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Materials for Extreme Environments

The major applications in which polymers have been subjected to extreme stress are aerospace, geothermal and undersea exposure. All of these environments require an extraordinary behavior of coatings, seals or adhesives (1).

Aerospace uses have received a lot of attention; therefore, the research efforts of the past twenty-five years have concentrated on the development of polymer backbones that are resistant to high temperatures and unusual chemical environments.

Geothermal energy production also has extreme temperature requirements, but in an environment quite different from aerospace. Here, hydrolytic and reductive stresses are seen rather than oxidative stress: therefore, less exotic materials are used, including rubber blends and polymer-concrete composites.

In undersea electronic applications, time is the greatest enemy of a seal meant to provide a barrier to water intrusion. Achieving a fifteen-year lifetime of a rubber-sealed device is quite difficult using economical materials. Here, some additives in rubber can be critical, as are processing and adhesion technology. The most challenging task is developing valid accelerated aging techniques to estimate useful life (1).

In the tables below, the polymeric materials are listed and basic uses are briefly given. The uses are detailed in subsequent chapters. Homopolymers and their uses are listed in Table 1.1. Copolymers and their uses are listed in Table 1.2. In addition, in order to make the basic uses of polymeric types easier to see, the basic uses of homopolymers are listed in Table 1.3.

Table 1.1 Homopolymers and uses.

Polymer	Usage	References
Acacia	Drug delivery	(2)
Acrylonitrile butadiene styrene	Spacecraft	(3)
Acylated insulin	Microspheres	(4)
Agar	Drug delivery	(2)
Albumin	Microspheres	(4)
Alginate	Drug delivery	(2)
Allyl diglycol carbonate	Spacecraft	(3)
Carboxymethyl cellulose	Pore-forming	(5)
Carboxymethyl cellulose	Stents	(6)
Carrageenan	Drug delivery	(2)
Cellophane	Stents	(6)
Cellulose acetate	Spacecraft	(3)
Cellulose acetate	Membranes	(7)
Cellulose acetate butyrate	Stents	(6)
Cellulose acetate	Stents	(6)
Cellulose butyrate	Stents	(6)
Cellulose nitrate	Membranes	(7)
Cellulose nitrate	Stents	(6)
Cellulose propionate	Stents	(6)
Cellulose	Drug delivery	(2)
Cellulose	Stents	(6)
Chitosan	Drug delivery	(2)
Chitosan	Microspheres	(4)
Chitosan	Stents	(6)
Collagen	Microspheres	(4)
Collagen	Stents	(6)
Collagen	Tissue marker	
Crystalline poly(vinylfluoride) with white pigment	Spacecraft	(3)
Dextran	Drug delivery	(2)
Dextrin	Drug delivery	(2)
Elastin	Microspheres	(4)

Table 1.1 (cont.) Homopolymers and uses.

Polymer	Usage	References
Epoxide or epoxy resin	Spacecraft	(3)
Epoxy Araldite A	Spacecraft, Adhesive	(8)
Epoxy. Araldite F	Spacecraft, Potting	(8)
Epoxy-glass laminate	Spacecraft, Circuit board	(8)
Fibrin	Microspheres	(4)
Fibrinogen	Stents	(6)
Gelatin	Microspheres	(4)
Gelatin	Tissue marker	
Gellan Gum	Drug delivery	(2)
Glycoproteins	Microspheres	(4)
Guar Gum	Drug delivery	(2)
Heparin	Contact lenses	(9)
Hyaluronic acid	Stents	(6)
Hydroxylpropyl cellulose	Pore-forming agent	(5)
Hydroxypropyl methyl cellulose	Bilayer tablets	(10)
Inulin	Drug delivery	(2)
Isotactic poly(propylene)	Membranes	(11)
Kapton H film	Spacecraft, Thermal insulation	(8)
Karaya Gum	Drug delivery	(2)
Konjac Glucomannan	Drug delivery	(2)
Laminin	Microspheres	(4)
Locust Bean Gum	Drug delivery	(2)
Nylon 66 Poly(caprolactam)	Stents	(6)
Pectin	Drug delivery	(2)
PETP Mylar film	Spacecraft, Thermal insulation	(8)
Perfluorosulfonic acid polymer	Membranes	(7)
Poly(*D*,*L*-lactic acid)	Stents	(12)

Table 1.1 (cont.) Homopolymers and uses.

Polymer	Usage	References
Poly(*D*-glucosamine)	Cationic polyelectrolyte	(13)
Poly(*L*-lactic acid)	Stents	(12)
Poly(*L*-lactic acid)	Stents	(6)
Poly(*L*-lysine)	Triboelectricity	(14)
Poly(*N*,*N*-diethyl acrylamide)	Contact lenses	(9)
Poly(*N*,*N*-dimethyl acrylamide)	Contact lenses	(9)
Poly(*N*-vinyl-2-pyrrolidone)	Pore-forming agent	(5)
Poly(*N*-acetylglucosamine)	Stents	(6)
Poly(*N*-isopropyl acrylamide)	Contact lenses	(9)
Poly(*N*-methyl-*N*-vinyl acetamide)	Contact lenses	(9)
Poly(*N*-methylvinylamine)	Cationic polyelectrolyte	(13)
Poly(*N*-vinyl acetamide)	Contact lenses	(9)
Poly(*N*-vinyl formamide)	Contact lenses	(9)
Poly(*N*-vinyl pyrrolidone)	Contact lenses	(9)
Poly(*N*-vinyl pyrrolidone)	Wound dressing	(15)
Poly(*N*-vinyl-2-caprolactam)	Contact lenses	(9)
Poly(*N*-vinyl-2-piperidone)	Contact lenses	(9)
Poly(*N*-vinyl-3-ethyl-2-pyrrolidone)	Contact lenses	(9)
Poly(*N*-vinyl-3-methyl-2-caprolactam)	Contact lenses	(9)
Poly(*N*-vinyl-3-methyl-2-piperidone)	Contact lenses	(9)
Poly(*N*-vinyl-4,5-dimethyl-2-pyrrolidone)	Contact lenses	(9)
Poly(*N*-vinyl-4-methyl-2-caprolactam)	Contact lenses	(9)
Poly(*N*-vinyl-4-methyl-2-piperidone)	Contact lenses	(9)
Poly-(*p*-phenylene terephthalamide)	Spacecraft	(3)

Table 1.1 (cont.) Homopolymers and uses.

