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ENGINEERING CHEMISTRY, 24ECHB102 - UNIT 2 - CHAPTER 5: POLYMER CHEMISTRY

Introduction

Prior to the early 1920's, chemists doubted the existence of molecules having molecular weights greater than a few thousand. This limiting view was challenged by Hermann Staudinger, a German chemist with experience in studying natural compounds such as rubber and cellulose.

Staudinger proposed that they were made up of **macromolecules** composed of 10,000 or more atoms. He formulated a polymeric structure for rubber, based on a repeating isoprene unit (referred to as a monomer). For his contributions to chemistry, Staudinger received the 1953 Nobel Prize. The terms **polymer** and **monomer** were derived from the Greek roots poly (many), mono (one) and meros (part).

Polymers are macromolecules built by the linking together of a large number of small molecules called 'monomers' which play a vital role in our every-day life providing basic needs of our lives viz. food, shelter and clothing. In contrast to the prevailing rationalization of these substances as aggregates of small molecules.

The synthetic development in the polymer science and technology led to the production of plastics, fibres, elastomers, biopolymers, resins which possess the properties from soft silk to strong steel and are very light, chemically inert, long life use and economically cheap which have made them indispensable materials in Engineering and Technology.

Basic Definitions

- **Polymer:**

A polymer is defined as a large molecule formed when a large number of small repeating molecules unite together. These small repeating molecules are linked by covalent bonds.

Example: PE, PP, PVC, Teflon, etc.

Normally molecular mass of polymers ranges from 10,000 to 1, 00,000. The properties of polymers are entirely different from those of monomers.

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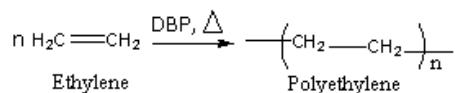
- **Monomer:**

Monomer is defined as a simple molecule having two or more bonding sites through which each can link to the other monomers to form a polymer chain. Monomers are called as building blocks of a polymer.

Example: Alkenes, vinyl chloride, adipic acid, glycol, etc.

- **Polymerization:**

The chemical process through which a large number of small molecules (monomers) are converted into a huge molecule (polymers) is called as polymerization.



For the process of polymerization, a monomer should have at least two bonding sites. That is a double bond. Monomer alone cannot undergo polymerization but requires the presence of a chemical called initiator like hydrogen peroxide.

- **Functionality:**

The number of bonding sites (or) reactive sites (or) functional groups present in the monomer molecule and involved in polymerization process is called its functionality.

Monomers may be bi-functional, tri-functional or poly-functional. For simple polymerization process, a monomer should possess at least bi-functionality.

Sl. No.	Monomers	Functionality	Functional Group
1	Ethylene glycol	2	2
2	Glycerol	2	3
3	Ethylene	2	Nil

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PROPERTIES OF A POLYMER

The properties of a polymers are affected by the structure, type of monomer units from which the polymers are formed and from other factors.

- Polymers are light in weight and are chemically stable.
- Polymers can be easily moulded into different shapes and sizes.
- Polymers have high melting point and boiling point due to its greater intermolecular forces and longer chain length.
- Polymers with weak intermolecular bonds stretch to a greater extent and are more elastic.
- The tensile strength of a polymer increases with increase in chain length and cross-linking.
- The crystallinity of the polymer increases its strength.
- Polymers have good transparency, insulation and impact resistance.
- They resist corrosion and are resistant to many chemicals.
- Polymers have low thermal conductivity and do not rust.
- Due to the ability to change the refractive index with temperature, polymers are used in lasers for spectroscopic applications and in analytical applications.
- Low density polymers are less permeable to air and hence are used to pack food items. Example: LDPE
- Adhesive property of a polymers are used extensively in the woodworking and packaging industries.
- Nowadays, conducting polymers are used in semiconductor devices. Their conductivity arises due to conjugated carbon-carbon double bonds.
- Polymers can degrade by the action of decomposers. Natural polymers like rubber are biodegradable while synthetic polymers are non-biodegradable.
- Processing cost of Polymers is low.

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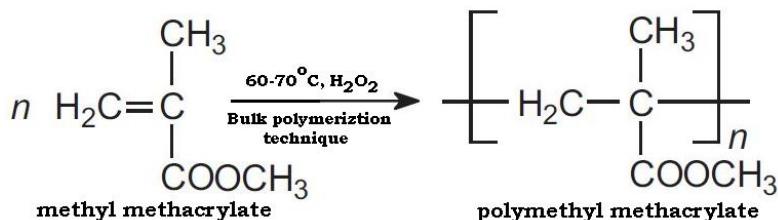
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COMMERCIAL POLYMERS

1. Plexi glass (or) Lucite (or) polymethyl methacrylate (or) PMMA:

Polymethyl methacrylate is an addition polymer formed from the monomer methyl methacrylate. Methyl methacrylate is heated to 60-70°C in presence of hydrogen peroxide initiator. Under these conditions, through bulk polymerization technique, methyl methacrylate (MMA) undergoes addition polymerization and forms poly methyl methacrylate (PMMA). It is commercially known as Plexi glass.

