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Interpenetrating Polymer Network- A Promising Method for Widening Applications of Polymers

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ABSTRACT

Polymers have wide range of applications from aviation industry to biomedical field. Other major applications of polymers include drug delivery system, biosensor devices, tissue engineering, cosmetics. Some important properties of polymers are heat capacity, conductivity, crystallinity, thermal expansion, permeability, elastic modulus, tensile strength, resilience, resistance to electric current and refractive index. In IPNs, two or more networks are at least partially interlaced on a polymer scale. Base on applications, polymers and polymer networks needs to have certain properties. IPNs can be used with interpenetration of suitable polymers to have desired properties for specific applications. Polylactic acid is widely used in biological applications due to biodegradable properties. Reinforcement of polymeric compound can improve mechanical properties of the double polymer network hydrogels. Stability of gel polymer electrolyte can be improved by using chemical cross linking. Interpenetrating polymer network has scope for its use as carrier system in drug delivery system. Characteristics of rubber can be modified by using different reinforcements.

Keywords: Intermolecular forces, bonds, refractive index, biodegradability, microstructure.

INTRODUCTION

Polymers have applications ranging from their use in aviation industry to biomedical field. Other major applications of polymer include drug delivery system, biosensor devices, tissue engineering, and cosmetics. When similar units are bonded together, polymer is formed. Based on sources, polymers are classified as natural and synthetic. They are classified as linear, branch chain and cross linked or network polymers based on their structure. The polymerization can be addition or condensation polymerization.

Different intermolecular forces are present in elastomers, thermoplastic, thermosetting plastics and fibers. Some important properties of polymers are heat capacity, heat conductivity, crystallinity, thermal expansion, permeability, elastic modulus, tensile strength, resilience, resistance to electric current and refractive index. In IPNs, two or more networks are at least partially interlaced on a polymer scale. In full IPNs, both components are present as cross-linked networks. In semi IPNs only one component is present as network. Base on applications, polymers and polymer networks needs to have certain properties. IPNs can used with interpenetration of suitable polymers to have desired properties for specific applications. This paper sheds light on the use of interpenetrating network in different applications.

Studies and investigations on IPN

Medical Applications

Natural polymers exhibit reasonably good properties for their use in the medical applications. [1] Interpenetration and interpenetrating network is one of the most widely investigated research area in polymer material science. The properties of polylactic acid can be improved by using interpenetration. Polylactic acid is widely used in biological applications due to biodegradable properties. It has second largest consumption of any bioplastic in the world. This along with 2-hydroxyethyl methacrylate (PHEMA) can be considered as two of the most widely used materials in medical applications. Polyhydroxy ethyl methacrylate had good biocompatibility. Passos et al. carried out an investigation to improve the properties of polylactic acid by using poly 2-hydroxyethyl methacrylate. [2] They observed that there was decrease in glass transition temperature by 13-14 percent for semi-IPN network associated with the segments of the molecular chain of the polylactic acid (PLLA). Also melting temperature decreased by 9 percent. Use of PHEMA can improve the applicability of the PLLA in the medical applications.

Based on chemical bonding, interpenetrating networks can be classified as cross semi IPN, non-covalent semi IPN, non-covalent full IPN. Various arrangement patterns can be used in interpenetration. [3] Fossil fuel is source of many polymers and macromolecular products. [3] Their resistance to water and other chemical compounds, durability, flexibility makes them valuable product. Depleting reservoirs and rising fossil fuel prices call for use of other alternatives such as biopolymers. These polymers can be recycled. Interpenetrating network structure can be used to impart special properties. Multifunctional monomer polymerization is high speed and low temperature reaction. Kaczmarek and Kwiatkowska carried out an investigation for interpenetration network of polyacrylates and poly lactic acid. [3] They observed that initial morphology of substances has strong effect on polymerization. According to a review carried out by Panteli and Patrickios, reinforcement of polymeric compound can improve mechanical properties of the double polymer network hydrogels. [4] Also, they may enhance properties such as biodegradability, low-friction coefficients and conductivity with proper choice of IPN.

