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GREEN AND SUSTAINABLE POLYMER MATERIALS: A REVIEW

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ABSTRACT

Green and sustainable production has gained popularity as they have a less impact on the environment. This chapter main goal is to introduce the characterization, applications and the most important is to manufacture green polymers. Synthetic polymers have been the focus of research since the middle of the nineteenth century. Natural polymers have focused the attention of numerous researchers due to their attractive qualities for pharmacological applications. Also there is opportunity to investigate new polymers for targeted drug delivery. Although synthetic polymers have many advantages, their durability has resulted in a global plastic pollution problem that now poses one of the most pervasive and extensive threats to our planet's health and future.

Keywords : Synthetic polymer, Sustainable polymers, Biodegradable polymer.

INTRODUCTION

The word "polymer" have derived from the greek word "poly" for numerous and "mer" for components. Long-chain compounds or macromolecules made up of a variety of short-chain monomers that are referred to as polymers. The reaction of carbon elements with oxygen, hydrogen, nitrogen, organic and inorganic elements results in polymer material[1]. Green and sustainable manufacturing use to reduce waste and it is also used in the synthesis of polymer materials. Green and sustainable production has become a widely accepted trend as they have a less impact on the environment[2]. We are surrounded by products made of polymers, including clothes made of synthetic fibers, Teflon- coated cookware, fiberglass, nylon bearings, plastic bags, and polyethylene cups[3]. The polymer sector today has been growing more rapidly than the combined sizes of the steel, aluminum, copper, and other industries[4].Sustainable polymers are materials that are made from renewable, recycled and waste carbon resources. Reduced environmental impact is also an another characteristic of sustainable polymers throughout their life cycles. Sustainable polymers should require fewer non-renewable resources for the synthesis and processing low toxic and less harmful emissions and pollutants, also able to decomposed or even fertilize when their useful lives are over[5].

1. CHARACTERISTICS OF POLYMERS:

Polymers are characterized into three category these are – Physical, Chemical and Mechanical properties.

1.1 Physical and Chemical properties of polymer:

S.NO.	Physical Properties	Chemical Properties
1	**Forces Between Polymer Chains-** The properties of polymers that are not highly cross-linked but are highly dependent on the forces that act between the chains. The forces between the chains in polyethene crystallites are known as Vander Waals or dispersion forces, in other types of polymers, hydrogen bonding can produce even stronger intermolecular forces[6].	**Bonding and reactivity** – The reactivity of polymers is determined by many weak forces such as hydrogen bonding between the particles and some strong covalent bond.
2	**Tensile Strength-** Polymers have the ability to expand without breaking. This characteristic of polymers affects strength and durability.	Polymer adhesion on the surface interact with coating that have an impact on the quality of paints[7].
3	**Melting and Boiling point-** Due to the large molecular chain and the strong intermolecular forces, polymers tend to have high melting and boiling point.	**Biodegradability**– Decomposers have the ability to degrade polymers. Natural polymers such as rubber are biodegradable whereas synthetic polymers are not biodegradable[8].
4	**Density-** Polymer have high and low density.	High density
5	**Elasticity-** Polymer chains must be extremely flexible. Polymers with weak intermolecular bonds stretch and are more elastic[9].	The polymer's high flexibility is made possible by the side chains' dipole- dipole bonding.
6	**Hardness** – Hard polymers are resistant to hard substance absorption.	They have toughness, resilience, and corrosion resistance properties.
7	**Crystallinity-** They are brittle, polymers with less crystallinity are more valuable. Crystallinity ranges from 0 to 1 where 0 for amorphous polymer and 1 for perfectly crystalline polymer[10].	Having Compressibility, radioactivity, toxicity, flammability, heat of combustion, and chemical reactivity.

1.2 Mechanical Properties of a Polymer:

Polymer's mechanical property is its capacity to withstand physical stress. Some of these properties are:

1. **Strength** – The strength of a polymer is

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defined as the minimum stress required for breaking a sample of a particular polymer. Tensile strength, compressibility and flexibility are three types of polymer strength. The factors that affect its strength are as follows:

a. **Molecular Weight**: As the molecular weight increases the tensile strength of the polymer also increases and reaches saturation after a certain value[11].
b. **Cross-linking**: In polymers cross-linking enhance the material's tensile strength but also limit the chain movement.