Polymer	Usage	References
Poly(*p*-phenylene-2.6-benzobisoxazole)	Spacecraft	(3)
Poly(1,6)-*α*-*D*-glucose sulfate	Anionic electrolyte	(13)
Poly(1-butyl-3-vinylimidazolium hexafluorophosphate)	Electrolytes	(16)
Poly(2-dimethylaminoethyl methacrylate)	Cationic electrolyte	(13)
Poly(2-ethyl oxazoline)	Contact lenses	(9)
Poly(2-hydroxy-3-methacryloxypropyltrimethyl-ammonium chloride)	Cationic electrolyte	(13)
Poly(2-hydroxyethyl methacrylate)	Contact lenses	(17)
Poly(2-hydroxyethyl methacrylate)	Contact lenses	(18)
Poly(2-methacryloxyethyltrimethylammonium bromide)	Cationic electrolyte	(13)
Poly(2-vinyl-1 methylpyridinium bromide)	Cationic electrolyte	(13)
Poly(2-vinylimidazole)	Contact lenses	(9)
Poly(2-vinylpyridine *N*-oxide)	Cationic electrolyte	(13)
Poly(2-vinylpyridine)	Cationic electrolyte	(13)
Poly(3-chloro-2-hydroxypropyl-2-methacroxyethyldimethyl ammonium chloride)	Cationic electrolyte	(13)
Poly(3-hexylthiophene)	Heterojunction solar cells	(19, 20)
Poly(4-aminostyrene)	Cationic electrolyte	(13)
Poly(4-hydroxy-L-proline ester)	Stents	(12)
Poly(4-vinyl-1 methylpyridinium bromide)	Cationic electrolyte	(13)
Poly(4-vinylbenzyltrimethylammonium chloride)	Cationic electrolyte	(13)

Table 1.1 (cont.) Homopolymers and uses.

Polymer	Usage	References
Poly(4-vinylpyridine *N*-oxide)	Cationic electrolyte	(13)
Poly(4-vinylpyridine) Poly(acetal)	Spacecraft, Insulating parts	(8)
Poly(acetylene)	Photovoltaics	(21)
Poly(acryl esters)	Contact lenses	(9)
Poly(acrylamide)	Capping agent	(13)
Poly(acrylamide/2-methacryloxyethyl-trimethylammonium bromide)	Cationic electrolyte	(13)
Poly(acrylate)	Contact lenses	(9)
Poly(acrylic acid)	Lubricant Additives	(22)
Poly(acrylic acid)	Anionic electrolyte	(13)
Poly(acrylic acid)	Bilayer tablets	(10)
Poly(acrylonitrile)	Spacecraft	(3)
Poly(acrylonitrile)	Membranes	(7)
Poly(acryloyl morpholine)	Contact lenses	(9)
Poly(allylamine hydrochloride)	Cationic electrolyte	(13)
Poly(amic acid)	Spacecraft Coating	(23)
Poly(amide) 6 or nylon 6	Spacecraft	(3)
Poly(amide) 66 or nylon 66	Spacecraft	(3)
Poly(aniline)	Electrically conductive polymer	(24–29)
Poly(benzimidazole)	Spacecraft	(3)
Poly(benzimidazole)	Garment system	(30)
Poly(benzoxazine)	Cathode polymer	(31)
Poly(butylene terephthalate)	Spacecraft	(3)
Poly(caprolactone)	Stents	(6)
Poly(caprolactone)	Tissue marker	
Poly(carbonate)	Contact lenses	(32)

Table 1.1 (cont.) Homopolymers and uses.

Polymer	Usage	References
Poly(carbosilane)	Preceramic precursor	(33, 34)
Poly(carboxylate)	Surfactant	(35)
Poly(chonroitin-4-sulfate)	Microspheres	(4)
Poly(diallyldimethylammonium chloride)	Cationic electrolyte	(13)
Poly(dimethyl siloxane)	Capping agent	(13)
Poly(dimethyl siloxane)	Ceramics	(36)
Poly(dimethyl siloxane)	Rubber sponge	(37, 38)
Poly(dioxanone)	Tissue marker	
Poly(dopamine)	Batteries	(39)
Poly(etherimide)	Spacecraft	(3)
Poly(etherimide)	Membranes	(7)
Poly(ethersulfone)	Membranes	(7)
Poly(ethylene acrylate)	Stents	(6)
Poly(ethylene amide)	Stents	(6)
Poly(ethylene glycol)	Capping agent	(13)
Poly(ethylene glycol)	Microspheres	(4)
Poly(ethylene glycol)	Pore-forming agent	(5)
Poly(ethylene glycol)dimethyl ether	Capping agent	(13)
Poly(ethylene glycol)mono methyl ether	Capping agent	(13)
Poly(ethylene imine)	Cationic electrolyte	(13)
Poly(ethylene oxide)	Spacecraft	(3)
Poly(ethylene oxide)	Capping agent	(13)
Poly(ethylene oxide)	Contact lenses	(9)
Poly(ethylene terephthalate)	Membranes	(7)
Poly(ethylene)	Spacecraft	(3)
Poly(ethylene) glycol dimethacrylate	Contact lenses	(40)

Table 1.1 (cont.) Homopolymers and uses.

Polymer	Usage	References
Poly(ethylene-dioxythophene)	Electrically conductive	(29)
Poly(glycolic acid)	Stents	(6)
Poly(glycolide)	Microspheres	(4)
Poly(glycolide)s	Tissue marker	
Poly(heparan sulfate)	Microspheres	(4)
Poly(hexamethylene oxamate)	Microspheres	(4)
Poly(hydroxybutyrate)	Stents	(12)
Poly(hydroxybutyrate)	Stents	(6)
Poly(hydroxymethylethylene hydroxymethylacetal)	Biodegradable	(41)
Poly(hydroxymethylethylene hydroxymethylacetal)	Contact lenses	(17)
Poly(hydroxyvalerate)	Stents	(12)
Poly(hydroxyvalerate)	Stents	(6)
Poly(imide)	Spacecraft	(3)
Poly(imide)	Spacecraft, Solid lubricant	(8)
Poly(imide) (BPDA)	Spacecraft	(3)
Poly(imide) (PMDA)	Spacecraft	(3)
Poly(imide) resin, high temperature	Spacecraft	(3)
Poly(isopropyl *N*-polyacrylamide)	Contact lenses	(42)
Poly(lactide)	Microspheres	(4)
Poly(lactide)s	Tissue marker	
Poly(lauryl methacrylate)	Anionic electrolyte	(13)
Poly(lysine)	Contact lenses	(43)
Poly(maleic acid)	Anionic electrolyte	(13)
Poly(metaphosphate)	Scale inhibitors	(44, 45)
Poly(methacrylic acid)	Lubricant Additives	(22)

Table 1.1 (cont.) Homopolymers and uses.

