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Research Article

Polymers in the Textiles and in the Construction Industry

Hebah Abdel Wahab*, Tamara Gund

Department of Chemistry and Environmental Science, New Jersey Institute of Technology, Newark, United States

Abstract

Ionic solids, ceramics and most polymers and plastics are insulators, they do not conduct electrical current. Plastics are materials that can be formed into various shapes by the application of pressure or heat. Plastics are classified into thermosetting plastics, thermoplastic material, or an elastomer. A thermosetting plastic cannot be reshaped readily as it's made from an irreversible reaction. Thermoplastic materials can be reshaped, for example polyethylene polymer used in the making of milk containers. Elastomers are plastics with elastic behavior or rubbery plastics, as they can be subject to stretching and bending. Polymers can be either naturally occurring from animals or plants or synthesized in chemical plants or chemical laboratories. This work is aimed to identify the polymers that are used in the textile industry and the polymers used as fill in materials in the construction industry, to find polymers that are less toxic with similar properties as PVC in the textile industry due to the environmental concerns that comes with using PVC, to know whether poly vinyl chloride is still used in the textile industry in the United States, and to find suitable polymers used as fill material in the construction industry.

Keywords

Polymers, Textiles, Types of Polymers, Construction

1. Introduction

An independent business owner in Oxford, PA, USA is looking to possibly manufacture waterproof pants made of a material that has the same look and feel as polyvinyl chloride. He wanted to know whether polyvinyl chloride is still being used in the United States due to the environmental concerns that arouses with using this polymer. Another independent business owner in Olympia, WA, USA is looking for waterproof coatings to encapsulate grinded roof materials in a non-biodegradable chemical compound that would last and not leach chemicals into the ground. He is looking for a fill polymer material to encapsulate the waste grinded roof material.

Materials can be classified according to the forces holding the particles together and it can be also classified according to their electrical conductivity, the ability to conduct electrical current. Materials are a mixture of substances or a substance that are held together by chemical bonds. Materials can be classified according to the forces holding the molecules into metallic solids, ionic solids, molecular solids and covalent network solids. In molecular solids, the forces between particles can be dispersion forces, dipole-dipole forces, or hydrogen bonding. In covalent network solids, the forces that hold the particles together are covalent bonding. In ionic solids and metallic solids, the forces that hold the particles together are ionic bonding (electrostatic attractions between ions) and metallic bonds representatively. Examples for molecular solids are carbon dioxide (CO_2), and methane (CH_4), examples for covalent network solids are diamond and quartz (SiO_2),

*Corresponding author: heathera@gmail.com (Hebah Abdel Wahab)

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examples for ionic solids are sodium chloride (NaCl) and calcium nitrate (Ca $(NO_3)_2$), and examples for metallic solids are sodium (Na), and potassium (K) metals. Materials are classified into conductors, semi-conductors, and insulators according to their ability to conduct electrical current. Ionic solids, ceramics and most polymers and plastics are insulators, they do not conduct electrical current. Metallic solids are conductors as they conduct electrical current at room temperature. Covalent network solids are semi-conductors, they have intermediate electrical conductivity between insulators and conductors. Aluminum oxide (Al_2O_3), silicon carbide (SiC), silicon nitride (Si_3N_4), aluminum oxide, zirconia (ZrO_2), and beryllia (BeO) are examples of ceramic insulating material. Silicon, germanium, tin, and carbon are examples of elemental semi-conductors, and aluminum phosphide (AlP), gallium phosphide (GaP), zinc selenide (ZnSe), and cupper (I) bromide (CuBr) are examples of material semi-conductors. Polymers and plastics are high molecular weight substances that are mostly insulators. They can be found in nature or synthesized in the laboratories. Naturally occurring polymers are starch and cellulose, found in plants, and proteins found in both animals and plants. Other examples for naturally occurring polymers are natural rubber, silk, leather, wool. Plastics are materials that can be formed into various shapes by the application of pressure or heat. Plastics are classified into thermosetting plastics, thermoplastic material, or an elastomer. A thermosetting plastic cannot be reshaped readily as it's made from an irreversible reaction. Thermoplastic materials can be reshaped, for example polyethylene polymer used in the making of milk containers. Elastomers are plastics with elastic behavior or rubbery plastics, as they can be subject to stretching and bending. Polymers can be either naturally occurring from animals or plants or synthesized in chemical laboratories or chemical plants. Polypropylene, polyethylene, polyethylene vinyl acetate, polyethylene terephthalate, polyurethane laminate (polyurethane), polyisoprene, nitrile butadiene rubber, natural rubber, Teflon (a fluoropolymer), poly vinyl chloride, paraffin waxes, styrene butadiene rubber, neoprene, polyurethane, PDMS (A Silicone), styrene-acrylic polymers, PE-Polyester Resin, and phenol formaldehyde (a phenolic resin) are well known polymers. [1, 2].

