a three dimensional network structure are called network or cross linked polymers. The links involved are called cross links. They are hard, rigid .and brittle due to their network structure. e.g. Bakelite, phenol-formaldehyde resins, vulcanized rubber etc.

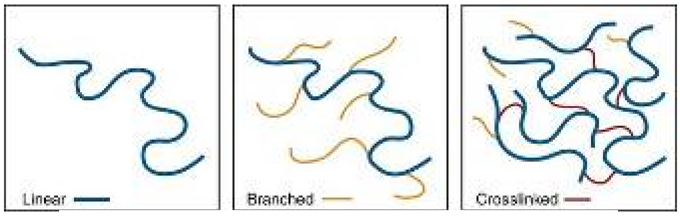


Fig 8: Linear, branched and cross-linked polymers

3. Some Common Polymers Used in Everyday Life

Polymers may sound like a very industry specific thing, but they are actually a pretty big part of a lot of industries you may indeed recognize. Polymers are used in several industries such as aerospace, automotive, electronics, packaging, medical, rubber, paint, cosmetics, adhesives, and agriculture etc. Polymers are incredibly diverse materials that represent such fields of engineering from avionics through biomedical applications, drug delivery system, biosensor devices, tissue engineering, cosmetics etc. the application of polymers and their subsequent composites is still advancing and increasing quickly due to their ease regarding manufacturing. It is important to understand that polymeric materials may include: raw materials, polymer compounds, foams, structural adhesives and composites, fillers, fibres, films, membranes, emulsions, coatings, rubbers, sealing materials, adhesive resins, solvents, inks and pigments.

Some common polymers used in everyday life are described below:

3.1. Polyethylene or Polythene

Polythene is one of the most prominent plastic polymers, accounting for 34% of the total plastic market in the world. It is a lightweight and durable thermoplastic with a crystalline structure and the general chemical formula $(C_2H_4)_n$. It has several excellent physical properties such as high ductility, high impact strength, and very great chemical resistance. Although there are different types of polyethylene classified by their density and branching, the most common types that we encounter in our daily life are

1. **Low-Density Polyethylene (LDPE):** It is a semi-rigid and translucent polymer with a high degree of long and short side-chain branching, which lowers the density of the polymer. It is produced using a free radical polymerization method at temperatures ranging from 80 to 300 °C and high pressures of 1000-3000 bar. The average molecular structure of LDPE polymer contains 4,000-40,000 carbon atoms, with up to 20 branches per 1000 carbon atoms. This makes them a useful plastic for molding and extruding in any desired shapes. The most common use of LDPE is in the manufacturing of plastic bags that we use to carry items; however, certain governments around the globe have banned the use of plastic bags due to rising environmental concerns. LDPE is also used for manufacturing various containers, dispensing bottles, tubes, plastic parts for computer components, and various molded laboratory equipment.

Fig 9: Materials made from Low-Density Polyethylene (LDPE)

2. **Linear Low-Density Polyethylene (LLDPE):** LLDPE is produced by polymerization of ethylene (or ethane monomer) with 1-butene and smaller amounts of 1-hexene and 1-octene, using Ziegler-Natta or metallocene catalysts. The molecular structure of LLDPE contains a linear backbone and homogeneous short-length branches. Unlike LDPE, these short branches can slide against each other on stretching without becoming entangled. In recent years, LLDPE has infiltrated almost all traditional polyethylene markets. It has replaced the use of LDPE for plastic bags and sheets, allowing for lower thickness and almost equivalent efficiency. Other items made of LLDPE include transparent film, stretch packaging, bags, toys, lids, caps, pipes, cables, geomembranes, and mainly flexible tubing.

Fig 10: Materials made from Linear Low-Density Polyethylene (LLDPE)

3. **High-Density Polyethylene (HDPE):** As the name suggests, HDPE is a high-density thermoplastic because of its linear structure and no or low degree of branching. It is produced using a gas phase polymerization method at temperatures ranging from 70 to 300 °C and pressures of 10-80 bar. Due to the absence of branching, HDPE has a strong tensile strength with a temperature tolerance ranging up to 120 °C for a short period of exposure. Because of its strong chemical resistance, HDPE is one of the preferred choices for piping. It is an ideal combination of strength, cost-efficiency, and environmental friendliness because of its great malleability, stiff strength, and corrosion resistance.

