

## **Polymers (Extended Response)**

### **1) Explanation of the term “polymer”**

Polymers are adaptable types of materials sometimes referred to as plastics or resin. They can be moulded into various shapes and are relatively inert during normal use. Polymers consist of a large number of similar subunits bonded together, called monomers, and its repeating structure continues on throughout the entire polymer. This explains the etymology of the word - with “poly” meaning many and “mer” meaning parts. Monomers have to be organic compounds for this reaction to occur. Each polymer has many different properties based on the monomer unit used and which reaction it undergoes as well as the condition the reaction is taking place in. As such, polymers exist everywhere in our world. Two major types of polymers exist - they are classified based on the reaction used to form the polymer, which are addition and condensation reactions.

### **2) A comparison of ‘addition’ and ‘condensation’ polymerisation**

#### Addition polymerisation

This form of polymerisation begins with the addition of a free radical, the term given to the catalyst used in this reaction. Its name arises from the fact that it is an unstable molecule with a strong desire to bond, due to an unpaired electron that forms half of a covalent bond. It is added to the solution of monomers, which in the case of addition polymerisation consists of alkenes. The initiation stage then proceeds, where the free radical forms a bond with one monomer, which effectively breaks the double bond that was originally present in the monomer. This can only occur in alkenes, which are unsaturated monomers as they do not have the maximum number of atoms bonded to the carbon atoms and can therefore create more bonds between itself and free radicals.

In the second stage (propagation), the monomer with the attached free radical becomes a bigger free radical, which then proceeds to bond with another monomer. This allows the process to continue indefinitely, until all the monomers have been used up. However, since more than one molecule of free radical has been added to the solution, there will be multiple chains of these monomers existing at the same time.

In the final step (Termination), the long free radical chains bond with each other, once all the monomers in the solution have been used. As such, there will be no more free radicals remaining in the solution, and we can effectively term the end product a polymer. There is no by-product in this process.

#### Condensation polymerization:

Condensation polymers are formed by a similar process. Instead of the alkene monomers, they are formed by alternating repetitions of certain monomers, and no use of free radicals are required. Instead, the formation of the bonds will create byproducts of small molecules such as water and carbon dioxide. The monomers must have 2 reactive sites on the monomers in order to react and form polymers - their structures will be mentioned later. Usually, 1 functional group from 2 different monomers will react. For example, the -OH from a carboxylic acid functional group may interact with the -H from an alcohol or an amide group, and the removal of the by-product water will allow the two monomers to bond together, in an ester bond or a peptide (amide) bond. This process will repeat such that each monomer will bond to two other monomers by the process described above. For example, a

protein is formed by the joining of alpha amino acid monomers, since the functional groups can bond together and lose a water molecule.

### **3) Structure**

For addition polymerisation, the starting material must be the same - only one type of monomer should be in the solution when the free radical is added. The monomer must be unsaturated, to allow the free radicals to be able to bond with the monomers, and this is why alkenes is usually used for this type of reaction. Only the Carbon to carbon double bond is considered for this reaction, and the rest of the monomer, however long it is, will be considered to be a side chain, since it will not react during the polymerisation reaction.

In condensation polymerisation, different monomers can be used to achieve the same effect, and each monomer will have two functional groups on it so that there are 2 reaction sites. (e.g. diol, diamine and dioic acid groups). The functional groups will react and form either esters (CA and alcohol groups) or amide bonds (CA and amine groups). Ester types include nylon 6,6 while amide bonds has proteins.

### **4) Properties of polymers and the uses of these polymers**

Polymers usually have high melting points, as polymer molecules consists of many monomers and polymers tend to have relatively high molecular masses. Some polymers such as nylon and Teflon are suitable for producing strong threads called fibres that can be woven into fabrics. There are two categories of polymers, thermoplastics and thermosetting. Thermoplastics soften and melt when heated. These types of polymer are easily recycled as they can be melted and reshaped many times. Thermosetting, unlike thermoplastics, cannot be melted and reshaped. These polymers simply decompose to form their original monomers when heated to a certain extent.

Polymer molecules may consist of straight chains or atoms or they may have side chains. These side chains can sometimes join to other side chains, also known as cross linking. Cross linking is also the reason why some polymers are able to show elastic properties. The more cross linking a molecule have, the stiffer and less flexible the end product becomes. Therefore, in the manufacturing of polymers, they try to control all these aspects of a polymer, altering properties like stiffness, hardness, density and appearance.