Synthesis:



Properties:

- Plexi glass is a highly transparent thermoplastic.
- Plexi glass softens at 120°C and it can be easily molded.
- It is resistant to the action of organic solvents.
- It allows UV rays to pass through it.
- It has excellent optical clarity.

Applications:

- Plexi glass is used as a substitute for glass in making unbreakable windows, lenses in cameras, safety glasses, etc.
- It is used as glazing material in automobile.
- It is used in the manufacture of chemical equipments, sign boards, domestic appliances, light fittings, street lamp fittings, etc.
- It can be obtained in the form of beads hence it is used in Jewelers
- It is used as transparent guard for machinery lacquers and decorative paints.
- Plexi glass is used for making aircraft windows, artificial eye lenses and dentures.

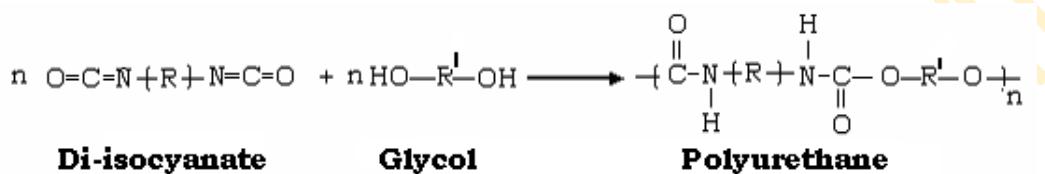
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2. Polyurethanes:

Polyurethanes have the characteristic urethane, $-\text{NHC}(\text{O})\text{COO}-$ linkage in their repeat units and are produced by the addition polymerization of diisocyanate with glycol (diol or triol) through intra-molecular rearrangement without the elimination of by-products.

Synthesis:



Properties:

- Polyurethanes can be obtained in the form of elastomers, fibers, coatings or as foams.
- Polyurethanes are resistant to oil, grease and corrosive chemicals.
- They are highly stretchable.
- They have high abrasion resistance.
- Polyurethane foams are available in both rigid and flexible forms.

Applications:

- Polyurethanes are used for making tyre treads and industrial wheels.
- Perol - U is a typical polyurethane fiber used in lightweight garments and swim suits.
- They are used to coat gymnasium floor and dance floor.
- Flexible foams of polyurethanes are widely used as cushions for furniture and automobiles.
- Rigid foams of polyurethanes are used to reinforce hollow structural units.

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CONDUCTING POLYMERS

Until 1960, all organic polymers were regarded as insulators. Polymers which can conduct electricity were discovered accidentally at plastic research laboratory of BASA.

It was found that polyphenylene and polythiophene exhibited electrical conductivities up to 10 S/m. This gave impetus for the discovery of other conducting polymers. Heiger Mac Diarmid (USA) & Shirakawa (Japan) were awarded Noble Prize in Chemistry for the development of electrically conducting polymers such as polyacetylene which conducts almost like a metal.

Definition:

“An organic polymer with highly delocalized pi electron system having electrical conductance of the order of a conductor” is called a conducting polymer.

Normally electrons in a polymer are localized and don't take part in the conductivity; but doping can delocalize the electrons responsible for conduction.

Conducting polymers are generally obtained by doping an oxidizing agent (p-type) or a reducing agent (n-type) into organic polymers with conjugated backbone consisting of alternate double and single c-c bonds.

Advantages of conducting polymers:

- Conducting polymers are light in weight, flexible and easy to process.
- Fabrication of conducting polymers is easy and requires low cost.
- They have excellent mechanical properties.
- They have good stability.

Applications:

Conducting Polymers are used:

- In telecommunication systems.
- As conductive tracks on printed circuit boards.
- For wiring in aircrafts and aerospace components.

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- In solar cells, drug delivery system for human body, etc.
- As sensors for humidity sensor, gas sensor, biosensor for glucose, galactose, etc.
- As an electrode material for commercial rechargeable light weight batteries.

Example: perchlorate doped polyacetylene lithium system. These are about 10 times lighter than conventional lead storage batteries. Such batteries are sufficiently flexible to fit a variety of designed configuration.

- In optical display devices.

Example: polythiophene. When the structure is electrically biased (1 to 3V), the optical density of the film changes, that is its colour changes. Such electro chromic systems produce colored displays with faster switching time and better viewing than conventional liquid crystal display devices (LED).

- In electro chromic display windows and in information storage devices.
- In electromagnetic screening materials and in non-linear optical materials.
- In electronic devices such as light emitting diodes and transistors.
- In antistatic coatings for clothing.
- As film membranes for gas separations.
- In fuel cells as the electro catalytic materials.
- In photo voltaic devices. Example: Al/polymer/Au photovoltaic cells.
- In molecular wires and in molecular switches.