Polymers can be made in the laboratory or in chemical plants by either addition or condensation polymerization. Addition polymerization involves the opening of a double bond in a molecule, and two new C-C bonds are formed with another two molecules as in equation 1:

$$n\ CH2{=}CH2 \rightarrow -[-CH2\text{-}CH2-]_n- \quad (1)$$

n= hundreds to thousands of monomer molecules.

In condensation polymerization two molecules are joined to form a larger molecule via a condensation reaction and by the elimination of a small molecule such as a water molecule. Nylon 6, 6 is an example of a copolymer synthesized by condensation polymerization, shown in equation 2.

$$n\ H2N\text{-}(CH2)\ 6\text{-}NH2 + n\ HO\text{-}CO\text{-}(CH2)\ 4\text{-}CO\text{-}OH \rightarrow -[HN\text{-}(CH2)\ 6\text{-}NHCO\text{-}(CH2)\ 4\text{-}CO-]_n- + 2n\ H2O \quad (2)$$

Polycarbonate, polyurethane, Nylon 6, 6, are examples of copolymers synthesized by condensation polymerization. [1]

Polyvinyl chloride is a thermoplastic that can be either in the rigid or the flexible form, and it has countless industrial and commercial applications. Flexible PVC is used in cable insulation, wiring insulation, roof lining, hoses and conveyor belts. Rigid PVC is used in roofing, electricity distribution boxes, pipes, plug housing, and battery terminals. [2]

Studies show that PVC releases concentrations of toxic substances to the environment as the PVC ages and deteriorates. PVC contains phthalate plasticize, a harmful chemical additive, and cadmium, calcium, barium and lead heat stabilizers, another harmful additive. CBC press release indicated that it releases carcinogens and harmful chemical substances including phthalate plasticizers and dioxin at every stage of its life cycle. [3]

PVC is considered a hazardous waste, it is a carcinogen, phthalates additives are toxic, phthalate exposure influence prenatal hormone regulation resulting in abnormal development of the brain, it causes pregnancy complications, it causes abnormalities in wildlife species- A lawsuit was filed against EPA, US Environmental protection agency on May 2021 regarding The PVC threat of toxic chemicals released from discarded plastic waste. According to NJ state-2008 law banning from using phthalates in children's toys and not banned from being used in school supplies as of today. Phthalates interfere with children's hormones [4, 5].

2. Experimental

Table 1 lists some polymers, their chemical names, their chemical structures and their usages and applications and its usages in either or both industries.

Polypropylene is used in the fabrication of both cold and warm weather clothing. Undergarments made of polypropylene retain body odors and is the major polymer used for the making of diapers, where the polymer is treated to become hydrophilic and absorb water. [6-8]. It is used for plastic molding, for example bottles, bottle tops and fittings. It is used in roofing as a waterproofing roofing a membrane. It is also used in the production of packaging, storage boxes, and stationary folders. It is used as an alternative to PVC, polyvinyl chloride, as it emits less harmful smoke with no toxic halogens. It is used as a concrete additive to reduce cracking, and it's also added to soil to improve its strength when constructing the foundation of the buildings. [9, 10].

