Review of Polymer Forms, Properties and Application in Medical Field

Nuha Salih Mustafa

College of Applied Medical Science-Department of Radiologic Science – Najran University – Najran - KSA

Abstract: ***Multiple biological, synthetic and hybrid polymers used for multiple medical applications. A wide range of different polymers is available, and they have further the advantage to be tunable in physical, chemical and biological properties in a wide range to match the requirements of specific applications. This review gives a brief overview about the introduction, polymer types, properties and developments of polymers in medicine in general, addressing first stable polymers, then polymers with degradability as a first biological function, followed by various other functional and responsive polymers. There is subsequently an overview of the most frequently used polymer classes. The main body of the review then structured according to the medical applications, where key requirements of the applications and the currently used polymer solutions they indicated.***

Keywords: Polymer, Properties, application in Medical Field,Review

1. Introduction

A polymer is a large molecule, or macromolecule, composed of many repeated subunits. Because of their broad range of properties, (Painter et al 1997) both synthetic and natural polymers play an essential and ubiquitous role in everyday life. 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 molecule compounds produces unique physical properties, including toughness, viscoelasticity, and a tendency to form glasses and semi crystalline structures rather than crystals (McCrum et al 1997)

The term was coined in 1833 by Jöns Jacob Berzelius, though with a definition distinct from the modern IUPAC definition (Jensen et al, 2008). The modern concept of polymers as covalently bonded macromolecular structures was proposed in 1920 by Hermann Staudinger, who spent the next decade finding experimental evidence for this hypothesis. (Allcock et al, 2003).

Polymers are studied in the fields of biophysics and macromolecular science, and polymer science which include polymer chemistry and polymer physics. Historically, products arising from the linkage of repeating units by covalent chemical bonds have been the primary focus of polymer science; emerging important areas of the science now focus on non-covalent links. Poly isoprene of latex rubber and the polystyrene of Styrofoam are examples of polymeric natural/biological and synthetic polymers, respectively. 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 e.g., isoprenylated lipid modified glycoproteins, where small lipidic molecule and oligosaccharide modifications occur on the polyamide backbone of the protein (Ten Feizi et al, 2004). The trend of the following review is to highlight the general polymer types, Properties and their application in medical field.

Polymer Composite:

Polymers are large molecules that are buildup of a number of repeating units called monomers. The name of the polymers is often based on their repeating units as example from the monomer styrene which is consists of 7 backbones of Carbone atoms, 3 hydrogen atoms as in Figure (1).

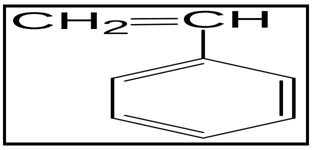

Figure 1: Shows the chemical structure of monomer styrene (M S) (Young, R. J. (1987), Clayden, J. et al 2000)

Polystyrene are made up from the repeating unit each one consists of 4 monomer styrene unit and the structural formula of polystyrene is usually written as shows in Figure (2) or (3).

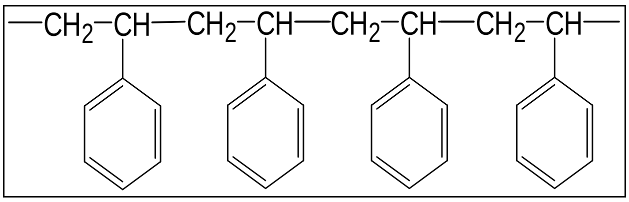

Figure 2: Shows the chemical structure of polystyrene (PS) (Clayden, J. et al 2000)

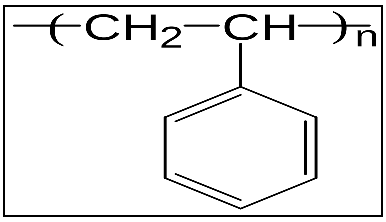

Figure 3: Shows the structural formula of polystyrene where n is the number of repeating units in the polymer (Clayden, J. et al 2000)

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The above polymers and many others are usually made by synthesis from their monomers. However, one can also make polymers from natural sources. These polymers are called biopolymers. Some examples of biopolymers are cellulose derivatives, gelatin, pectin, chitosan and alginate. These polymers often have a complex molecular structure as in Figure (4)

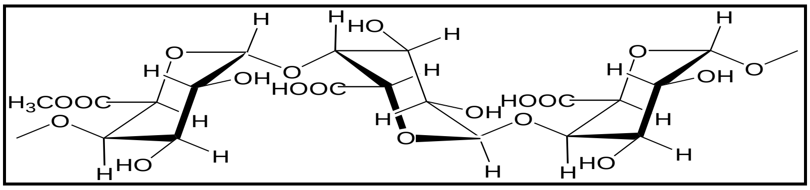

Figure 4: Shows chemical structure of biopolymers (Clayden, J. et al 2000)

Polymerization:

Polymerization is a process in which the unsaturated molecules of a low molecular unit known as monomer to form high molecular mass polymer or even with different monomers to produce crosslink polymer as show in Figure (7).