Polymers can have various properties depending on its structure. For example, polymers with longer chains have stronger intermolecular forces of attraction from dispersion forces and its higher molecular size. As a result they are stronger and more rigid compared to softer short chain polymers. Polymers with side chains also tend to be weaker, more flexible, softer and have a relatively low melting point compared to polymers with straight chains. This is due to the side chains preventing molecules from packing efficiently thus reducing the strength of intermolecular forces and creating an amorphous (irregular arrangement of molecules).

Polyethene (polyethylene) is a thermoplastic with variable crystalline structures. Due to the different types of polyethylene, it has an large range of applications. There are three main forms of polyethylene. Low Density Polyethylene (LDPE), High Density Polyethylene (HDPE), and Ultrahigh Molecular Weight Polyethylene (UHMWPE). LDPE consists of side chains, which prevents molecules from packing efficiently thus reducing the strength of intermolecular forces and creating an irregular arrangement of molecules. LDPE has relatively low melting point, soft, flexible and is fairly weak compared to HDPE. HDPE consists of only straight chains, and has a linear shape. This allows the molecules to pack

more efficiently and increasing the intermolecular forces, which results in a stronger polymer, stiffer, more rigid and has a higher working temperature. UHMWPE has molecules averaging around ten times the length of those in HDPE. When UHMWPE aligns, the collective strength of dispersion forces between them becomes significant due to their very large molecular size, meaning its strength is extremely strong.

Due to its weaker intermolecular forces, and its flexibility, LDPE is commonly used to make thin flexible films for food wrapping and bagging, and it also can be moulded into soft flexible articles such as wire insulation and toys. HDPE is stronger, more rigid and has a higher working temperature, so it could be used for food containers, and its chemical resistance also helps to create objects such as piping, fuel tanks and kitchenware. UHMWPE, with its superior strength, can be used to create bulletproof vests or even the bearing material in hip and knee replacement joints.

Polytetrafluoroethylene (PTFE) consists of only carbon atoms and fluorine atoms bonded to the carbon atoms. PTFE consists of the high strength Carbon-Fluorine bond, which contributes to PTFE's greater resistance to chemical attack and its chemical stability, up to temperatures of 260°C. The strongly bonded fluorine atoms also resist bonding or reacting with other chemicals such as acids, water, oil, or food products. This gives PTFE a non-stick, low friction surface, resistant to chemical attack.

As such, PTFE finds itself extremely useful as non-stick coating on cookware, or as a solid lubricant since it creates a low-friction surface. It also finds usage in machinery since it resists corrosive substances and has low friction in moving parts. (someone explain breathable waterproof fabric pls)

Nylon is produced by condensation polymerisation. Nylons are known as polyamides because of the repeating amide linkages they contain. These are formed by the condensation polymerisation of a diamine and dicarboxylic acid. Polyamides are able to form hydrogen bonds between the lone pair of electrons on the oxygen atom from a carbonyl group, increasing the tensile strength and stiffness of nylon. The presence of hydrogen bonding between nylon's polyamide chains also enhances their strength, ability to stretch under tension, wear and abrasion resistance, durability, low coefficient of friction and good chemical resistance.

As such, nylon sees itself used in many places, such as fabric since it can stretch well and is durable. Its high strength and its high wear and abrasion resistance allows it to be useful in a solid form too, as skate wheels and bearings. A variation of nylon 6,6 where aromatic benzene rings replace two carbon chain sections exists, and it stiffens up the polymer chains and strengthens it. This new material is termed Kevlar, which can be woven into cables that are 5 times lighter but equally as strong as steel cables, due to its high strength. Its high strength also allows it to be used for sails and bulletproof vests.

Polyethylene terephthalate (PET) have a permanent net dipole around each of the ester groups. This means their molecules can attract and align by dipole-dipole forces as well as by dispersion forces. The exceptional toughness and strength of PET fibres result from its crystallinity, produced during extrusion of the melted polymer and then drawing (pulling or stretching) to its final shape. Polyester fibres made this way are exceptionally strong and resistant to creasing and wrinkling. Products made from PET are relatively stiff, strong, and dimensionally stable. Their good gas barrier properties and chemical resistance make them ideal for handling soft drinks, and the stiff and dimensionally strong bottle structure makes it an appealing choice. PET products are also easily recycled as the polymer can be remelted and regenerated as a fibre for future use.

## Reference

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