Polyethylene is synthesized from ethylene, and ethylene is mainly obtained from natural gas or petroleum or renewable resources. Polyethylene is not biodegradable and accumulates in landfills causing difficulties for waste management [11, 12]. It is used in furniture, industrial materials, and in textiles. It isn't biodegradable and it ends up in landfills every year. It

can be blended with other fibers for various applications. The uses and applications of polyethylene is based on its type. Polyethylene fibers are classified based on its density values into very-low-density polyethylene with density range of 0.880-0.915 g/cm3, low-density polyethylene with density range of 0.910-0.940 g/cm3, linear low-density polyethylene with density range of 0.915-0.925, medium-density polyethylene with density range of 0.926-0.940, cross-linked polyethylene with medium to high density, high-density polyethylene with density range of 0.941 g/cm^3, ultra-high-molecular-weight polyethylene usually has a molecular weight between 3.5 and 7.5 million atomic mass units. Polyethylene is generally used in plastic film applications, packaging, rigid containers, plastic bags, pipes, containers, bottles, waterproof vests, and cables. [13]

Polyethylene vinyl acetate, PEVA, can be used as a safe alternative to PVC as it is not a carcinogen and it also it does not contain chlorine. It has no known effect on human health, living organisms, and like many polymers it is not biodegradable. [14, 15]. It is used as adhesives in bookbinding, binding of metal surfaces, textiles, coated paper, and cement binders. EVA foams known as foam rubber are used as padding equipment in boots, boxing, gloves, helmets, and it's used as a shock absorber in shoes. [16-19]

Polyethylene terephthalate, PETE, is used in fibers for clothing, thermoforming for manufacturing, containers for foods, and resins in engineering after its combination with glass fiber. It is also used as a waterproof barrier in cables, food packaging, thermal insulators, and as a film base. [20-34].

Polyurethane laminate, PUL, is a laminated cloth fabric, in one or both sides with polyurethane thin film. It is used in garment uses, automotive and in medical applications. PUL cloth is soft, flexible, somewhat stretches, breathes and it is a waterproof fabric. It is used in the making of shower curtains, outerwear clothing, tents, waterproof backpacks, mattress protectors, medical bedding, diapers, and cloth menstrual pads. [35-38]

Polyisoprene, in the form of natural rubber or synthetic polyisoprene is mainly used for tires, footwear, belting, hoses, latex products, and condoms. [39]

Nitrile butadiene rubber is used in the preparation of pigment binders and adhesives, synthetic leather, oil seals, transmission belts, and cable jacketing. [40]

Polytetrafluoroethylene is a fluoropolymer containing multiple C-F bonds. It has high resistance to bases, acids, and solvents. It is unreactive and it is used in non-stick coating for cookware, in containers for corrosive chemicals, and as lubricants to reduce wear and friction of machinery. [41-43]

Polyvinyl chloride, PVC, is a white brittle solid, and is the most widely used synthetic polymer after polyethylene and polypropylene, and it comes in either the flexible or the rigid form. The rigid form is used for the making of windows, doors and pipes, plastic bottles, membership cards, and food covering sheets. The flexible form is made flexible by the addition of plasticizers to the rigid form, for example phthalates. The flexible form is used in imitation leather, cable insulation, flooring, plumbing, and the production of canvas when used with linen and cotton. [44-47].

Paraffin wax, (Petroleum wax), consists of hydrocarbon molecules of 20-40 carbon atoms. It begins to melt at temperatures higher than 37 C. It is used in candles, lubrication, electrical insulators, and in the making of crayons after it's dyed. It also has applications in textiles, in the making of canvas textiles and in construction. [48-52]

Styrene-butadiene rubber, SBR, is a type of synthetic rubber. Various types of SBR are used in the making of car tires, soles, chewing gum, jaskets, and shoe heels. Emulsion styrene-butadiene rubber (latex) is used in building applications as a binding agent and is also used in binding pigmented coatings. It's used as an alternative to PV as it's more durable, increases flexibility, and it's also resistant to emulsifications. [53-55]

Natural rubber can be either uncured, plantation (crepe) or Vulcanized rubber. Uncured rubber is used with cement for insulating, adhesive and friction tape. Planation rubber is used in footwear and insulating blankets. Vulcanized rubber is used in vehicle tires, pump housing, and piping as it has great resistance to abrasion. Natural rubber accounts for 30% of annual rubber production. [56-59].