2. **Toughness:** The toughness of the polymers is determined by the region under the stress-strain curve[12].
3. **Viscoelasticity** – Viscoelasticity characterizes both elasticity and viscosity. It is caused by temporary link between fiber particles because of this property, return to their original shape after being stretched.

1.3 Factors Affecting the Properties of a Polymer:

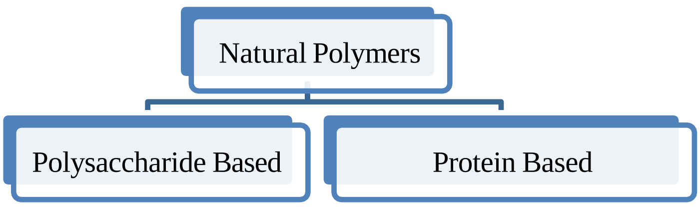
The factors that affecting the properties of a polymer are discussed below:

1. **Temperature** – Polymers are temperature sensitive, as the temperature increases, the kinetic energy of the molecules also increases but compressive strength and flexibility decreases with the increase in temperature.
2. **Chain Length** – Polymers strength increases with the increase of their chain length.
3. **Branching** – Polymers mechanical strength enhance as branching increases. High density polyethylene, for example, has a high degree of crystallinity but has poor mechanical properties. As a result, branching then cause stiffens, hardens, and reinforces of polymers.
4. **Cross-linking**: The extensively cross-linking forming a strong covalent bonds between the polymers chain which make their strength increases and thus raising the melting point[13].

2. CLASSIFICATION OF POLYMERS-

On the basis of origin polymers are categorized into two parts - Natural Polymers, Synthetic Polymers.

Natural Polymers- Animal and plant sources are used to make natural polymers. The development of advanced polymeric materials, such as nano composites, blends, and composites made from natural polymers is the current research priority[14].There is opportunity to investigate new polymers for targeted drug delivery and sustained drug release[15]. As a result, polymer selection is important in drug manufacturing. However, while choosing polymers, it is important to consider their toxicity and drug compatibility. Synthetic polymers can be replaced by natural polymers and many of the synthetic polymers' side effects can be avoided by using natural polymers[16].



Synthetic Polymer- Synthetic polymers are man made polymers. Polyethylene is one of the most basic

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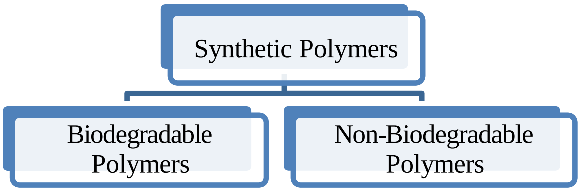
polymers with ethene or ethylene as the monomer unit and the linear polymer is referred as high- density polyethylene- Most synthetic polymers are organic in nature with carbon-carbon backbones. Poly(vinyl acetate), poly(propylene glycol), poly(dimethylsiloxane), poly(oxalate), poly(acrylic acid), polystyrene, and polyurethane are some examples of synthetic polymers used in pharmaceutical and biomedical applications[17].



3. DESIGN FOR SUSTAINABILITY

One viewpoint that aims to reduce adverse environmental effects is design for sustainability. The phrase "design for sustainability" describes the broad idea of sustainable and feasible expansion. Three pillars of sustainability have been proposed by lawmakers: social, environmental, and economic, or the 3Ps: people, planet, and profits. Designing for sustainability entails developing ideas and arrangements for materials, parts, and technology to produce better goods. The standard design specifications for these products must also be met, including good performance, appealing appearance, safety, affordability, ease of production, and consumer acceptance[18].