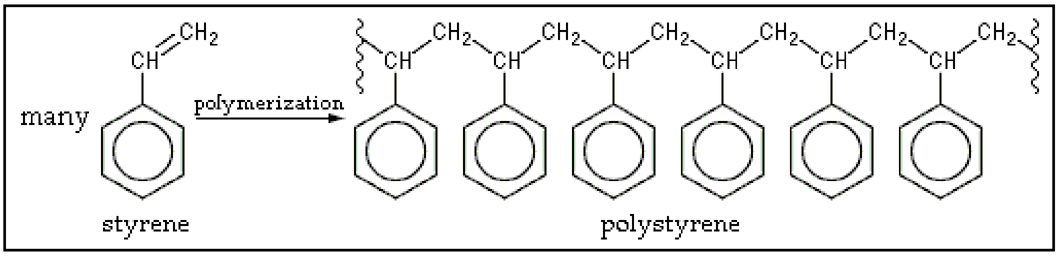

Figure 5: Show an example of alkene polymerization, in which each styrene monomer's double bond reforms as a single bond plus a bond to another styrene monomer. The product is polystyrene ((Baeurle, 2009).

Polymers properties:

Chemical properties:

The attractive forces between polymer chains play a large part in determining polymer's properties. Because polymer chains are so long, these inter chain forces are amplified far beyond the attractions between conventional molecules. Different side groups on the polymer can lend the polymer to (ionic bonding) or (hydrogen bonding) between its own chains. These stronger forces typically result in higher tensile strength and higher crystalline melting points.

The intermolecular forces in polymers can be affected by (dipole) in the monomer units. Polymers containing (amide) or (carbonyl) groups can form (hydrogen bonds) between adjacent chains; the partially positively charged hydrogen atoms in N-H groups of one chain are strongly attracted to the partially negatively charged oxygen atoms in C=O groups on another. These strong hydrogen bonds, for example, result in the high tensile strength and melting point of polymers containing (Carbamate urethane) or urea linkages (Duarte, 2003), which could be ascertained by polymerization interaction i.e. increasing of molecular weight as for instance as show in Figure (6).

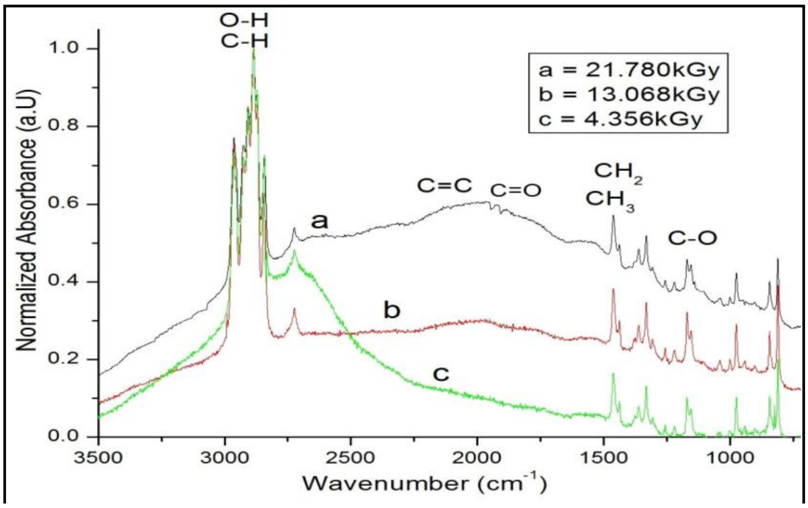

Figure 6: Raman spectra showing the effects of irradiation on iPP

Optical properties:

Polymers such as PMMA and HEMA: MMA are used as matrices in the gain medium of solid-state dye lasers that are also known as polymer lasers. These polymers have a high surface quality and are also highly transparent so that the laser properties are dominated by the laser dye used to dope the polymer matrix. These types of lasers that also belong to the class of organic lasers are known to yield very narrow

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line widths which are useful for spectroscopy and analytical applications. An important optical parameter in the polymer used in laser applications is the change in refractive index with temperature (Duarte, 2003).The optical properties were studied by UV-Vis Spectroscopy as shown in Figure (7).