Fig 11: Materials made from High-Density Polyethylene (HDPE)

3.2. Polypropylene (PP) or Polypropene

Polypropylene $(C_3H_6)_n$ is one of the most versatile and cost-effective thermoplastic polymers in all plastics. It is a rigid and partially-crystalline polymer produced via chain-growth polymerization of propene (or propylene) monomer. It has several properties that make it a better choice of plastic than polyethylene, e.g., higher melting point makes it employable in the manufacture of microwave-safe containers, and higher resistance to cracking and stress, even when flexed, makes it less vulnerable to daily wear and tear. Polypropylene's characteristics make it ideal for tough and robust products ranging from protective car bumpers to life-saving medical tools and cold-weather gear for soldiers. Moreover, it can also be engineered into a wide range of packaging that helps protect products we rely on every day, from medicine to yogurt and baby food. A large volume of PP is utilized in the fabric industries. PP fiber is utilized in a host of applications including slit-film, tape, strapping, bulk continuous filament, staple fibers, spun bond, and continuous filament. For marine applications, PP ropes and twines are used as they are very strong and moisture resistant.

Fig 12: Materials made from Polypropylene (PP) or Polypropene

3.3. Polyvinyl Chloride (PVC)

Polyvinyl Chloride (PVC or Vinyl) is a high-strength thermoplastic material that comes in two basic forms, rigid and flexible. It is produced by the polymerization of vinyl chloride monomer. It's a white, brittle solid that comes in powder or granule form. PVC has replaced several conventional building materials such as wood, metal, concrete, rubber, ceramics, and others in a variety of applications due to its versatile properties such as lightweight, durability, low cost, and ease of processing. PVC pipes have replaced the metal pipes used for household distribution of water, thereby reducing the risk of contamination via corrosion. It is commonly used as an insulating cover for electricity wires network throughout the house. PVC is used in the manufacturing of sliding doors and window frames that are extremely durable, affordable, and help conserve energy when heating and cooling homes. In fact, vinyl windows have three times the heat insulation of aluminum windows. It also plays a critical safety role in dispensing life-saving medicine through IV bags and medical tubing. Almost one-third of plastic-based medical materials are made from PVC.

Fig 13: Materials made from Polyvinyl Chloride (PVC)

3.4. Polytetrafluoroethylene (PTFE) or Teflon

Polytetrafluoroethylene (PTFE) is a synthetic fluoropolymer of tetrafluoroethylene and is known by its common brand name Teflon. It is one of the most slippery man-made materials. Apart from its use in the kitchen (non-stick cooking utensils), PTFE is used as a cost-effective solution for industries ranging from oil & gas, chemical processing, industrial to electrical/electronic and construction sector because of its extensive properties such as exceptional heat and chemical resistance, good electrical insulating power in hot and wet environments, low dielectric constant, strong anti-adhesion, flexibility, and low water absorption. These properties make Teflon employable in several automotive parts such as gaskets, valve stem seals, shaft seals, linings for fuel hoses, power steering, transmission, etc. In the chemical industry, it can be used as coatings for heat exchangers, pumps, diaphragms, impellers, tanks, reaction vessels, autoclaves, containers, etc. Due to its electrical properties, it is widely used in insulation, flexible printed circuit boards, semiconductor parts, etc.

Fig 14: Materials made from Polytetrafluoroethylene (PTFE) or Teflon

3.5. Polystyrene (PS)

Polystyrene is a synthetic aromatic hydrocarbon polymer made from the monomer known as styrene or vinyl benzene. Polystyrene can be solid or foamed. It is a poor barrier to oxygen and water vapour and has a relatively low melting point. Polystyrene is one of the most widely used thermoplastic polymer, the scale of its production being several million tonnes per year. Polystyrene can be naturally transparent, but can be coloured with colourants. It is used in protective packaging (such as packing peanuts and in the jewel cases used for storage of optical discs such as CDs and DVDs), containers, lids, bottles, trays, tumblers, disposable cutlery, in the making of models, and as an alternative material for phonograph records.