Polymer	Usage	References
Poly(methacrylic acid)	Anionic electrolyte	(13)
Poly(methyl methacrylate)	Spacecraft	(3)
Poly(methyl methacrylate)	Anionic electrolyte	(13)
Poly(methyl methacrylate)	Capping agent	(13)
Poly(morpholinedione)	Microspheres	(4)
Poly(organo siloxane)	Airbag	(46)
Poly(ornithine)	Contact lenses	(43)
Poly(oxyethylene)	Capping agent	(13)
Poly(oxymethylene)	Spacecraft	(3)
Poly(phenylene isophthalate)	Spacecraft	(3)
Poly(phenylene oxide)	Membranes	(7)
Poly(phenylene vinylene)	Photovoltaics	(47)
Poly(phosphate)	Lubricant Additives	(48)
Poly(phosphazene)	Microspheres	(4)
Poly(propylene glycol)	Capping agent	(13)
Poly(propylene oxide)	Capping agent	(13)
Poly(propylene)	Spacecraft	(3)
Poly(pyrrole)	Electrically conductive polymer	(24–29)
Poly(saccharide)	Thickeners	
Poly(saccharide)	Contact lenses	(9)
Poly(sebacic anhydride)	Microspheres	(4)
Poly(silazane)	Preceramic precursor	(33, 34)
Poly(siloxane)	Contact lenses	
Poly(styrene sulfonic acid)	Anionic electrolyte	(13)
Poly(styrene)	Spacecraft	(3)
Poly(styrene)	Stents	(6)
Poly(styrenephosphoric acid)	Anionic electrolyte	(13)

Table 1.1 (cont.) Homopolymers and uses.

Polymer	Usage	References
Poly(sulfide)	Lubricant Additives	(49)
Poly(sulfide)	Batteries	(50)
Poly(sulfide)	Fuel tank	(51)
Poly(sulfone)	Spacecraft	(3)
Poly(tetrafluoroethylene)	Membranes	(7)
Poly(tetramethylene oxide)bis-4-aminobenzoate	Cationic electrolyte	(13)
Poly(tetramethyleneoxide)	Shape memory	(52)
Poly(thiophene)	Electrically conductive polymer	(24–28)
Poly(trimethylene carbonate)	Stents	(6)
Poly(urethane)	Spacecraft	(3)
Poly(urethane) composite	Shape memory	(53, 54)
Poly(urethane) H 32	Spacecraft, Conducting Paint	(8)
Poly(urethane) Z 306	Spacecraft, Paint	(8)
Poly(urethane)	Scaffold	(55)
Poly(vinyl acetate)	Capping agent	(13)
Poly(vinyl acetate)	Clay stabilizers	
Poly(vinyl acetate)	Stents	(6)
Poly(vinyl alcohol) hydrogel	Contact lenses	(56)
Poly(vinyl alcohol)	Capping agent	(13)
Poly(vinyl alcohol)	Contact lenses	(9)
Poly(vinyl fluoride)	Spacecraft	(3)
Poly(vinyl methyl ether)	Capping agent	(13)
Poly(vinyl methyl ether)	Stents	(6)
Poly(vinyl pyrrolidone)	Capping agent	(13)
Poly(vinyl pyrrolidone)	Contact lenses	(17)
Poly(vinylamine)hydrochloride	Cationic electrolyte	(13)
Poly(vinylidene chloride)	Stents	(6)
Poly(vinylidene fluoride)	Membranes	(7)

Table 1.1 (cont.) Homopolymers and uses.

Polymer	Usage	References
Poly(vinylidene fluoride)	Electroactive	(57–60)
Poly(vinylphosphoric acid)	Anionic electrolyte	(13)
Poly(vinylsulfonic acid)	Anionic electrolyte	(13)
Polymeric ionic liquids		(61)
Polyolefin	Spacecraft, Heat-shrink sleeving	(8)
Psyllium Husk	Drug delivery	(2)
Pyrolytic graphite	Spacecraft	(3)
Rayon triacetate	Stents	(6)
Rayon	Stents	(6)
Silicone elastomer	Spacecraft, Seals	(8)
Siloxane poly(ether)	Wetting agent	(46)
Soy protein	Microspheres	(4)
Scleroglucan	Drug delivery	(2)
Starch	Drug delivery	(2)
Starch	Stents	(6)
Teflon	Spacecraft, Wire sleeving	(8)
Teflon film	Spacecraft, Thermal insulation	(8)
Teflon-glass-MoS_2	Spacecraft, Bearings	(8)
Viton A	Spacecraft, Seals	(8)
Xanthan Gum	Drug delivery	(2)

Table 1.2 Copolymers and uses.

Polymer	Usage	References
1,5-Dioxepan-2-one *L*-lactide copolymers	Microspheres	(4)
3-Oxacaprolactone copolymers	Microspheres	(4)
6-Caprolactone copolymers	Microspheres	(4)
Acrylate copolymer	pH-Responsive Thickeners	(62)
Acrylic acid ethyl acrylate tristyrylpoly(ethyleneoxy)$_x$ methyl carboxyl terminated poly(butadiene/acrylonitrile)	Anionic electrolyte	(13)
Copolyester elastomer	Cold weather articles	(63)
Methacrylate triblock copolymer	Engine oils	(64)
Pluronic™	Surfactant	(65)
Poly(*D*,*L*-lactic acid-*co*-*L*-aspartic acid)	Stents	(12)
Poly(*D*,*L*-lactic acid-*co*-ethylene glycol)	Stents	(12)
Poly(*D*,*L*-lactide-*co*-caprolactone)	Implant	
Poly(*L*-lactic acid-*co*-*L*-aspartic acid)	Stents	(12)
Poly(*L*-lactic acid-*co*-ethylene glycol)	Stents	(12)
Poly(*N*-vinylpyrrolidone/2-dimethylaminoethyl methacrylate)	Cationic electrolyte	(13)
Poly(1,10-decanediol-*co*-*L*-lactic acid)	Stents	(12)
Poly(1,10-decanodiol-*co*-*D*,*L*-lactic acid)	Stents	(12)

Table 1.2 (cont.) Copolymers and uses.