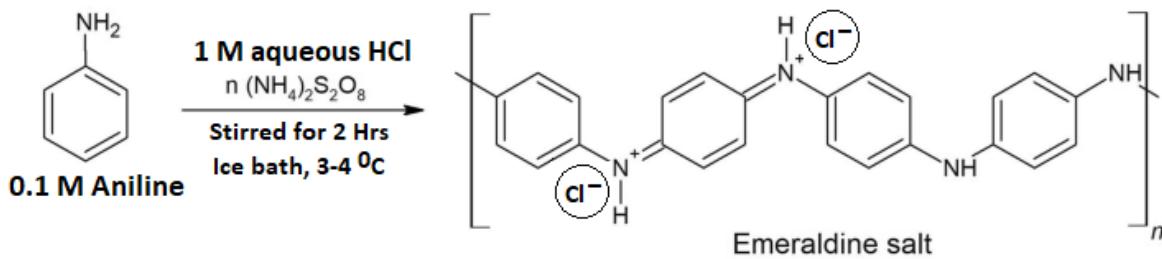
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Polyaniline

- It is a typical phenylene based polymer with a flexible –NH group.
- The polymer chain is flanked either side by a phenylene ring.
- It is considered as one of the most useful conducting polymers because of its ease of preparation, its stability and the facility to fine-tune electrical, optical and chemical properties through substituent effects.
- It shows a conductivity of greater than $10^5 \text{ s}^{-1}\text{m}^{-1}$.

Synthesis of conducting polyaniline:



Electrically conducting polyaniline – Green form

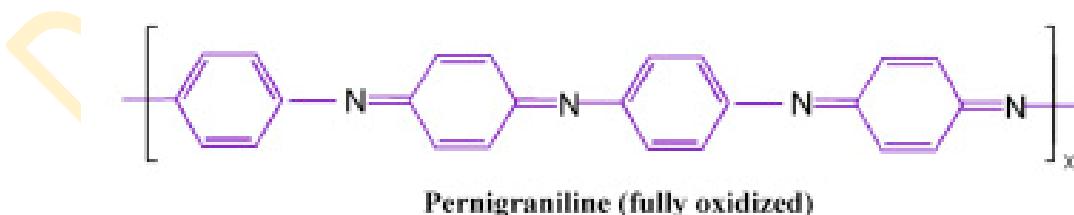
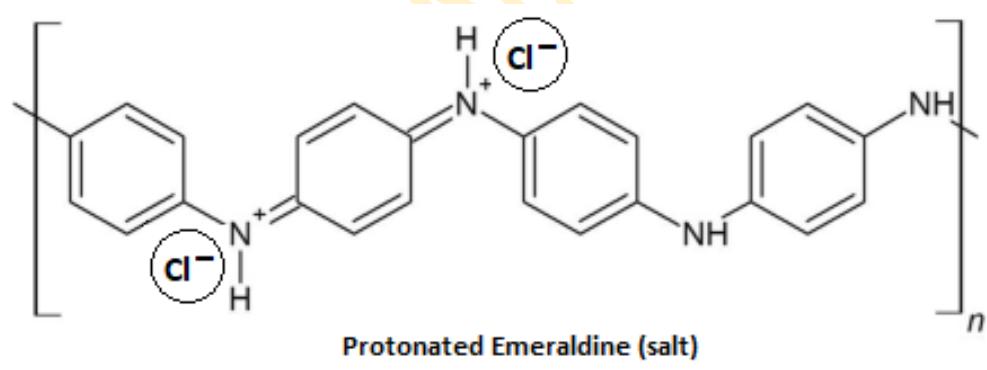
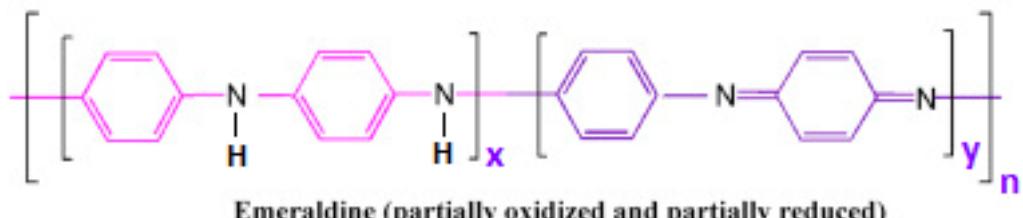
- It is prepared by dissolving 0.1M aniline in 1M aqueous solution of HCl (protic acid) and an aqueous solution of 0.1M ammonium peroxy disulphate, $(\text{NH}_4)_2\text{S}_2\text{O}_8$, an oxidizing dopant.
- The mixture is stirred slowly and continuously for 2 hours.
- The mixture is kept in ice-bath to maintain the polymerization temperature, $3-4^\circ\text{C}$, as the reaction is exothermic.
- The product polyaniline precipitates as in green-form.
- The precipitate is filtered repeatedly and washed well with distilled water and air dried.

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Mechanism of conduction in doped polyaniline

Structures of polyaniline on protonation and oxidation:



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Applications of conducting polyaniline:

- Used as a resist for Lithography.
- Used to control electromagnetic radiation.
- Used as an electrochemical transducer for biosensors.
- Used as an electrode material for rechargeable batteries.
- Polyaniline shows variation in color as a result of its protonation and oxidation forms.
- Its electromagnetic properties can be used to produce smart windows that absorb sun light and control solar energy.

BIODEGRADABLE POLYMERS

Meaning of biodegradable polymers:

Biodegradable polymers offer an alternative to conventional plastics, reducing plastic pollution and landfill waste. Biodegradable polymers offer a promising solution to plastic pollution, but research and development are needed to overcome challenges and maximize their potential for a sustainable future.

Biodegradable polymers are materials that can be broken down by microorganisms into natural substances like water, CO₂, and compost under specific conditions.