Uncured rubber is used for insulating, adhesives, and cement. Crepe rubbers are used in foot ware and insulating blankets. Vulcanized rubber (sulfur treated rubber) has more applications as it makes hard and soft rubber more valuable. Rubber has electrical resistance and is water resistant. Synthetic rubber is made from petrochemicals and is used in the making of latex products. Rubber is used as an additive to cement products to improve its quality. [60-63].

Neoprene is a synthetic rubber formed by the polymerization of Chloroprene. It has various commercial applications. It is used as an electrical insulator, an orthopedic brace, and as a laptop sleeve. It is used in corrosion resistant coatings and in hoses due to its inertness and its resistance to degradation than other natural or synthetic rubber. It is used in noise isolation in power transformers, and as a base for adhesives. It is a better resistance to burning than hydrocarbon-based rubber, makes it suitable for the use as combat facemasks and gloves. It is also used in landfills due to its high burn point of 260 °C (500 ℉). [64-67].

Polyurethane (PU) is produced from a variety of starting materials, mainly from the reaction of polyol with isocyanate. The resulting polymers have a variety of applications due to the different chemical structures formed. It includes flexible and rigid forms. PU made from aliphatic isocyanates is used in coatings. PU made from aromatic isocyanates interacts with light causing it to discolor from off-white to yellow then to red. I general polyurethanes hydrolyze by its reaction with moisture of air causing it to degrade. It is also subject to slow microbial degradation due to the action of some enzymes. Pestalotiopsis fungus can cause the biodegradation of PU at

the bottom of landfills. [68-73].

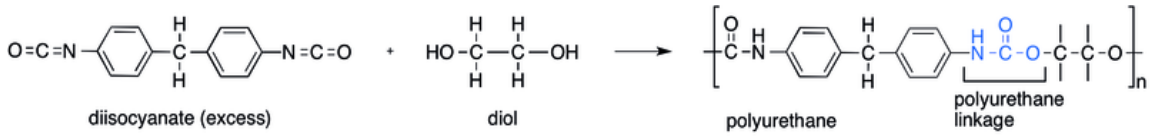


Figure 1. *Polyurethane Synthesis from the reaction of a diol with diisocyanate.*

PDMS, ploy dimethyl siloxane, is a polymer made of $-R_2Si-O-SiR_2-$, where R = CH3 units. They are rubber-like substances used in adhesives, electrical insulation, and lubricants. It has excellent chemical stability and waterproof properties. It's used as an additive to concrete to improve its waterproof properties, and it's also used to restore industrial roofs. It is also used to seal crevices, joints and gaps in buildings. Silicones cure by absorbing moisture from air. [74, 75]

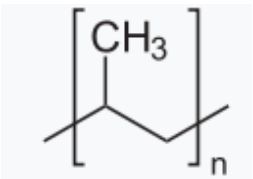
Polyester resins are formed by the reaction of a dibasic organic acid such as maleic anhydride with polyhydric alcohols. The unsaturated polyester resins are used in bulk or sheet molding compounds. Polyester concrete overlay, CPO, made from the reaction of isophthalic acid and high levels of styrene, are used as overlay on bridges and roads. The fiberglass reinforced plastic, the polyester resin reinforced with fiberglass, are used as wall panels in kitchens, restaurants, and restrooms. [76-79].