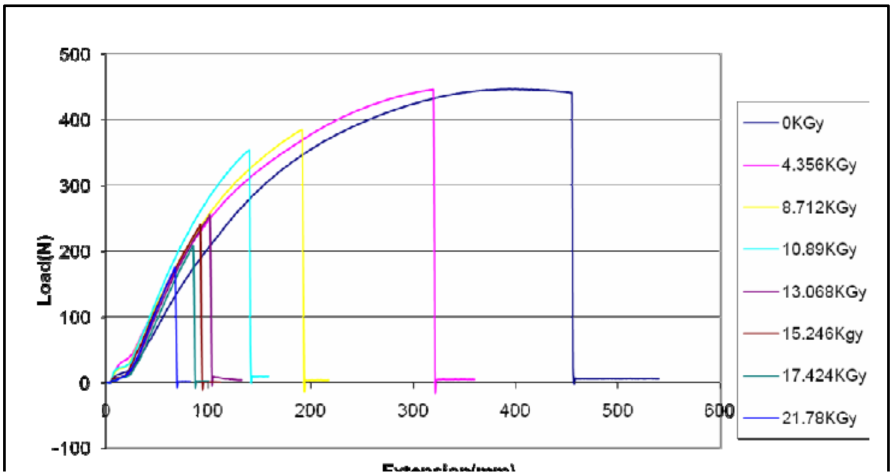

Figure 7: Shows the effect of irradiation on the elongation at fracture of PP (Abiona and Osinkolu , 2010).

Thermal properties:
A true workhorse for polymer characterization is thermal analysis, particularly Differential scanning calorimetry. Changes in the compositional and structural parameters of the material usually affect its melting transitions or glass transitions and these in turn can be linked to many performance parameters. For semi crystalline polymers it is an important method to measure crystallinity. Thermo gravimetric analysis can also give an indication of polymer thermal stability and the effects of additives such as flame retardants. Other thermal analysis techniques are typically combinations of the basic techniques and include differential thermal analysis, thermo mechanical analysis, dynamic mechanical thermal analysis, and dielectric thermal analysis. Dynamic mechanical spectroscopy and Dielectric spectroscopy are essentially extensions of thermal analysis that can reveal more subtle transitions with temperature as they affect the complex modulus or the dielectric function of the material as show in Figure (8)(Campbell et al, 1989).

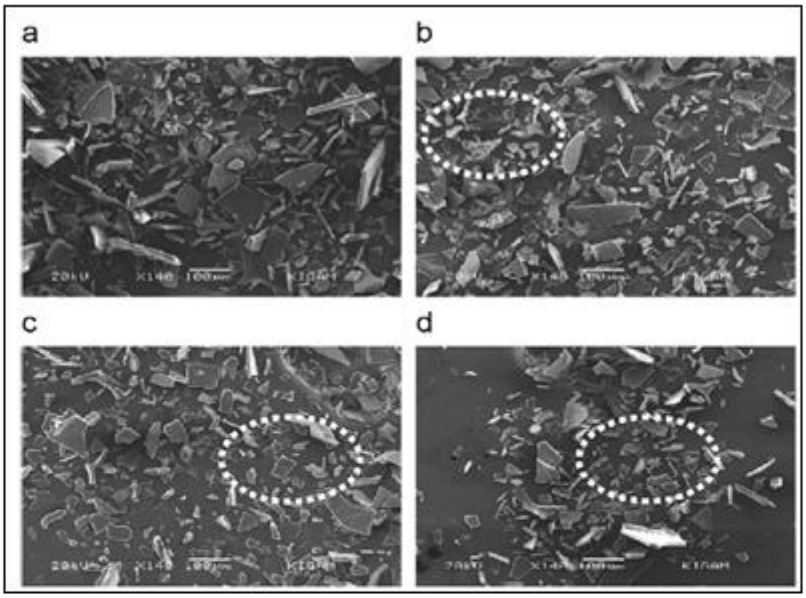

Figure 8: Shows thescanning electron microscopy (SEM) images of b-glucan irradiated at different doses; (a) 0 kGy, (b) 10 kGy, (c) 30 kGy, and (d) 50 kGy. Small particles within oval dots indicate the deformed granules of b-glucan after its exposure to different doses of gamma irradiation. (Eui et al, 2008)

Mechanical Properties

Applications of polymers in Medical field:
Variety of polymers have are used for medical care including preventive medicine, clinical inspections, and surgical treatments of diseases. Among the polymers employed for such medical purposes, specified groups of polymers they called polymeric biomaterials when they are used in direct contact with living cells of our body. Typical applications of biomaterials in medicine are for disposable products (e.g. syringe, blood bag, and catheter), materials supporting surgical operation (e.g. suture, adhesive, and sealant), prostheses for tissue replacements(e.g. intraocular lens, dental implant, and breast implant), and artificial organs for temporary or permanent assist(e.g. artificial kidney, artificial