Biodegradable polymers may be made from bio-sources like corn, wood cellulose etc. or can also be synthesized by bacteria from small molecules like butyric acid or valeric acid that give polyhydroxybutyrate (PHB) and polyhydroxyvalerate (PHV).

Biodegradable polymers are most effective when managed properly in designated composting facilities. Choosing the right biodegradable polymer for the intended application is crucial for effectiveness and responsible use.

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Sources of biodegradable polymers:

✚ Renewable resources:

Plant-based sources like starch (PLA), cellulose (bio-PEF), and wood (PHA).

✚ Microbial sources:

Polyhydroxyalkanoates (PHAs) produced by bacteria.

✚ Chemically modified natural polymers:

Cellulose acetate, starch acetate.

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Properties of biodegradable polymers:

Biodegradability:

Ability to break down by microorganisms varies based on polymer type and environmental conditions.

Mechanical properties:

Strength, stiffness and flexibility of biodegradable polymers varies based on the polymer and processing conditions.

Generally lower than conventional plastics.

Thermal stability:

It varies based on the type of biodegradable polymers and may limit high-temperature applications.

Barrier properties:

This may not always match those of conventional plastics, affecting applications like food packaging.

Biocompatibility:

Some biodegradable polymers are suitable for medical implants and drug delivery due to their non-toxic nature.

Applications of biodegradable polymers:

Packaging:

Food containers, agricultural films and disposable tableware.

Medical devices:

Sutures, implants and drug delivery systems.

Agriculture:

Mulch films and seed coatings.

Textiles:

Clothing and non-woven fabrics.

Composting bags and dust bins:

Designed to break down with organic waste.

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NATURAL FIBRES

Natural fibre is characterized by its adaptability, fineness and good aspect ratio. Agro-waste fibres can be referred to as lignocellulosic and they possess appropriate superior properties suitable to be used as fibre reinforcement for polymer composites.

Advantages of Natural Fibres as Reinforcement for Polymer Composites

- Scientific information of structure and properties of natural fibres are promptly accessible.
- The specific gravities of natural fibres are 1.25-1.50 g/cc which is lower than that of glass. This low specific gravity of natural fibre gives higher strength-to-weight ratio for reinforcing plastics.
- Natural fibres can be used to reinforce biodegradable polymers since these natural fibres themselves are biodegradable.
- Natural fibres are lighter than inorganic reinforcements and can lead to advantages such as fuel savings when their composites are used in transportation applications.
- Producible with low investment at low cost and hence makes the material an interesting product for low-wage countries.
- Natural fibres have good thermal and acoustic insulating properties.
- Thermal recycling of these natural fibre reinforcements is possible but glass causes problems in combustion furnaces.
- Natural fibres are nontoxic, eco-friendly, biodegradable and sustainable and hence they made the final product light weight and further they provide waste management solutions.

Hence, natural fibres are gaining progressive importance as renewable, light weight, strong, environmentally acceptable and biodegradable reinforcement material for composite preparation.

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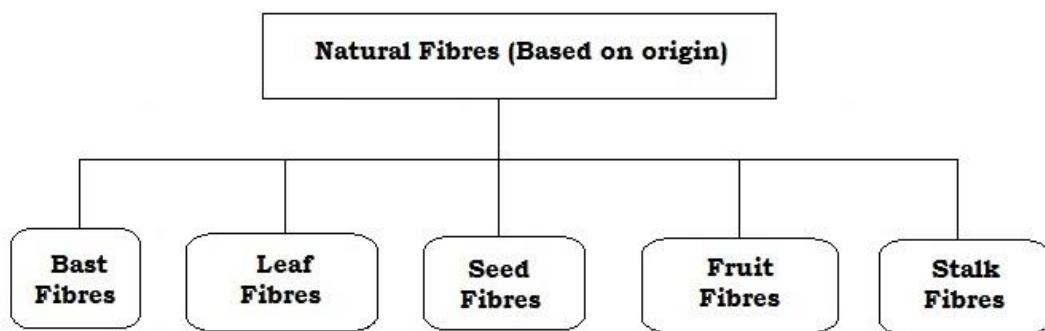
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Disadvantages of Natural Fibres as Reinforcement for Polymer Composites

- Quality of natural fibres cannot be maintained equally and it depends on unpredictable influences such as weather.
- Moisture absorption property of natural fibre causes swelling of fibres.
- Restricted maximum processing temperature for fabrication of natural fibre reinforced polymer composites.
- They have lower durability and natural fibre treatments can improve this considerably.
- Natural fibres have poor fire resistance.
- Cost of natural fibres can change by crop results.

Classification of Natural Fibres

The classification of natural fibres is shown below. They are bast, leaf, seed, fruit and stalk fibres.



Classification of natural fibres

The bast fibres consist of a wood center encompassed by a stem. Inside of the stem there are various fibre packages, each containing individual fibre cells. Hemp, jute and ramie are some examples for bast strands.

By nature, the leaf strands are coarser than the bast filaments. Sisal, manila, curaua, palm and banana are examples for leaf fibres.

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Cotton and kapok are examples of seed fibres. Cotton is the most widely recognized seed fibre.