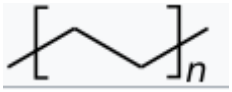
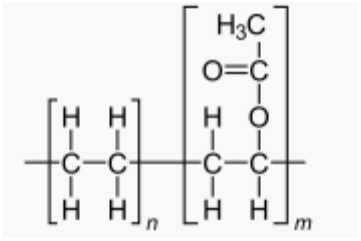
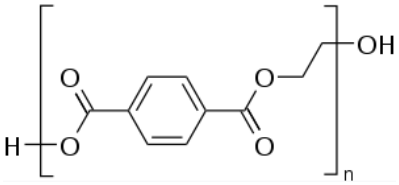
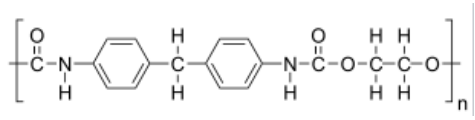
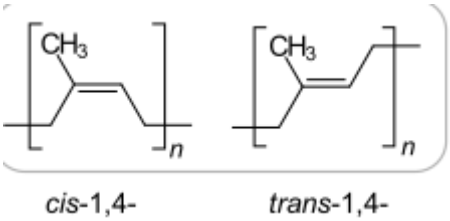
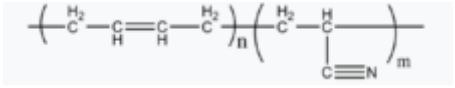
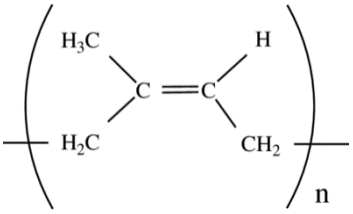
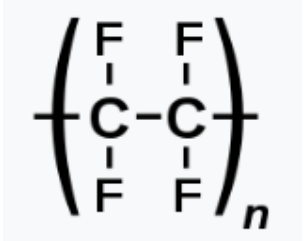
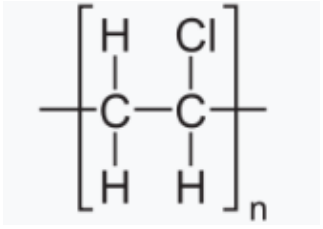
Polyvinyl acetate, PVC, is a type of thermoplastic polymer and it is a type of polyvinyl ester aliphatic polymer. It is known as wood glue, white glue, carpenter's glue, and it is used as adhesive in porous materials such as paper, wood, and cloth. It can be used to consolidate porous building stones. It is used as an envelope, cigarette paper and wallpaper adhesives. It is also used in chewing gum, as gum base. It is used as a raw material to make other polymers, such as, polyvinyl acetate phthalate, PVAP, where the PVC is first hydrolyzed and then reacts with phthalic acid, and polyvinyl alcohol, PVA, where the PVC hydrolyses, partially or completely into PVA. [80-86]

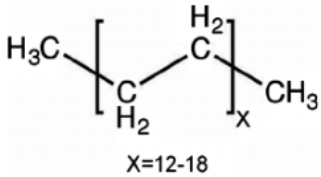
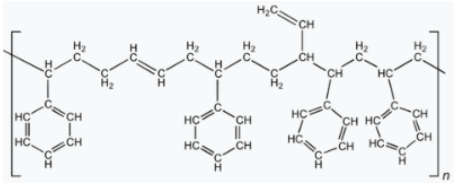
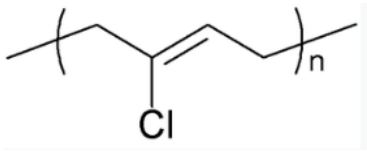
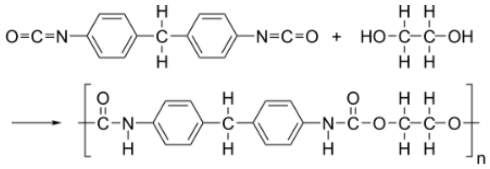
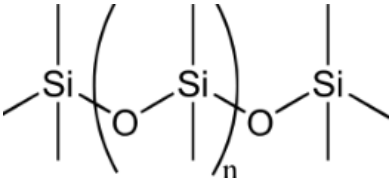
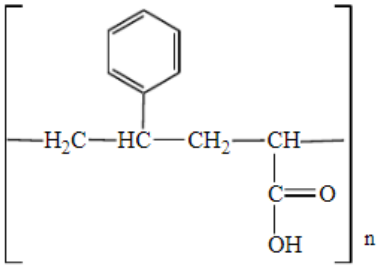
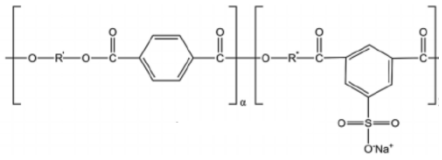
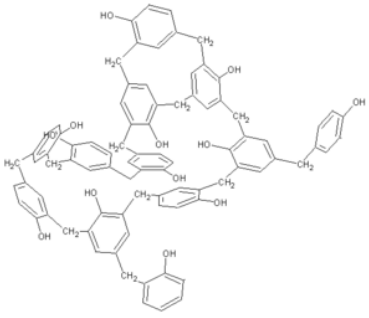
Compared to other acrylic polymers, styrene-acrylic polymers have superior moisture vapor transmission rate and water resistance properties. Low particle size styrene acrylic can be produced due to the styrene monomer being hydrophobic, resulting in applications such as binder for the paper industry and primers for the construction industry. Styrene acrylic polymers have good abrasion resistance, good mechanical properties, and they are durable due to their high glass transition temperature. Additional properties for styrene acrylic emulsion polymers are the ability to crosslink, good stain resistance, resistance to removal by detergents, high pigment binding capacity, film strength, good adhesion to steel and aluminum metals, and wood. The drawback of using styrene acrylic polymers is its yellowing upon exposure to sunlight, the degree of yellowing depends on the amount of styrene present in the polymer. Styrene acrylic polymers are still used in the construction industry as fillers, ceramic tile adhesive, roof coatings despite its drawbacks. They are also used in agriculture and in binding applications, such as wall coverings. [87]