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heart, and vascular graft).These biomaterials are quite different from other non-medical. (Maitz, 2015)

The main polymer type used in medicine:

1) Polyolefin:
The polyolefins polyethylene (PE) and polypropylene (PP) are very inert and hydrophobic materials which do not degrade in vivo. its main applications are sliding surfaces of artificial joints as show in Figure (9). (Breitbart et al, 2007)

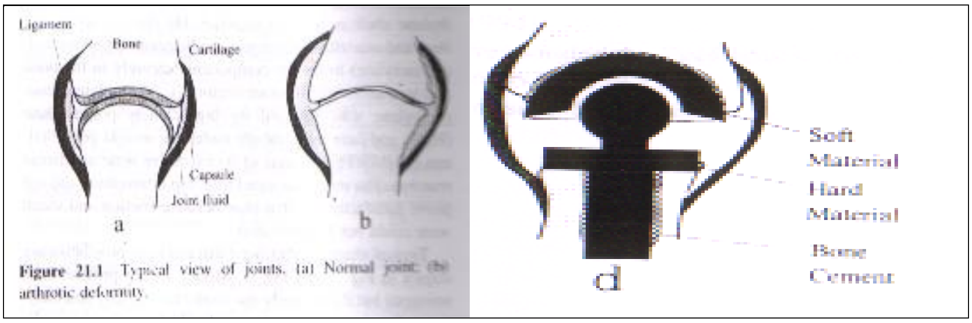

Figure 9: (a) Normal joint Figure (b) replacement of the joint is required (d) artificial joint has a sliding interface using combination of a hard material against a soft material

The artificial joint has a sliding interface using a combination of hard material Metallic femoral head, Soft material Polytetrafluoroethylene (PTFE) shell Cement material: cold-curing acrylic cement polymethyl methacrylate) to fix the components and to transfer the stress more uniformly as show in Figure (10).

Figure 10: Shown artificial joint has a sliding interface

2) Polytetrafluoroethylene (PTFE):
PTFE (Teflons) has an ethylene backbone with four covalently bound fluorine molecules. It is a highly hydrophobic non-degradable material. It's mainly applied as vascular graft as show in Figure (11). (Breitbart et al, 2007)

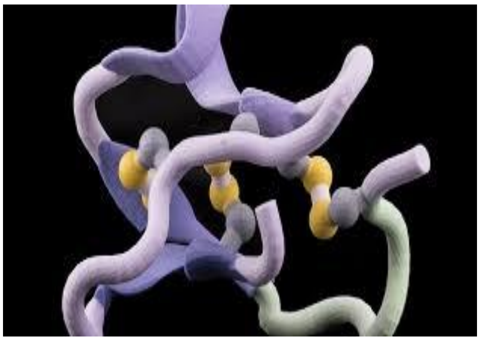

Figure 11: Shown the artificial vascular veins

3) Polyvinylchloride(PVC):
PVC has an ethylene backbone with one covalently bound chlorine. Its fabrication and application requires stabilizers and plasticizers, which are the main reason for medical concerns against this polymer. Plasticizers, most frequently phthalates, turnthe rigid PVC to a softpolymer, which used for extra corporeal tubing or blood storage bags.(Folarin et al, 2011)

4) Silicone:
Silicones consist of an –Si–O– backbone with different chain lengths and cross links, which determine mechanical properties from liquid oil via a gel structure to rubber elastomer. The biological response differs for various applications. There is high tolerance in ophthalmologic applications (.Mackenzie, 2007), fibrous capsule formation at breast implants.(Wong et al,2006)

5) Methacrylates:
Methyl methacrylates polymerize to very rigid polymers (PMMA) by radical polymerization and therefore find application in dentistry and in orthopedics. They are used for application with polymerization insitu. Due to the optical properties (Plexiglasss) and inertness in the eye, they are also used as intraocular lenses as shown in figure 12.

Figure 12: Show the artificial lenses

6) Polyesters:
Biostable and biodegradable polyesters are used in biomedicine. Biostable polyesters containing aromatic

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groups are poly carbonates (PC), poly (ethylene terephthalate) (PET,dacron). They are used inform of membranes, filaments and meshes. (Hofmann, 1996)

7) Polyethers:

Ether bondings are bio stable. Poly ether ether ketone (PEEK) as hard material for orthopedic applications and polyether sulfone (PES) for dialysis membranes are main representatives of this polymer class in biomedicine(Krieter et al, 2011)

8) Polyamides:

Naturally, all proteins consist of units liked by amide bondsand highly repetitive proteins like collagen or silk fibroin. The most important synthetic polyamidewith clinical application is nylon. For its high tensile strength it is used for suture materials. (Pruitt et al, 2009)

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