Areca and coir are fruit fibres of areca fruit husk and coconut shell respectively. These fibres are thick and coarse however strong fibre.

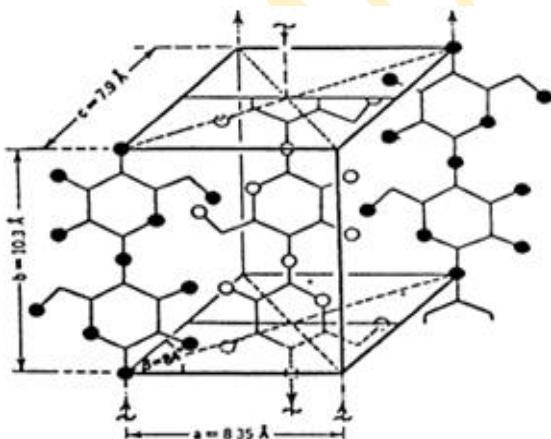
Bamboo, wheat, rice, grass and barley are examples for stalk fibres.

Chemical Composition of Natural Fibres

Cellulose, hemicelluloses, lignin, pectin and waxes are the fundamental significant principle components present in any natural filaments.

The major constituent present in natural fibres is cellulose and it is a linear polymer and it consists of D-anhydro glucose ($C_6H_{10}O_5$) repeating units with three hydroxyl groups per unit and is attached through 1, 4- β -D-glycosidic linkages at C₁ and C₄ position.

Cellulose is crystalline and following figure shows the crystal structure of cellulose.



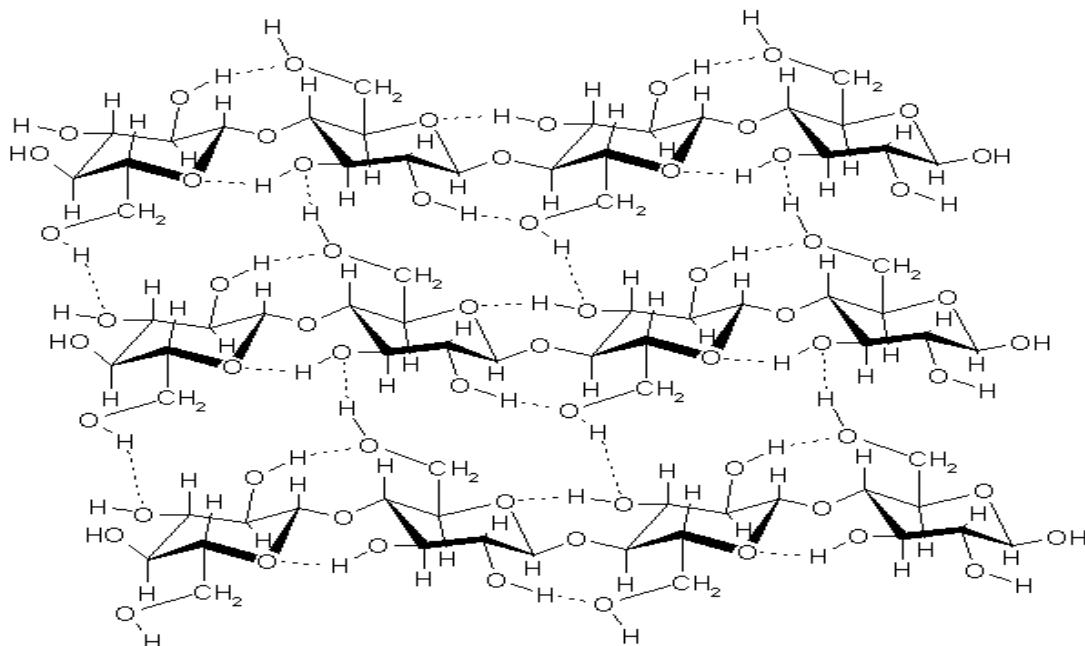
Crystal structure of cellulose

Cellulose plays a key role in providing strength, stiffness and structural stability. So, if higher is the cellulose content higher will be the fibre strength. Cellulose is having good resistance for oxidizing reagents and alkali but hydrolyzed by acid to form sugars which are water soluble.

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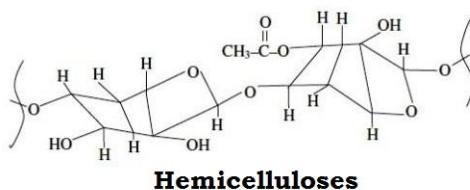
The molecular structure of cellulose is given below:



Molecular structure of cellulose

The molecular structure of cellulose is similar for different plant based natural fibres but the degree of polymerization and cell geometry is different and due to this, different properties are observed for different fibres.

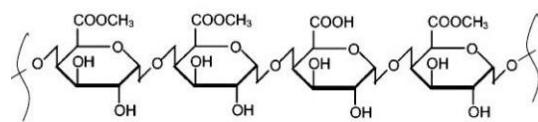
Chemical structures of hemicelluloses, lignin and pectin are shown below.