Phenolic resins are produced are synthetic polymers produced from the reaction of formaldehyde with substituted phenols. Phenolic resins are used in countless number of industrial products. Phenolic laminates, a thermostat polymer matrix, are made by saturating layers of paper, cotton, or fiberglass with a phenolic resin, under heat and pressure, the base material type and amounts are based on the application of the finished product. Paper phenolics are used in household laminates, and paper composites. Phenolic resins are used in brake pads, brake, shoes, and clutch desks as a binding agent. Some countertops are made of paper and phenolic resin. Phenolic resins are used in the making of a composite thermosetting resin plastic, known as duroplast. Duroplast is known to be used in the small car industry, Trabant automobile. It is also known to be used in the making of boil and weatherproof plywood (WBP). Phenolic resins are available in both solid and solution form for the ease of its application, as it is used in the industrial coatings industry. [88-91]

Table 1. *Polymers, chemical structures and their application.*

Chemical Name	Chemical Structure	Usage and Applications
Polypropylene [92]		Diapers, warm and cold weather clothing in textiles and as a concrete additive to increase strength and reduce cracking in the construction industry 2

Chemical Name	Chemical Structure	Usage and Applications
Polyethylene [93]		Textiles and furnishing.
Polyethylene Vinyl Acetate [94]		Adhesives in textiles and cement renders in the construction industry.
Polyethylene Terephthalate [95]		Fibers for clothing in the textile industry.
Polyurethane Laminate (Polyurethane) [96]		Clothing in the textile industry.
Polyisoprene [97]		Textiles and Construction Industry
Nitrile Butadiene Rubber [98]		Textiles
Natural Rubber [99]		Textiles, cement and Construction Industry
Teflon (A Fluoropolymer) [100]		Textiles, and cookware.
Poly vinyl Chloride [101]		Textiles and Construction Industry

Chemical Name	Chemical Structure	Usage and Applications
Paraffin waxes [102, 103]		Waxed Canvas in Textiles and Construction Industry
Styrene Butadiene Rubber [104]		Construction Industry as a binding agent in building applications.
Neoprene [105]		Wet Suit in Textiles, landfills and Construction Industry
Polyurethane [106]		Shoes Industry. Not recommended its use in the construction industry due to fungal biodegradation.
PDMS (A Silicone) [107]		Polymer cement-based coating in the Construction Industry
Styrene-acrylic polymers [108]		Primer, fillers, roof coatings in Construction Industry & Adhesive in the Paper Industry.
PE-Polyester Resin [109]		Construction Industry
Phenol Formaldehyde (Phenolic resin) [110]		Coatings Industry. Household Laminates. Paper Composites. As an Adhesive or as a binding agent.