In interpenetrating polymers two chemically distinct networks exists. [5] Enhancing strength and maintaining and increasing the recoverability can be result of continues crosslinking of two molecules. For formation of IPNs, two monomers can be mixed or one monomer can be dissolved in polymer network. Mechanical strength and stability of solid polymer electrolytes can be increased by using crosslinking. In IPNs molecules are interconnected in a three-dimensional network through microstructure. [6]

Wettability, protein adhesion and cell adhesion have influence on cell interactions. Photo switchable surfaces can control these characteristics. The photo switchable surfaces can be obtained by polymerizing light responsive polymers. [7] Clark carried out azobenzene modification and cell-material interaction studies. [7] In his investigation, he methyl methacrylate surfaces with hydroxyl and amine groups. [7]

Membranes

Interpolymer network (IPN) structure also can be used to improve the properties of the membranes. It can improve mechanical strength and selectivity. Lim and Kim carried out investigation on cross linked butyl methacrylate-co-methyl methacrylate membranes. [8] They investigated separation of water ethanol mixture by using composite membranes. These composite membranes were prepared with polyacrylic acid–poly (butyl methacrylate-co-methyl methacrylate) interpenetrating polymer network (PAA–P(BMA-co-MMA) (IPN). This was skin layer supported on cross-linked and porous poly (BMA-co-MMA). With the use of 70 percent N-methyl-2-pyrrolidone (NMP), they were able to highly porous cross-linked structure.

Polymer electrolytes

Rahman et al. used Chitosan obtained from chitin, as base raw material for synthesis of O-nitro chitosan. [9] They observed that the chitosan derived modified material has improved properties than poly (NIPAAm) hydrogel. [9] Use of organic solvents in batteries is unsafe because of the volatile and flammable properties of these solvents. Gel polymer electrolytes (GPEs) can be used to suppress the volatility of the solvents. [10] Stability of gel polymer electrolyte can be improved by using chemical cross linking. The interaction between the electrolyte and ethylene oxide makes them promising gel base for gel polymer electrolytes. Lua et al. synthesized gel polymer electrolyte membrane. [10] Due to advantages in time, energy and process control, they used UV light irradiation curing. According to their studies, the mechanical properties are improved due to the cross-linked poly (ethylene glycol) diacrylate-co-poly (vinylene carbonate) P(EGDA-co-VC), P(EGDA-co-VC) copolymer. Also, poly (vinylidene fluoride-cohexafluoropropylene (PVDF-HFP), PVDF-HFP polymer increases the toughness and flexibility. Excellent results were obtained by Prashantha et al., by using glycerol modified castor oil polyurethane interpenetration with PHEMA. [11]

Charge dissipaters

The interpenetration resulted in increased chemical resistance, hardness, elongation and tensile properties. Intrinsically conducting polymers find application as charge dissipaters for e-beam lithography. [12] They have many other applications including corrosion protection, artificial muscles, light-emitting diodes, field-effect transistors, photovoltaic cells, batteries. Dopants are used in these materials to obtain certain electrical properties and change conductivity of these materials.

Applications in energy, process, aeronautics

Silicon carbide based composite materials and ceramics find applications in energy, process, aeronautics and many other applications. [13] The temperature capacity of the commercially available silicon carbide is limited. Silicon carbide based interpenetrating phase composites were prepared by Singh. [13] According to him, the interpenetrating method provides better control over microstructure and morphology.

Elastomers

Interpenetrating polymer networks improve properties of elastomers. Properties of sensors, elastomers, actuators can be improved by interpenetration. Interpenetration networks, with covalent crosslinking of commercial silicon elastomers can improve the properties of dielectric elastomers. [14]

Improvement in Tribological properties

The science of interacting surfaces and study of friction, lubrication and wear is termed as tribology. Tribological properties of interpenetrating materials can be enhanced by introducing secondary phase. According to Wang et al. there is hardly any research material available for study of abrasive resistance of interpenetrating composites. [15] They studied Si3N4/AlSi11 interpenetrating polymer for dry sliding interpenetrating behavior. They identified four types of abrasive wears. These are initial adhesive, mixed adhesive, abrasive and final abrasive wear. According to their studies, due to reinforcement, abrasive resistance of the materials increased considerably.