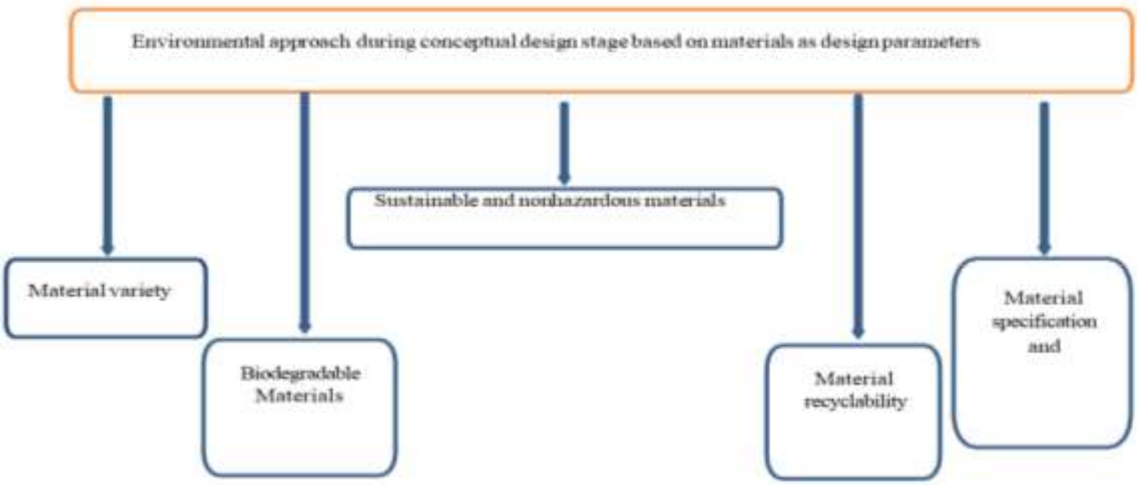
3.1 Conceptual design for environmental sustainability:

Conceptual design is defined by Phal in (2007) as:

This phase of the design process involves identifying the key issues through abstraction, creating function structures, looking for suitable working principles, and integrating them into a working structure in order to lay out the fundamental solution path through the explanation of a solution principle.

The main goal was to avoid dumping products into landfills by remanufacturing and recycling them.

❖ **Selected environmental strategies during conceptual design stage are:**



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3.2 Proposed Guidelines and strategies toward design for environmental sustainability:

3.2.1 Guidelines for design for the environment-

- Designs that use less materials and energy.
- Create a safe workplace.
- Biodegradable materials are used.
- Create a recyclable design.
- Plan for waste recovery and reuse in manufacturing.

3.2.2 Guidelines for the selection of biocompatible and renewable materials-

- The use of renewable and biodegradable materials.
- Avoiding prolonged materials.
- Making use of remaining materials from production.
- Making use of restored element from discarded products.

Guidice et al. highlighted the importance of considering environmental aspects during the conceptual design stage, and engineers should integrate environmental considerations throughout the design process[19].Policy creation, innovation, and product enhancement are the three stages and processes involved in new product design[20].

4. SYNTHESIS OF SYNTHETIC AND NATURAL POLYMERS

4.1 Synthetic Polymer - There are various type of Synthetic polymers

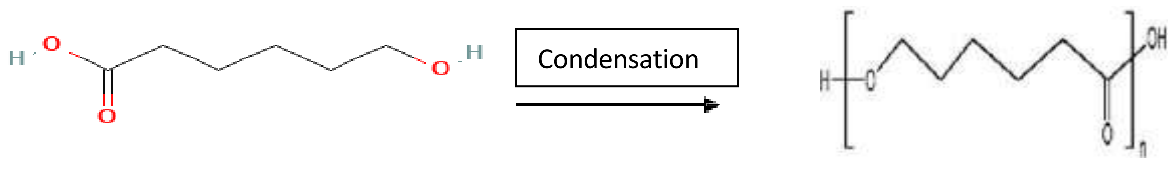
- Poly(ε-caprolactone)
- Polyethylene (PE)
- Polypropylene (PP)
- Polystyrene (PS)
- Polyvinyl chloride (PVC)
- Polyethylene terephthalate (PET)

One of the clearest and specific examples is synthetic polymers, which have only been widely synthesized since the 1950s. Although synthetic polymers have many advantages, their durability has resulted in a global plastic pollution problem that now poses one of the most pervasive and extensive threats to our planet's health and future[21].