3. Conclusions

Polymers used in the textile industry are, polypropylene (PP), polyethylene (PE), polyethylene vinyl acetate (PEVA), Polyethylene Terephthalate (PETE or PET), polyurethane laminate (PUL), polyisoprene, nitrile butadiene rubber (NBR), latex and natural rubber (made from oil secreted from rubber tree), fluoropolymers (PTFE, high performance clothing, and teflon), polyurethane laminate (Polyurethane), and polyurethane. Polypropylene (PP) is favored over polyethylene (PE) due to its durability; they are stronger and lighter than PE. PE do not stretch. Polyethylene vinyl acetate (PEVA)- is considered a non-chlorinated alternative to PVC, and polyurethane laminate (PUL)- soft, flexible, durable, waterproof, wear next to the skin and comfortable. Nitrile butadiene rubber is used in the making of synthetic leather. PUL is similar in properties as PVC with other environmental concerns due to the inclusion of solvents and chemicals and due to its non-biodegradable. Plastic materials similar to PVC are natural rubber, NBR, PUL, polyisoprene, and fluoropolymers (PTFE).

Polymers used in the Construction Industry are styrene butadiene rubber, PDMS (A Silicone), styrene-acrylic polymers, PE-polyester resin and ploy vinyl acetate (PVA), Polyisoprene Natural (NR) and Synthetic (IR), Styrene Butadiene (SBR), Neoprene, Polyurethane, Silicones, Ploy Vinyl Chloride (PVC)+ Ethylene, Styrene-acrylic polymers, PE-Polyester Resin, and Phenolic resins.

Polyisoprene Natural (NR) and Synthetic (IR) have an excellent vibration isolating material. Polyisoprenes are not recommended for high heat, ozone, sunlight, petroleum, or hydrocarbon environments.

Polymers that are used as binders and/ or sealers in the construction industry are Neoprene, Paraffin waxes, Styrene Butadiene (SBR). Silicones, Polypropylene, and Poly Vinyl Chloride (PVA)+ Ethylene. Polymers that are used in industrial coating and waterproofing are Styrene Butadiene (SBR), Polyurethane, Silicones, Styrene-acrylic polymers, PE-Polyester Resin, and Phenolic resins. Neoprene is the material of choice for exterior applications such as profiles used in building seals as it is resistant to oil, wax, and grease, and can withstand temperatures from −50 to 120 ℃. It is also resistant to ozone, weathering, and water immersion.

PVC is considered a hazardous waste, it is a carcinogen, phthalates additives are toxic, phthalate exposure influence prenatal hormone regulation resulting in abnormal development of the brain, it causes pregnancy complications, it causes abnormalities in wildlife species- A lawsuit was filed against EPA, US Environmental protection agency on May 2021 regarding The PVC threat of toxic chemicals released from discarded plastic waste. According to NJ state-2008 law banning from using phthalates in children's toys and not banned from being used in school supplies as of today. Phthalates interfere with children's hormones.

PVC was not banned and currently being in the US and overseas. There is an environmental concern in the discarding of the PVC material, it is considered a hazardous waste, it's a carcinogen, phthalates additives are toxic, phthalate exposure influence prenatal hormone regulation resulting in abnormal development of the brain, it causes pregnancy complications, it causes abnormalities in wildlife species- A lawsuit was filed against EPA, US Environmental protection agency on May 2021 regarding The PVC threat of toxic chemicals released from discarded plastic waste. According to NJ state-2008 law banning from using phthalates in children's toys and not banned from being used in school supplies as of today. Phthalates interfere with children's hormones.

Abbreviations

PDMS	Poly Dimethyl Siloxane
PE	Polyester Resin
PVC	Ploy Vinyl Chloride
EPA	US Environmental Protection Agency
PUL	Polyurethane Laminate
PU	Polyurethane
PVAP	Polyvinyl Acetate Phthalate
PVOH	Polyvinyl Alcohol
PP	Polypropylene
PE	Polyethylene
PEVA	Polyethylene Vinyl Acetate
PETE or PET	Polyethylene Terephthalate
PUL	Polyurethane Laminate
NBR	Nitrile Butadiene Rubber
PTFE	Fluoropolymers
PP	Polypropylene
PE	Polyethylene
PVA	Poly Vinyl Acetate
NR	Polyisoprene Natural

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Conflicts of Interest

The authors declare no conflicts of interest.

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