Minimizing the vibration level of moving machineries

Polymers having good viscoelastic properties can be used for minimizing the vibration level of moving machineries and parts. The broadening of glass transition region can help to improve the viscoelastic properties. Jia et al. investigated interpenetration network, poly (methyl methacrylate) (PMMA)/epoxy (EP) for studying mechanical, thermal and dampening properties. [16] They observed that there was decrease in thermal stability with increase in the PMMA content. During Interpenetration of PMMA into epoxy, broadening the glass transition region was considerable. This will obviously help in improving vibrational properties. Dolata carried out comparative investigation on tribological properties of the $AlSi1_2/Al_2O_3$ interpenetrating composite layers and unreinforced $AlSi1_2$ matrix areas. [17] This study indicated that the reinforcement brings about additional wear resistance and frictional stability in the material. Kamal carried out investigation on use of camphor and polyantimonyacrylate for forming interpenetrating polymer network. [18] This study indicated that introduction on Active Poly[2-(sec-butyl) aniline] PSBA increases swelling. Also, it was observed by the investigator that with increase in the concentration of PSBA, there was increase in the Young's modulus.

Drug delivery

In drug delivery, drug delivery regime and frequency of dosing need careful investigation for obtaining maximum effect of the drug. [19] Efforts are done to administer the dosage at the site of action. This can maximize the effect and minimize the side effects. Biopolymers find application in controlled release drug delivery system. The advantages of natural polymers such as non-toxicity, low cost and bio compatibility makes them important material in drug delivery systems. Many physical attributes of biopolymers impose limitation on their advantages. The combination of more than one polymer can meet the specific needs in drug delivery systems. According to the review done by Bhardwaj et al., interpenetrating polymer network has scope for its use as carrier system in drug delivery system. [19]

Water absorbing ability of the hydrogels used in drug delivery depends on the nature of the polymers used. Natural polymers have advantage in terms of cost and availability. [20] Afzal et al. used gelatin and sodium alginate for the preparation of hydrogels. [20] These polymers degrade easily in the human body. Bhattacharya et al. used daily phthalate and ethylene glycol dimethacrylate for IPN formation from polyvinyl chloride and polyethyl methacrylate. [21] They observed that quantity of polyethyl methacrylate (PEMA) affects the mechanical properties of the material. According to study carried out by Naseem et al., the dopant type has significant effect on the properties of Polyaniline (PAni) filled polymethyl methacrylate (PMMA) and polyurethane (PU) interpenetrating networks. [22] They observed that the organic dopants impart plasticization effect.

Modification of rubber characteristics

Characteristics of rubber can be modified by using different reinforcements. An investigation was carried out by Samui et al., to study interpenetration of Nitrile Rubber and Metal Methacrylate. [23] For obtaining sequential IPNs, they used both, compression molding and swelling-cutting methods. They observed that IPNs had superior properties compared to the metal oxide/hydroxide filled Nitrile Rubber. The material obtained by compression molding showed enhancement in tensile strength, which was not the case with the product obtained by swelling cutting method. Thermoresponsive polymer systems have limitation of poor mechanical properties. [24] Cross-linked hydrogels can be used to improve these properties. Hydrogels are polymeric materials, which are swollen due to presence of water. Hydrogel materials retain their mechanical properties even in the swollen state. High water content of these materials enhances their biocompatibility.

CONCLUSION

In IPNs, two or more networks are at least partially interlaced on a polymer scale. Polymers with IPNs can be used in dental, medical, mechanical and electrical applications more effectively. [25-26] In full IPNs, both components are present as cross-linked networks. In semi IPNs only one component is present as network. Based on applications, polymers and polymer networks needs to have certain properties. The properties of polylactic acid (PLA) can be improved by using interpenetration. Polylactic acid is widely used in biological applications due to biodegradable properties. Reinforcement of polymeric compound can improve mechanical properties of the double polymer network hydrogels.

Stability of gel polymer electrolyte can be improved by using chemical cross linking. Interpenetrating polymer network has scope for its use as carrier system in drug delivery system. Characteristics of rubber can be modified by using different reinforcements. Thus, IPNs can be used with interpenetration of suitable polymers to have desired properties for specific applications.

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