4.1.1 Synthesis of poly(ε-caprolactone)-

In early 1930s, Carothers group synthesized the first polymer known as Poly(caprolactone) (PCL) but it was immediately replaced by faster improved polymers[22]. Biodegradable polymers are gaining popularity as people become more concerned about environmental protection. Poly(caprolactone) is one of the most desirable and broadly utilized polymer because of its biomedical therapy, biodegradability, good solubility with other polymers, and cryogenic adhesiveness. It also utilized in packaging of food , drug administration, and tissue engineering[23]. PCL is a straight, aliphatic, semicrystalline, biodegradable, thermoplastic polyester made up of hexanoate repeating units that is produced by ring-opening polymerization (ROP) of -caprolactone (obtained from crude oil through chemical conversion)[24].

Condensation of 6-hydroxycaproic acid-



Uses of poly(ε-caprolactone)-

- PCL is a synthetic polyester polymer which undergoes extensive research for bone tissue engineering.
- Polycaprolactone (PCL) is a widely known hydrolytically degradable polymer produced by ring-opening polymerization of ε-caprolactone[25].
- They are able to generate novel polymers with incredible biomedical applications.
- As the demand for this polymer grows, the question of replacing its synthesis route with a more environmentally friendly and cost-effective approach arises[26].

4.2 Natural Polymer - There are various types of Natural Polymer

- Silk
- Chitosan
- Chitin
- Collagen

Plants, algae, and marine sea foods are valuable sources of natural polymers and are used to manufacture eco-friendly packaging. Prehistoric populations firstly used different natural materials, such as plant and animal parts, shells, ceramics, and others for their food packaging.

4.2.1 Synthesis of Natural Polymer-

A natural biopolymer based on polysaccharides, chitosan has been extensively researched in several scientific and engineering domains[27]. Chitosan was shown to be a moderate, direct solid catalyst that didn't require any post-modification in chemical synthesis[28]. The majority of research endeavours have been documented to create functional chitosan derivatives by chemical transformations. Particularly intriguing is chitosan's application in catalysis, a recent advancement in environmentally friendly and sustainable chemical processes that give preference to biological materials over feedstocks derived from petrochemicals[29].

Uses of Chitosan-

Advantages of using chitosan in different applications are as follows:

- It is cheap and environmentally friendly.
- It consists of advantageous property of hydrophilicity[30].
- Its properties can undergo modifications through chemical and physical processes.
- It is chemically stable, nontoxic, and biodegradable[31].
- It has a functional group that facilitates metal binding in it[32].

5. APPLICATION OF SUSTAINABLE POLYMER MATERIALS

Polymers have many applications as they are utilized in various fields those are as follows:

5.1 Use of Natural Water-Soluble Polymers

Natural polymer materials are less harmful and low priced. Out of them, dextran is a common organic macromolecule, has exquisite water solubility with the aid using a biocompatibility and biodegradability[33].Dextran parent drugs play a crucial role in development of medical utility of recent drugs[34].

5.2 Use of Synthetic Water-Soluble Polymers

The substances that dissolve, disperse in water through those system that alter the solution's physical characteristics through coagulation. The polymer Polyvinyl Pyrrolidone (PVP) is used as binder, enhance bioavailability, dispersible agent, toxicity minimize, stability, dehydrating agent, etc.[35].

5.3 Use of Polymer in agriculture

Polyethyleneimine (PEI), is an extraordinarily branched aliphatic polyamine, become the spine polymer for the research for lead extraction from soil. PEI is effectively functionalized with chloroacetic acid to provide amino carboxylate groups which might be recognized to chelate lead impressively[36].

5.4 Use of synthetic polymers in clinical medicine

Recently founded polymers, such polyesters and polyamides are used as artificial stitchmaterials[37].In general surgery, polymers are used for staples and stitch materials. The primary criteria for selecting stitch materials are tensile strength, friction/tissue trauma, degradability, and knot stability[38].In addition to biocompatibility, dental polymers must also fulfill demanding standards for attractiveness, toughness, and polymerization mode[39].