Fig 15: Materials made from Polystyrene (PS)

3.6. Polyvinyl acetate (PVA or PVAc)

Polyvinyl acetate (PVA or PVAc), commonly known as wood glue, white glue, carpenter's glue, school glue, or Elmer's glue in the US, is a widely available adhesive used for porous materials like wood, paper, and cloth. It is an aliphatic rubbery synthetic polymer with the formula $(C_4H_6O_2)_n$, it belongs to the polyvinyl ester family, with the general formula $-[RCOOCHCH_2]-$. It is a thermoplastic polymer and prepared by the polymerization of vinyl acetate monomer. PVAc is used as adhesive for porous materials, particularly for wood, paper, and cloth, and as a consolidant for porous building stone, in particular sandstone.

Fig 16: Materials made from Polyvinyl acetate (PVA or PVAc)

3.7. Acrylics

Acrylics, also known as acrylate polymers, are a group of polymers prepared from acrylate monomer (CH_2=$CHCOO^-$). These materials are commonly known for their transparency, resistance to breakage, and elasticity. These properties make acrylic extensively useful for applications requiring high transparency and impact resistance. Some of the common uses include acrylic nails, acrylic paint, security barriers, LCD screens, and acrylic home decors. Another acrylic includes cyanoacrylate resins, made into fast-acting adhesives, such as superglue, pressure-sensitive adhesive, etc. Poly-2-hydroxyethyl methacrylate, abbreviated poly HEMA, is acrylic used in the medical sector to make contact lenses.

Fig 17: Materials made from Acrylics

3.8. Polyester

Polyester is the class of polymers comprising an ester group in the monomer subunit. In daily life, it is most commonly referred to as a form of fiber called Polyethylene terephthalate (PET). Polyester can be both an amorphous and a semi-crystalline polymer, depending on its production and thermal history. Polyester fibers are often mixed with natural fibers to create a fabric with aggregate properties. As compared to natural fibers, polyester fibers have superior water, wind, and environmental resistance. Moreover, Its hydrophobic property makes it ideal for garments and jackets that are to be used in wet or damp environments by coating the fabric with a water-resistant finish intensifies this effect. Besides clothing and fabric, PET is also used as a substrate in solar cells, a waterproof barrier for cables, and also as an oxygen barrier for type IV composite high-pressure gas cylinders.

Fig 18: Polyester Fabric

Fig 19: Nylon Fibres

3.9. Polyamides or Nylons

Most of us are familiar with the term 'nylon' as a superstrong silky fiber that is generally found in umbrellas, socks, and ropes. In chemistry, nylon is a generic designation for a class of polyamides (polymers with repeating monomer units linked by amide bonds). Nylons are generally produced by reacting difunctional monomers containing equal parts of amine and carboxylic acid so that amides are formed at both ends of each monomer. There are different types of nylon depending on the nature of the monomer units. Two of the most commonly used nylons are:

A. **Nylon-66:** It is one of the most commonly used polyamides in the textile industry. Nylon 66 is synthesized by the copolymerization of two monomers each containing 6 carbon atoms, which gives nylon 66 its name: hexamethylenediamine ($H_2N(CH_2)_6NH_2$) and adipic acid ($HOOC(CH_2)_4COOH$). Nylon 66 is frequently used when materials with high mechanical strength, rigidity, good stability under heat, and chemical resistance are required. Typical applications of nylon 66 include fiber for textiles, carpets, molded parts, pipes, zip ties, conveyor belts, hoses, polymer-framed weapons, and the outer layer of turnout blankets.

B. **Nylon-6:** It is another popular polyamide that we may come across in our daily life. Unlike nylon-66, nylon-6 is produced by the ring-opening polymerization of a single six-carbon monomer called Caprolactam. Nylon 6 fibers have high tensile strength, elasticity, and a lustrous finish. They're wrinkle-free and immune to abrasion as well as chemicals like acids and alkalis; however, they may lose their tensile strength when soaked with water. Most of the nylon-6 is produced in the form of filament yarns for the manufacturing of apparel, hosiery, upholstery, seat belts, parachutes, ropes, and industrial cords.