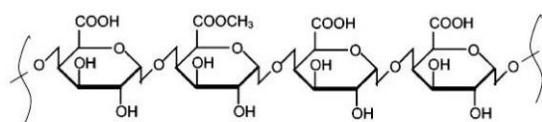
Hemicelluloses



Lignin



High methoxyl pectin



Low methoxyl pectin

Chemical structures of hemicelluloses, lignin and pectin

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Hemicelluloses are amorphous, branched polymers whose molecular weight is less than that of cellulose. Hemicelluloses consist of bunch of polysaccharides comprising a mixture of sugar units with 5-carbon and 6-carbon rings. Hemicelluloses show dissimilarity with cellulose molecules in 3 different ways.

First of all, hemicelluloses contain various dissimilar sugar units but cellulose consists of 1,4- β -D-glucopyranose units. Next, they are amorphous in nature due to the significant presence of branched polymers with pendant side groups while cellulose is linear in nature. At last, degree of polymerization value of hemicelluloses which is around 50-300 is 10-100 times lower than that of cellulose.

Hemicelluloses form a protective matrix for cellulose micro fibrils. Hemicelluloses enlarge in water, soluble in base and effortlessly hydrolyzed by acids.

Lignin is amorphous, complex polymer. It has both aliphatic and aromatic constituents. By nature, lignin is hydrophobic. It gives rigidity to the plants. Lignin contains five -OH groups and five -OCH₃ groups per building unit. Furthermore, it contains carbonyl groups.

Lignin can't be separated to monomeric units. They are absolutely insoluble in many solvents. Lignin readily dissolves in warm bases and can undergo oxidation easily. It is condensable with phenol but it will not undergo hydrolysis by acids.

Pectin is a complex hetero polysaccharide. The branches present in the pectin are cross linked with arabinose sugars and calcium ions. The flexibility to the plants is given by pectin.

The last part of the fibres is made by waxes and they comprise alcohols of various types.

The physical properties and chemical composition of natural fibres are the most imperative variables that focus the general properties of natural fibres.

Moisture Absorption Characteristics of Natural Fibres

In general, natural lignocellulosic fibres are hygroscopic and they ingest or discharge dampness relying upon the ecological conditions. The significant restrictions of utilizing natural lignocellulosic fibres as a part of sturdy polymer composite uses are their extreme dampness ingestion and weak dimensional strength (swelling). Bulging of natural fibres can prompt micro-cracking of composites and deprivation of composite properties.

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The hygroscopic nature of natural fibres can be reduced by surface modification of natural fibres which involves the replacement of few of the cell wall -OH groups with chemical moieties. So, chemical treatments of natural fibres are very vital in polymer composite fabrication.

Thermal Stability of Natural Fibres

Most of the natural filaments having cellulose and lignin constituents possess low degradation temperatures (around 200 °C) and make them inadequate for processing temperatures above 200 °C. Thermal properties of natural fibre filaments can be improved by chemical modification.

Natural Fibre – Polymer Matrix Interface

The quality and strength of natural fibre fortified polymer composite materials are controlled by the interface between the polymer matrix and the fortifying natural fibres. The interface impacts are observed as a kind of bonding and are frequently interpreted with reference to surface structure of the reinforced materials.

The imperative surface components are wettability, presence of polar groups and roughness of the material to be bonded. Interface cracks initiates composite damage and hence change the composite properties.

Hence, the bond potency among the reinforcing natural fibres and the surrounding polymeric resin is of crucial important for many polymer composite properties.

So, in order to improve the fibre-matrix interfacial bonding, chemical modifications of natural fibres are necessary to make the fibre surface clean and physically rough.

Chemical Treatment of Natural Fibres

The presence of hydroxyl groups in the constituents of natural fibres make them easy to take part in the chemical treatments. Due to the presence of hydrogen bonding, the reactivity of natural fibres towards the polymeric resin is decreased.

Surface modifications of natural fibres may stimulate these hydroxyl groups or add new chemical groups that can efficiently improve the interfacial bonding of fibres with the polymeric resin. Chemical modification improves surface properties for example, wetting, attachment and surface strain or porosity of natural strands. Chemical treatments reduce fiber's length dispersion and increase its aspect ratio.

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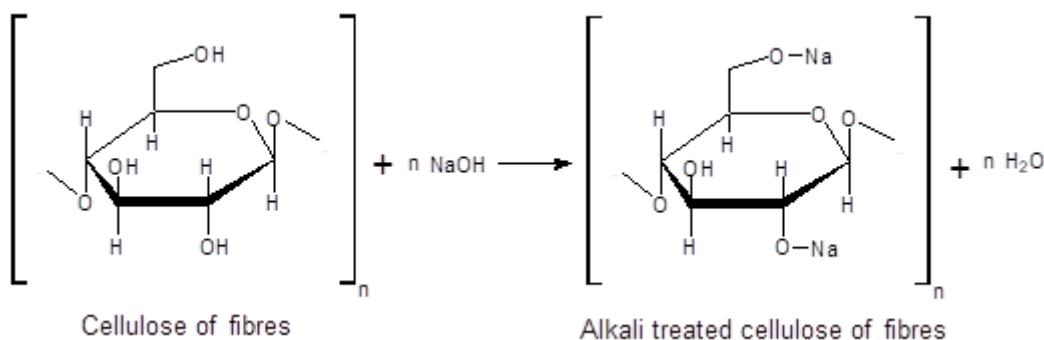
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Surface Modification of Natural Fibres by Chemical Treatments

- Alkali Treatment of Natural Fibres

Natural fibres are soaked in NaOH solution at room temperature for a period of 1h. Then, the alkali treated fibres are immersed in distilled water for 24 h to remove any residual NaOH. Final washing is done with distilled water containing little amount of acetic acid.