Polymer	Usage	References
Poly(1,2,6-hexanetriol-*co*-trimethylorthoacetate)	Stents	(12)
Poly(butadiene/maleic acid)	Anionic electrolyte	(13)
Poly(butyl acrylate/acrylic acid)	Anionic electrolyte	(13)
Poly(ether urethane)	Shape-memory foams	(66)
Poly(ethylene glycol-*co*-butylene terephthalate)	Stents	(12)
Poly(ethylene/maleic acid)	Anionic electrolyte	(13)
Poly(hydroxybutyrate-*co*-valerate)	Stents	(6, 12)
Poly(lactide-*co*-glycolide)	Stents	(6)
Poly(lactide-*co*-glycolide)	Wound dressing	(15)
Poly(maleic acid-*co*-sebacic acid)	Stents	(12)
Poly(methyl methacrylate/methacrylic acid)	Anionic electrolyte	(13)
Poly(stearyl methacrylate)-poly(benzyl Poly(vinyl methyl ether/maleic acid)	Anionic electrolyte	(13)
Poly(vinyl methyl ether/-mono ethyl maleate)	Anionic electrolyte	(13)
Poly(vinyl methyl ether/-monobutyl maleate)	Anionic electrolyte	(13)
Poly(vinyl methyl ether/-mono-iso-propyl maleate)	Anionic electrolyte	(13)

Table 1.3 Uses and homopolymers.

Usage	Polymer	References
Airbag	Poly(organo siloxane)	(46)
Anionic electrolyte	Poly(1,6)-*α*-*D*-glucose sulfate	(13)
Anionic electrolyte	Poly(acrylic acid)	(13)
Anionic electrolyte	Poly(lauryl methacrylate)	(13)
Anionic electrolyte	Poly(maleic acid)	(13)
Anionic electrolyte	Poly(methacrylic acid)	(13)
Anionic electrolyte	Poly(methyl methacrylate)	(13)
Anionic electrolyte	Poly(styrene sulfonic acid)	(13)
Anionic electrolyte	Poly(styrenephosphoric acid)	(13)
Anionic electrolyte	Poly(vinylphosphoric acid)	(13)
Batteries	Poly(dopamine)	(39)
Batteries	Poly(sulfide)	(50)
Bilayer tablets	Hydroxypropyl methyl cellulose	(10)
Bilayer tablets	Poly(acrylic acid)	(10)
Biodegradable	Poly(hydroxymethylethylene hydroxymethylacetal)	(41)
Capping agent	Poly(acrylamide)	(13)
Capping agent	Poly(dimethyl siloxane)	(13)
Capping agent	Poly(ethylene glycol)	(13)
Capping agent	Poly(ethylene glycol)dimethyl ether	(13)
Capping agent	Poly(ethylene glycol)mono methyl ether	(13)
Capping agent	Poly(ethylene oxide)	(13)
Capping agent	Poly(methyl methacrylate)	(13)

Table 1.3 (cont.) Uses and homopolymers.

Usage	Polymer	References
Capping agent	Poly(oxyethylene)	(13)
Capping agent	Poly(propylene glycol)	(13)
Capping agent	Poly(propylene oxide)	(13)
Capping agent	Poly(vinyl acetate)	(13)
Capping agent	Poly(vinyl alcohol)	(13)
Capping agent	Poly(vinyl methyl ether)	(13)
Capping agent	Poly(vinyl pyrrolidone)	(13)
Cathode polymer	Poly(benzoxazine)	(31)
Cationic electrolyte	Poly(2-dimethylaminoethyl methacrylate)	(13)
Cationic electrolyte	Poly(2-hydroxy-3-methacryloxy-propyltrimethyl-ammonium chloride)	(13)
Cationic electrolyte	Poly(2-methacryloxyethyltrimethyl-ammonium bromide)	(13)
Cationic electrolyte	Poly(2-vinyl-1 methylpyridinium bromide)	(13)
Cationic electrolyte	Poly(2-vinylpyridine *N*-oxide)	(13)
Cationic electrolyte	Poly(2-vinylpyridine)	(13)
Cationic electrolyte	Poly(3-chloro-2-hydroxypropyl-2-methacroxyethyldimethyl ammonium chloride)	(13)
Cationic electrolyte	Poly(4-aminostyrene)	(13)
Cationic electrolyte	Poly(4-vinyl-1 methylpyridinium bromide)	(13)
Cationic electrolyte	Poly(4-vinylbenzyltrimethyl-ammonium chloride)	(13)
Cationic electrolyte	Poly(4-vinylpyridine *N*-oxide)	(13)
Cationic electrolyte	Poly(acrylamide/2-methacryloxyethyl-trimethylammonium bromide)	(13)

Table 1.3 (cont.) Uses and homopolymers.