3.10. Rubber

Rubber is an elastomer, i.e., a polymer that is primarily characterized by its ability to regain its original shape after being deformed. There are many different kinds of rubber, but they all fall into two broad types: natural rubber and synthetic rubber. Natural rubber is harvested mainly in the form of the latex from the rubber tree (Hevea brasiliensis) or other plants. In chemical terms, it is a polymer of isoprene, also known as 2-methylbuta-1,3-diene, with the chemical formula $(C_5H_8)_n$. Synthetic rubbers are made in chemical plants using petrochemicals as their starting point. One of the most commonly known synthetic rubber is neoprene, chemically known as polychloroprene, made by reacting together acetylene and hydrochloric acid. Neoprene has good chemical stability and maintains elasticity over a wide temperature range, which makes it a preferred material for the manufacturing of wetsuits, wrist and orthopedic knee braces, surgical gloves, laptop sleeves, mousepads, and gaskets. Another popular family of synthetic rubbers is styrene-butadiene rubber (SBR), which is derived from the copolymerization of two monomers: styrene and 1,3-Butadiene. This rubber is widely used for the manufacturing of tires all around the world.

Fig 20: Materials made from Rubber

3.11. Bakelite

Bakelite is the commercial name for the polymer obtained by the polymerization of phenol and formaldehyde. It was the first plastic made from synthetic components. It is a thermosetting phenol formaldehyde resin, formed by the condensation reaction of phenol with formaldehyde in acidic or basic medium. It was developed by the Belgian-American chemist Leo Baekeland in Yonkers, New York, in 1907. Due to its electrical nonconductivity and heat-resistant properties it is used in electrical insulators, radio and telephone casings and such diverse products as kitchenware, jewelry, pipe stems, children's toys, and firearms.

Fig 21: Materials made from Bakelite

3.12. Silicone or Polysiloxane

Silicone, also known as polysiloxane, is a high-performance elastomer made of polymerized siloxanes (chains made of alternating silicon and oxygen atoms). By varying the lengths, side groups, and crosslinking of –Si–O– chain, silicones can be synthesized with a wide variety of properties and compositions. These properties range from high-temperature performance to durability, excellent electrical insulation properties as well as varying transparency. With these unique characteristics, silicone rubber is widely used in industries such as aerospace, automotive, construction, medical, electricity, food processing, etc. For instance, sealants and adhesives made of silicone are used to seal and protect doors, windows, wings, and electrical components in the aviation and construction sectors. Due to their non-toxic properties, silicones are often used in the medical sector for implants and drug delivery systems. Advances in silicone technology enable today's exterior paints and coatings to last longer and stand up to the sunlight and pollution. Paints made with silicones offer exceptional adhesion, pigment dispersion, and chemical, weather, and stain resistance.

Fig 22: Silicone Adhesives

3.13. Hydrogels

A hydrogel is a three-dimensional (3D) network of hydrophilic polymers that can absorb and hold a substantial amount of water while maintaining the structure due to the chemical or physical cross-linking of individual polymer chains. Physical crosslinks consist of hydrogen bonds, hydrophobic interactions, and chain entanglements, whereas chemical cross-linkage involves covalent bonds between polymer strands. The polymers used to create hydrogels usually have monomers containing hydrophilic groups such as $–NH_2$, –COOH, –OH, $–CONH_2$, and $–SO_3H$, which is why they are so efficient in absorbing water. Hydrogels appear in various everyday products such as hair gel, toothpaste, and cosmetics. Some superabsorbent hydrogels are acrylate-based materials, which are mainly used to absorb fluids in disposable diapers. The high-porosity structure of hydrogels allows drugs to be loaded and then released, making long-term transdermal drug delivery easier and allowing for a controlled drug delivery system. Another important use of hydrogels in the medical sector involves tissue engineering (a set of methods that can replace or repair damaged or diseased tissues with natural, synthetic, or semisynthetic tissue mimics). Both synthetic and naturally derived materials can be used to form hydrogels for tissue engineering scaffolds.

Fig 23: Hydrogels

4. Conclusion

As we have seen that polymer is not a single compound, it has a large variety. All the different form comes under one umbrella. From a simple polyethylene to a complex composite, all comes under the heading of polymers. Polymers have been around us in the natural world since the very beginning (e.g., cellulose, starch, and natural rubber). Man-made polymeric materials have been studied since the middle of the nineteenth century. Today, the polymer industry has rapidly developed and is larger than the copper, steel, aluminum and some other industries combined. Perhaps polymer chemistry, more than any other research field, crosses over and cuts the traditional lines of all branches of chemistry, biology, physics, material, engineering, pharmacy, and even medicine. And, a newcomer to polymer science requires enough ability to mix together the vast knowledge from all aforementioned fields. Therefore, this review paper has been written to show the very significant and unforgettable roles of polymers in human life.

5. Acknowledgement

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