Then, the alkali treated natural fibres are washed again in running water to remove the last traces of acid sticking on to it, so that the pH of the fibres is approximately 7. Then the alkali treated fibres are air dried.



Reaction between natural fibres and sodium hydroxide

The effect of alkali on cellulose fibre is a swelling reaction, during which the natural crystalline structure of cellulose relaxes and provides more access to the penetration of chemicals.

Alkali sensitive hydroxyl groups existing among the molecules are broken down and resulted in the formation of Fibre – cell – O – Na groups between the cellulose molecular chains.

The alkali treatment led to the increase in the amount of amorphous cellulose at the expense of crystalline cellulose.

The hydrogen bonding present in the network structure is removed and new reactive hydrogen bonds are formed between the cellulose molecular chains. Due to this, hydrophilic hydroxyl groups are reduced and moisture resistance property of natural fibres is increased.

Alkali treatment takes out certain portion of hemicelluloses, lignin, adhesive pectin, waxy epidermal tissues and oil covering materials.

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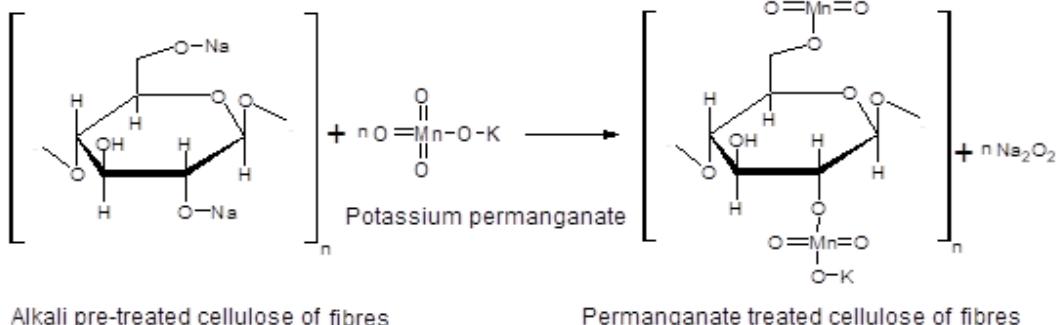
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As a result, fibre surface became clean and rough and there is a change in the surface topography of alkali treated fibres.

In addition to this, alkali treatment reduces the fibre diameter and thereby increases its aspect ratio which in-turn results in better fibre-polymer matrix interfacial adhesion.

• Potassium Permanganate Treatment of Natural Fibres

Natural fibres, pre-treated with alkali (NaOH) are immersed in KMnO_4 in acetone solution for 2 to 3 min. Potassium permanganate treated fibres are then washed well with distilled water and dried in air.



Reaction between natural fibres and KMnO₄

During alkali pre-treatment, certain amount of extractable materials such as lignin, waxes and oil covering materials are removed and more reactive groups are exposed on the fibre surface.

KMnO₄ reacts with alkali pre-treated cellulose of fibres in acetone solution and forms cellulose-manganate.

Permanganate ions also react with the lignin constituents and carve the fibre surface. As a result, fibre surface became physically rough.

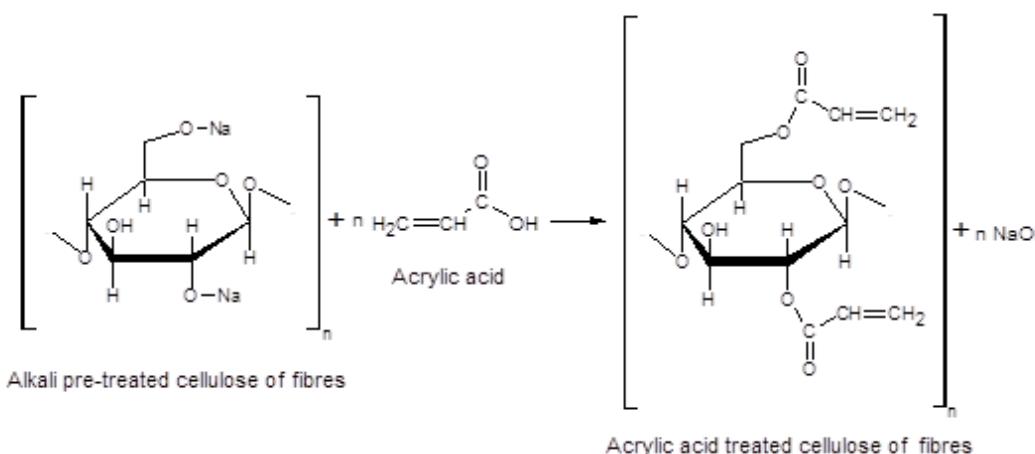
This reduces hydrophilic nature of fibres and improves chemical interlocking at the interface and provides better adhesion with the polymer matrix.