Usage	Polymer	References
Cationic electrolyte	Poly(allylamine hydrochloride)	(13)
Cationic electrolyte	Poly(diallyldimethylammonium chloride)	(13)
Cationic electrolyte	Poly(ethylene imine)	(13)
Cationic electrolyte	Poly(tetramethylene oxide)bis-4-aminobenzoate	(13)
Cationic electrolyte	Poly(vinylamine)hydrochloride	(13)
Cationic polyelectrolyte	Poly(*D*-glucosamine)	(13)
Cationic polyelectrolyte	Poly(*N*-methylvinylamine)	(13)
Ceramics	Poly(dimethyl siloxane)	(36)
Clay stabilizers	Poly(vinyl acetate)	
Contact lenses	Heparin	(9)
Contact lenses	Poly(*N*,*N*-diethyl acrylamide)	(9)
Contact lenses	Poly(*N*,*N*-dimethyl acrylamide)	(9)
Contact lenses	Poly(*N*-isopropyl acrylamide)	(9)
Contact lenses	Poly(*N*-methyl-*N*-vinyl acetamide)	(9)
Contact lenses	Poly(*N*-vinyl acetamide)	(9)
Contact lenses	Poly(*N*-vinyl formamide)	(9)
Contact lenses	Poly(*N*-vinyl pyrrolidone)	(9)
Contact lenses	Poly(*N*-vinyl-2-caprolactam)	(9)
Contact lenses	Poly(*N*-vinyl-2-piperidone)	(9)
Contact lenses	Poly(*N*-vinyl-3-ethyl-2-pyrrolidone)	(9)
Contact lenses	Poly(*N*-vinyl-3-methyl-2-caprolactam)	(9)
Contact lenses	Poly(*N*-vinyl-3-methyl-2-piperidone)	(9)
Contact lenses	Poly(*N*-vinyl-4,5-dimethyl-2-pyrrolidone)	(9)

Table 1.3 (cont.) Uses and homopolymers.

Usage	Polymer	References
Contact lenses	Poly(*N*-vinyl-4-methyl-2-caprolactam)	(9)
Contact lenses	Poly(*N*-vinyl-4-methyl-2-piperidone)	(9)
Contact lenses	Poly(2-ethyl oxazoline)	(9)
Contact lenses	Poly(2-hydroxyethyl methacrylate)	(17)
Contact lenses	Poly(2-hydroxyethyl methacrylate)	(18)
Contact lenses	Poly(2-vinylimidazole)	(9)
Contact lenses	Poly(acryl esters)	(9)
Contact lenses	Poly(acrylate)	(9)
Contact lenses	Poly(acryloyl morpholine)	(9)
Contact lenses	Poly(carbonate)	(32)
Contact lenses	Poly(ethylene oxide)	(9)
Contact lenses	Poly(ethylene) glycol dimethacrylate	(40)
Contact lenses	Poly(hydroxymethylethylene hydroxymethylacetal)	(17)
Contact lenses	Poly(isopropyl *N*-polyacrylamide)	(42)
Contact lenses	Poly(lysine)	(43)
Contact lenses	Poly(ornithine)	(43)
Contact lenses	Poly(saccharide)	(9)
Contact lenses	Poly(siloxane)	
Contact lenses	Poly(vinyl alcohol)	(9)
Contact lenses	Poly(vinyl alcohol) hydrogel	(56)
Contact lenses	Poly(vinyl pyrrolidone)	(17)
Drug delivery	Acacia	(2)
Drug delivery	Agar	(2)
Drug delivery	Alginate	(2)
Drug delivery	Carrageenan	(2)
Drug delivery	Cellulose	(2)
Drug delivery	Chitosan	(2)
Drug delivery	Dextran	(2)
Drug delivery	Dextrin	(2)
Drug delivery	Gellan Gum	(2)
Drug delivery	Guar Gum	(2)

Table 1.3 (cont.) Uses and homopolymers.

Usage	Polymer	References
Drug delivery	Inulin	(2)
Drug delivery	Karaya Gum	(2)
Drug delivery	Konjac Glucomannan	(2)
Drug delivery	Locust Bean Gum	(2)
Drug delivery	Pectin	(2)
Drug delivery	Psyllium Husk	(2)
Drug delivery	Scleroglucan	(2)
Drug delivery	Starch	(2)
Drug delivery	Xanthan Gum	(2)
Electrically conductive	Poly(ethylene-dioxythophene)	(29)
Electrically conductive polymer	Poly(aniline)	(24–29)
Electrically conductive polymer	Poly(pyrrole)	(24–29)
Electrically conductive polymer	Poly(thiophene)	(24–28)
Electroactive	Poly(vinylidene fluoride)	(57–60)
Electrolytes	Poly(1-butyl-3-vinylimidazolium hexafluorophosphate)	(16)
Fuel tank	Poly(sulfide)	(51)
Garment system	Poly(benzimidazole)	(30)
Heterojunction solar cells	Poly(3-hexylthiophene)	(19, 20)
Lubricant Additives	Poly(acrylic acid)	(22)
Lubricant Additives	Poly(methacrylic acid)	(22)
Lubricant Additives	Poly(phosphate)	(48)
Lubricant Additives	Poly(sulfide)	(49)
Membranes	Polymeric ionic liquids	(61)
Membranes	Cellulose acetate	(7)

Table 1.3 (cont.) Uses and homopolymers.

Usage	Polymer	References
Membranes	Cellulose nitrate	(7)
Membranes	Isotactic poly(propylene)	(11)
Membranes	Perfluorosulfonic acid polymer	(7)
Membranes	Poly(acrylonitrile)	(7)
Membranes	Poly(etherimide)	(7)
Membranes	Poly(ethersulfone)	(7)
Membranes	Poly(ethylene terephthalate)	(7)
Membranes	Poly(phenylene oxide)	(7)
Membranes	Poly(tetrafluoroethylene)	(7)
Membranes	Poly(vinylidene fluoride)	(7)
Microspheres	Acylated insulin	(4)
Microspheres	Albumin	(4)
Microspheres	Chitosan	(4)
Microspheres	Collagen	(4)
Microspheres	Elastin	(4)
Microspheres	Fibrin	(4)
Microspheres	Gelatin	(4)
Microspheres	Glycoproteins	(4)
Microspheres	Laminin	(4)
Microspheres	Poly(chonroitin-4-sulfate)	(4)
Microspheres	Poly(ethylene glycol)	(4)
Microspheres	Poly(glycolide)	(4)
Microspheres	Poly(heparan sulfate)	(4)
Microspheres	Poly(hexamethylene oxamate)	(4)
Microspheres	Poly(lactide)	(4)
Microspheres	Poly(morpholinedione)	(4)
Microspheres	Poly(phosphazene)	(4)
Microspheres	Poly(sebacic anhydride)	(4)
Microspheres	Soy protein	(4)
Photovoltaics	Poly(acetylene)	(21)
Photovoltaics	Poly(phenylene vinylene)	(47)
Pore-forming	Carboxymethyl cellulose	(5)
Pore-forming agent	Hydroxylpropyl cellulose	(5)

Table 1.3 (cont.) Uses and homopolymers.