5.5 Use of polymer in construction and building materials

PEG (Poly (ethylene glycol)) was chosen as the polymer composite material since it is environmentally friendly and heat resistance. It's having ability to replace the moisture inside the wood on light heat and maintain long-term stability of both the substance[40].

5.6 Use of polymer in industries

In regards of polymeric components, gums represent a significant number that dissolve easily in water and generates a high thickness. They are extensively used for producing gels and binders within food, medicinal, and food sectors. Arabic gum is a unique combination of polysaccharides and glycoproteins that is mostly utilized as a preservative in the food industry[41].The compounds known as resins are highly absorbent and typically have a strong smell, which makes them suitable for utilization in the cosmetics industry[42].

5.7 Use of biodegradable polymers

The biodegradable polymers is expanding usage and their annual global market worth is in the millions of dollars. There are several uses for biodegradable polymers, such as in food packaging, computer monitors, automotive interior parts, and clinical uses such as implanted big devices, pharmaceutical treatment[43].

5.8 Use of nanoparticles in water purification

The best kind of tool are polymer nanocomposites (PNCs), which seem to be new materials with distinctive chemical and physical features as a result of nanomaterials distributing in a polymer chain[44].Because they have customizable porosity architectures, high mechanical qualities, and chemically constrained functional groups, polymers make unique substrates for nanomaterials. PNCs are looking for substances with strong treatment of water and sewage capabilities[45].

5.9 Use of polymers in automobile industry

The following are some of the elements in the automotive industry:

1. **Breaking system:** The braking systems of automotive parts can reach temperatures up to 1,000 degrees Celsius, making the use of monolithic metal in their construction ineffective because it cannot withstand such high temperatures. Therefore, when making these braking materials for large trucks, and crane hydraulic actuators, carbon composite bonded silicon carbide (C-Si) became the preferred material.

2. **Door panels:** Natural fiber are typically added to the composite materials for the component's manufacturing in order to enhance the diameter of the polyurethane compound structures. This enhancement further raises the car door frames for coefficient of sound absorption.

3. **Automobile body parts:** Many automobile service parts, including motor shields, panels, and storage vessels, are manufactured with stronger natural fibers like flax, hemp, jute, sisal, and ramie. According to the testing results, the material's durability and power have increased while its mass has been significantly reduced.

5.10 Use of polymer in aerospace industry

a. **Signal transmission**

b. **Aircraft parts:** 12%-14% weight of aircraft wings is reduced only by fabrication.

c. **Safety:** The usage of composite materials containing zirconia fiber increase the security of aircraft by functioning as thermal protection. These materials also have important manufacturing properties which make them extremely resistant to extreme temperature[46].

6. ADVANTAGES AND DISADVANTAGES OF SUSTAINABLE POLYMERS

- **Advantages**

i. Polymer modified mortar is very useful for repairing because it has good binding properties[47].

ii. Biofuel production gives new income source on farmers to improve the economic conditions as it gives a chance to open new market and helps to expand the agricultural products[48].

iii. Due to production of high purity nanoparticles, it is used in large scale as it has higher-level physical properties like it increases the solubility of the drug components that are poorly soluble in water in a commercial method.

iv. It offers upward thrust to a few advanced properties to the additives impart on their grain length and fabric composition[49].

- **Disadvantage**

i. It is high cost of agricultural development as compared to traditional crops[50].

ii. The first-generation biofuels are very costlier than gasoline.

iii. There Due to high cost and lack of knowledge about biopolymers the demand of bioplastic products is low.

iv. Yield production is very low.

v. The final product has higher price than the existing product because the production cost of the final product is high[51].

CONCLUSION

Macromolecules known as polymers that produced by the covalent bonding of monomer units. Practically every part of life uses polymers, including manufacturing plastics, industrial applications, dental, medical, and fashion. Depending on its chemical and physical characteristics, polymers are utilized in various range of sectors. In order to enhance and stimulate plant development, polymeric materials are employed in the soil. The combination of therapy and diagnostics, using cancer as an example, has been one of the main areas of focus in the development of nanomedicine in recent years. To provide an intrusive treatment strategy for allergic diseases, the potential for textile- based systemic drug delivery devices based on thermo-responsive natural polymers is highlighted.

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