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- **Acrylic Acid Treatment of Natural Fibres**

The alkali (NaOH) pre-treated natural fibres are immersed in acrylic acid solution for a period of 1 h and then the treated fibres are washed thoroughly using distilled water and air dried.



Reaction between natural fibres and acrylic acid

Extractable materials such as lignin, waxes and oil covering materials are removed slightly and more reactive groups are exposed on the fibre surface when natural fibres are pre-treated with alkali.

Acrylic acid provides more access of reactive cellulose macro radicals to the polymerization medium by reacting with alkali treated cellulose of fibres.

An ester linkage is formed with the natural fibres by the carboxylic acids present in acrylic acid. It also removed certain amount of hemicelluloses and lignin and destroyed the cellulose structure.

Moisture absorption property of chemically treated fibres are reduced due to the introduction of hydrophobic ester groups and the effective fibre surface area available for good adherence with polymer matrix is increased.

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POLYMER COMPOSITES

The growth in scientific and technological fields demands the materials of modified properties like low density, high strength and stiffness, abrasion and impact resistance and corrosion resistance.

No single metal, alloy, ceramic or the polymeric material can alter the combination of these properties. The search for such materials by the modern technology has led to the development of composite materials.

Polymer composite is any material made of by more than one component. Polymer composites are composites made from polymers or from polymers along with other kinds of materials.

Bispolymeric composites such as feathers and wood have been available for thousands of years and the fibre glass reinforced polyester was the earliest man-made polymer composite.

Polymer composites were first developed for military and aerospace applications during 1940. Since then, considerable advancements have been for the use of these materials in the construction sector by civil and mechanical engineers for bridge repair, moving cables, structural strengthening and in related engineering applications.

Definition:

Polymer composites are defined as a **physical mixture of two or more structurally dissimilar materials acting in harmony suitable for structural applications**.

The need to develop composite materials is due to their mechanical properties which are superior to their parent constituents.

The unique properties of polymer composites:

- Polymer composites are light in weight.
- They have high strength to weight ratio.
- They are much stronger and durable than the conventional metals such as steel and Aluminium.
- They have high corrosion resistance.

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Applications of polymer composites:

Polymer composites find innumerable applications in:

- **Aerospace:** Antennas, Helicopter blades, landing gears, seat, floors, rocket motor cases.
- **Automobiles:** Shafts, gears and bearings.
- **Boats and ships:** Hulls, decks, engine shrouds.
- **Chemical Equipments:** Pipes, tanks, pressure vessels, hoppers, valves and pumps.
- **Domestic Appliances:** Interior and exterior panels, chairs and tables.
- **Electrical Equipments:** Panels, housings, switch gears and connections.
- **Others:** Protective helmets, fishing rods and diving boards.

Natural fiber reinforced polymer composites

Cellulose and its composites for sustainable environment:

Cellulose:

It is the most abundant organic biopolymer on Earth, derived from plants and essential for their structure.

It is a renewable, biodegradable, and non-toxic material, making it attractive for sustainable applications.

They composed of glucose units linked by strong β -1,4 glycosidic bonds, leading to a crystalline structure with high strength and stiffness.

Understanding the relationship between cellulose structure, processing methods, and composite properties is crucial for optimizing performance.

Cellulose Composites:

Combining cellulose with other materials like polymeric resins or nanoparticles expands its applications.

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Types of Cellulose Composites:

- **Natural fiber-reinforced composites:**

It utilizes natural fibers like sisal, hemp, areca or flax as reinforcement in a polymer matrix.

- **Nano-cellulose composites:**

It incorporates nano-cellulose (e.g., cellulose nano-fibers, nano-crystals) as reinforcement in a polymer matrix.

Advantages of Cellulose Composites:

- **Lightweight and strong:**

It offers good mechanical properties at lower weight than conventional materials.

- **Biodegradable and eco-friendly:**

It reduces reliance on petroleum-based materials and minimizes environmental impact.

- **Versatility:**

It can be tailored for diverse applications through material selection and processing techniques.

Applications of Cellulose Composites:

Natural fiber reinforced cellulose polymer composites finds applications in

- **Automotive parts:**

Lightweight car components, interior panels, bio-based composites for electric vehicles.

- **Construction:**

Sustainable building materials, bio-based insulation, flooring and furniture.

- **Packaging:**

Biodegradable alternatives to plastic packaging, food containers, and medical packaging.

- **Aerospace:**

Lightweight aircraft components such as antennas, helicopter blades, landing gears, rocket motor cases, etc.

- **Electronics:**

Bio-based substrates for printed electronics, flexible displays and sensors.

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Research and Development:

- Focuses on improving processing techniques, enhancing interfacial adhesion, and developing novel functionalities for specific applications.
- Exploring nano cellulose based composites for high-performance applications due to their unique properties.
- Life cycle assessment and economic feasibility studies are crucial for wider adoption of cellulose composites.

Challenges and Future Prospects:

- Limited solubility in most solvents hinders processing and modification.
- High crystallinity can make it brittle and susceptible to degradation.
- Hydrophilicity can lead to swelling and dimensional changes.
- Cost reduction and efficient production methods are key for economic competitiveness.
- Standardization and quality control are essential for widespread acceptance.
- Continued research and development efforts will unlock the full potential of cellulose and its composites for a sustainable future.