Usage	Polymer	References
Pore-forming agent	Poly(*N*-vinyl-2-pyrrolidone)	(5)
Pore-forming agent	Poly(ethylene glycol)	(5)
Preceramic precursor	Poly(carbosilane)	(33, 34)
Preceramic precursor	Poly(silazane)	(33, 34)
Rubber sponge	Poly(dimethyl siloxane)	(37, 38)
Scaffold	Poly(urethane)	(55)
Scale inhibitors	Poly(metaphosphate)	(44, 45)
Shape memory	Poly(tetramethyleneoxide)	(52)
Shape memory	Poly(urethane) composite	(53, 54)
Spacecraft	Acrylonitrile butadiene styrene	(3)
Spacecraft	Allyl diglycol carbonate	(3)
Spacecraft	Cellulose acetate	(3)
Spacecraft	Crystalline poly(vinylfluoride) with white pigment	(3)
Spacecraft	Epoxide or epoxy resin	(3)
Spacecraft	Poly-(*p*-phenylene terephthalamide)	(3)
Spacecraft	Poly(*p*-phenylene-2.6-benzobisoxazole)	(3)
Spacecraft	Poly(acrylonitrile)	(3)
Spacecraft	Poly(amide) 6 or nylon 6	(3)
Spacecraft	Poly(amide) 66 or nylon 66	(3)
Spacecraft	Poly(benzimidazole)	(3)
Spacecraft	Poly(butylene terephthalate)	(3)
Spacecraft	Poly(etherimide)	(3)
Spacecraft	Poly(ethylene oxide)	(3)
Spacecraft	Poly(ethylene)	(3)
Spacecraft	Poly(imide)	(3)

Table 1.3 (cont.) Uses and homopolymers.

Usage	Polymer	References
Spacecraft	Poly(imide) (BPDA)	(3)
Spacecraft	Poly(imide) (PMDA)	(3)
Spacecraft	Poly(imide) resin, high temperature	(3)
Spacecraft	Poly(methyl methacrylate)	(3)
Spacecraft	Poly(oxymethylene)	(3)
Spacecraft	Poly(phenylene isophthalate)	(3)
Spacecraft	Poly(propylene)	(3)
Spacecraft	Poly(styrene)	(3)
Spacecraft	Poly(sulfone)	(3)
Spacecraft	Poly(urethane)	(3)
Spacecraft	Poly(vinyl fluoride)	(3)
Spacecraft	Pyrolytic graphite	(3)
Spacecraft Coating	Poly(amic acid)	(23)
Spacecraft, Adhesive	Epoxy Araldite A	(8)
Spacecraft, Bearings	Teflon-glass-MoS_2	(8)
Spacecraft, Circuit board	Epoxy-glass laminate	(8)
Spacecraft, Conducting Paint	Poly(urethane) H 32	(8)
Spacecraft, Heat-shrink sleeving	Polyolefin	(8)
Spacecraft, Insulating parts	Poly(acetal)	(8)
Spacecraft, Paint	Poly(urethane) Z 306	(8)
Spacecraft, Potting	Epoxy. Araldite F	(8)
Spacecraft, Seals	Silicone elastomer	(8)
Spacecraft, Seals	Viton A	(8)

Table 1.3 (cont.) Uses and homopolymers.

Usage	Polymer	References
Spacecraft, Solid lubricant	Poly(imide)	(8)
Spacecraft, Thermal insulation	Kapton H film	(8)
Spacecraft, Thermal insulation	PETP Mylar film	(8)
Spacecraft, Thermal insulation	Teflon film	(8)
Spacecraft, Wire sleeving	Teflon	(8)
Stents	Carboxymethyl cellulose	(6)
Stents	Cellophane	(6)
Stents	Cellulose	(6)
Stents	Cellulose acetate	(6)
Stents	Cellulose acetate butyrate	(6)
Stents	Cellulose butyrate	(6)
Stents	Cellulose nitrate	(6)
Stents	Cellulose propionate	(6)
Stents	Chitosan	(6)
Stents	Collagen	(6)
Stents	Fibrinogen	(6)
Stents	Hyaluronic acid	(6)
Stents	Nylon 66 Poly(caprolactam)	(6)
Stents	Poly(*D*,*L*-lactic acid)	(12)
Stents	Poly(*L*-lactic acid)	(12)
Stents	Poly(*L*-lactic acid)	(6)
Stents	Poly(*N*-acetylglucosamine)	(6)
Stents	Poly(4-hydroxy-L-proline ester)	(12)
Stents	Poly(caprolactone)	(6)
Stents	Poly(ethylene acrylate)	(6)
Stents	Poly(ethylene amide)	(6)
Stents	Poly(glycolic acid)	(6)

Table 1.3 (cont.) Uses and homopolymers.

Usage	Polymer	References
Stents	Poly(hydroxybutyrate)	(12)
Stents	Poly(hydroxybutyrate)	(6)
Stents	Poly(hydroxyvalerate)	(12)
Stents	Poly(hydroxyvalerate)	(6)
Stents	Poly(styrene)	(6)
Stents	Poly(trimethylene carbonate)	(6)
Stents	Poly(vinyl acetate)	(6)
Stents	Poly(vinyl methyl ether)	(6)
Stents	Poly(vinylidene chloride)	(6)
Stents	Rayon	(6)
Stents	Rayon triacetate	(6)
Stents	Starch	(6)
Surfactant	Poly(carboxylate)	(35)
Thickeners	Poly(saccharide)	
Tissue marker	Collagen	
Tissue marker	Gelatin	
Tissue marker	Poly(caprolactone)	
Tissue marker	Poly(dioxanone)	
Tissue marker	Poly(glycolide)s	
Tissue marker	Poly(lactide)s	
Triboelectricity	Poly(*L*-lysine)	(14)
Wetting agent	Siloxane poly(ether)	(46)
Wound dressing	Poly(*N*-vinyl pyrrolidone)	(15)

References

1. P.E. Cassidy, An overview of polymers for harsh environments; aerospace, geothermal and undersea in L.-H. Lee, (Ed.), *Adhesives, Sealants, and Coatings for Space and Harsh Environments*, pp. 187–200. Springer US, Boston, MA, 1988.
2. N. Rajesh, N. Uma., and R. Valluru, Natural polymers - a boon for drug delivery in V. Mittal, (Ed.), *Renewable Polymers: Synthesis, Processing, and Technology*, chapter 10, pp. 429–472. Wiley-Scrivener, Beverly, USA, October 2011.

3. B.A. Banks, J.A. Backus, M.V. Manno, D.L. Waters, K.C. Cameron, and K.K. de Groh, Atomic oxygen erosion yield prediction for spacecraft polymers in low Earth orbit, in *Proceedings of the International Symposium on Materials in a Space Environment (ISMSE-11)*, 2009.
4. D. Radulescu, Method for forming polymer microspheres, US Patent 6 998 074, assigned to MicroFab Technologies, Inc. (Plano, TX), February 14, 2006.
5. R.L. Dunn, A.J. Tipton, G.L. Southard, and J.A. Rogers, Biodegradable polymer composition, US Patent 5 599 552, assigned to Atrix Laboratories, Inc. (Fort Collins, CO), February 4, 1997.
6. W.J. Fox, N. Harold, A. Garcia, and A. Tochterman, Bioabsorbable stent with prohealing layer, US Patent 8 535 372, assigned to Abbott Cardiovascular Systems Inc. (Santa Clara, CA), September 17, 2013.
7. M. Ulbricht, Advanced functional polymer membranes, *Polymer*, Vol. 47, p. 2217, 2006. Single Chain Polymers.
8. T.J. Patrick, Space environment and vacuum properties of spacecraft materials, *Vacuum*, Vol. 31, p. 351, 1981.
9. T.L. Maggio, M.C. Turnage, M.R. Clark, K. Fujisawa, and M. Nakamura, Silicone (meth)acrylamide monomer, polymer, ophthalmic lens, and contact lens, US Patent 8 415 405, assigned to Johnson and Johnson Vision Care Inc., April 09, 2013.
10. J. Lichter, B. Vollrath, A.M. Trammel, S.G. Duron, F. Piu, L.A. Dellamary, Q. Ye, C. Lebel, M.C. Scaife, and J.P. Harris, Controlled release corticosteroid compositions and methods for the treatment of otic disorders, US Patent 8 680 083, assigned to Otonomy, Inc. (San Diego, CA) The Regents of the University of California (Oakland, CA), March 25, 2014.
11. L.J. Zeman and A. Zydney, *Microfiltration and Ultrafiltration: Principles and Applications*, CRC Press, 2017.
12. S.F.A. Hossainy and D. Dutta, Biodegradable polymers for use with implantable medical devices, US Patent 7 875 283, assigned to Advanced Cardiovascular Systems, Inc. (Santa Clara, CA), January 25, 2011.
13. J.A. Lewis, Q. Li, and R. Rao, Biphasic inks, US Patent 8 187 500, assigned to The Board of Trustees of the University of Illinois (Urbana, IL), May 29, 2012.
14. S.-H. Shin, Y.H. Kwon, Y.-H. Kim, J.-Y. Jung, M.H. Lee, and J. Nah, Triboelectric charging sequence induced by surface functionalization as a method to fabricate high performance triboelectric generators, *ACS Nano*, Vol. 9, p. 4621, 2015.
15. B.G. Belenkaya, V.I. Sakharova, and V.N. Polevov, Biodegradable absorbents and methods of preparation, US Patent 7 309 498, December 18, 2007.

16. S. Mogurampelly and V. Ganesan, Ion transport in polymerized ionic liquid—ionic liquid blends, *Macromolecules*, Vol. 51, p. 9471, 2018.
17. Y. Goto and M. Nakada, Decentered type contact lens and decentered type contact lens set, US Patent 10 444 542, assigned to Menicon Co. Ltd., October 15, 2019.
18. M.S. Rad, B. Khameneh, Z. Sabeti, S.A. Mohajeri, and B.S.F. Bazzaz, Antibacterial activity of silver nanoparticle-loaded soft contact lens materials: The effect of monomer composition, *Current Eye Research*, Vol. 41, p. 1286, 2016.
19. C.-J. Ko, Y.-K. Lin, F.-C. Chen, and C.-W. Chu, Modified buffer layers for polymer photovoltaic devices, *Applied Physics Letters*, Vol. 90, p. 063509, 2007.
20. M. Reyes-Reyes, K. Kim, and D.L. Carroll, High-efficiency photovoltaic devices based on annealed poly(3-hexylthiophene) and 1-(3-methoxycarbonyl)-propyl-1-phenyl-(6,6)C61 blends, *Applied Physics Letters*, Vol. 87, p. 083506, 2005.
21. J. Kanicki and P. Fedorko, Electrical and photovoltaic properties of trans-polyacetylene, *Journal of Physics D: Applied Physics*, Vol. 17, p. 805, 1984.
22. S. Hachiya, K.-I. Shinoda, and Y. Higo, Lubricant for use in hot rolling of stainless steel, US Patent 5 468 402, assigned to Nippon Steel Nisshin Co. Ltd., November 21, 1995.
23. G. Poe and B. Farmer, Polymeric coating for the protection of objects, US Patent 8 309 627, assigned to NeXolve Corp., November 13, 2012.
24. J. Wang, J. Chen, K. Konstantinov, L. Zhao, S. Ng, G. Wang, Z. Guo, and H. Liu, Sulphur-polypyrrole composite positive electrode materials for rechargeable lithium batteries, *Electrochimica Acta*, Vol. 51, p. 4634, 2006.
25. M. Sun, S. Zhang, T. Jiang, L. Zhang, and J. Yu, Nano-wire networks of sulfur-polypyrrole composite cathode materials for rechargeable lithium batteries, *Electrochemistry Communications*, Vol. 10, p. 1819, 2008.
26. X. Liang, Y. Liu, Z. Wen, L. Huang, X. Wang, and H. Zhang, A nano-structured and highly ordered polypyrrole-sulfur cathode for lithium-sulfur batteries, *Journal of Power Sources*, Vol. 196, p. 6951, 2011. 15th International Meeting on Lithium Batteries (IMLB).
27. X. Liang, Z. Wen, Y. Liu, H. Zhang, J. Jin, M. Wu, and X. Wu, A composite of sulfur and polypyrrole–multi walled carbon combinatorial nanotube as cathode for Li/S battery, *Journal of Power Sources*, Vol. 206, p. 409, 2012.
28. Y. Fu, Y.-S. Su, and A. Manthiram, Sulfur-polypyrrole composite cathodes for lithium-sulfur batteries, *Journal of the Electrochemical Society*, Vol. 159, p. A1420, 2012.

29. C.R. Dandekar, K. Mahalatkar, M.K. Verma, S. Sarkar, K.G. Phaneuf, and J.A. Mapkar, Electrically conductive polymers as sensing media to detect leaks in aerospace pneumatic ducts, US Patent 9 989 435, assigned to Eaton Intelligent Power Ltd., June 05, 2018.
30. L.M. Evans, M.L. Flora, M.-P.S. Santo, and T.J. Trombly, Integrated garment system, US Patent 9 015 864, assigned to Massif Mountain Gear Company LLC, April 28, 2015.
31. S.H. Je, T.H. Hwang, S.N. Talapaneni, O. Buyukcakir, H.J. Kim, J.-S. Yu, S.-G. Woo, M.C. Jang, B.K. Son, A. Coskun, and J.W. Choi, Rational sulfur cathode design for lithium–sulfur batteries: Sulfur-embedded benzoxazine polymers, *ACS Energy Letters*, Vol. 1, p. 566, 2016.
32. J.C. Yoo, Y.L. Kang, and M.Y. Kong, Transparent hydrogel membrane including hyaluronic acid, and contact lens including same, US Patent Application 20 200 262 985, assigned to JCBio Co. Ltd., August 20, 2020.
33. E. Ionescu, H.-J. Kleebe, and R. Riedel, Silicon-containing polymer-derived ceramic nanocomposites (PDC-NCs): preparative approaches and properties, *Chemical Society Reviews*, Vol. 41, p. 5032, 2012.
34. G. Mera, M. Gallei, S. Bernard, and E. Ionescu, Ceramic nanocomposites from tailor-made preceramic polymers, *Nanomaterials*, Vol. 5, p. 468, 2015.
35. N.S. Berke, J.S. Merritt, L. Li, J. Antonio J. Aldykiewicz, R.A. Wiercinski, and M.D. Morgan, Articles made from cementitious foam and slurry, US Patent 8 277 556, assigned to WR Grace and Co. Conn., October 02, 2012.
36. D.A. Beckley and J. Stites, Processable silicone composite materials having high temperature resistance, US Patent 5 612 399, assigned to HITCO Carbon Composites Inc., March 18, 1997.
37. M. Irie, Sponge-formable silicone rubber composition and silicone rubber sponge, US Patent Application 20 180 037 709, assigned to Dow Corning Toray Co. Ltd., February 8, 2018.
38. M. Irie, Sponge-formable silicone rubber composition and silicone rubber sponge, US Patent Application 20 180 057 652, assigned to Dow Corning Toray Co. Ltd., March 1, 2018.
39. G.C. Li, H.K. Jing, Z. Su, C. Lai, L. Chen, C.C. Yuan, H.H. Li, and L. Liu, A hydrophilic separator for high performance lithium sulfur batteries, *Journal of Materials Chemistry A*, Vol. 3, p. 11014, 2015.
40. D. Myung, J. Noolandl, C. Ta, and C.W. Frank, Interpenetrating polymer network hydrogel contact lenses, US Patent 7 857 447, assigned to The Board of Trustees of the Leland Stanford Junior University (Palo Alto, CA), December 28, 2010.

41. D.R. Elmaleh, S.C. Robson, and M.L. Papisov, Conjugates comprising a biodegradable polymer and uses therefor, US Patent 7 785 618, August 31, 2010.
42. T. Xu, J.J. Yoo, A. Atala, and D. Dice, Inkjet printing of tissues and cells, US Patent 8 691 274, assigned to Wake Forest University Health Sciences (Winston-Salem, NC), April 8, 2014.
43. E.C. Opara, Microencapsulated pancreatic islet cells, US Patent 6 783 964, assigned to Duke University (Durham, NC), August 31, 2004.
44. Y. Duccini, A. Dufour, W.M. Harm, T.W. Sanders, and B. Weinstein, High performance oilfield scale inhibitors, in *Corrosion97*, New Orleans, LA, March 1997. NACE International.
45. A.A. Umar and I.B.M. Saaid, Silicate scales formation during ASP flooding: A review, *Research Journal of Applied Sciences, Engineering and Technology*, Vol. 6, p. 1543, 2013.
46. M. Barth, W. Blackwood, V. Clerici, and A.W. Mountney, Coated fabric products, US Patent 10 023 994, assigned to Dow Silicones Corp., July 17, 2018.
47. S. Chambon, A. Rivaton, J.-L. Gardette, M. Firon, and L. Lutsen, Aging of a donor conjugated polymer: Photochemical studies of the degradation of poly[2-methoxy-5-(3′,7′-dimethyloctyloxy)-1,4-phenylenevinylene], *Journal of Polymer Science Part A: Polymer Chemistry*, Vol. 45, p. 317, 2007.
48. S. Wan, A.K. Tieu, Y. Xia, H. Zhu, B.H. Tran, and S. Cui, An overview of inorganic polymer as potential lubricant additive for high temperature tribology, *Tribology International*, Vol. 102, p. 620, 2016.
49. N. Canter, Special report: Trends in extreme pressure additives, *Tribology and Lubrication Technology*, Vol. 63, p. 10, 2007.
50. J. Zhu, P. Zhu, C. Yan, X. Dong, and X. Zhang, Recent progress in polymer materials for advanced lithium-sulfur batteries, *Progress in Polymer Science*, Vol. 90, p. 118, 2019.
51. B.E. Stevens, B.D. Booth, and A.M. Zweig, Chemically foamed polysulfide sealant for aerospace fuel tank use, US Patent 10 160 893, assigned to Boeing Co., December 25, 2018.
52. R. Biju, C. Gouri, and C.P. Reghunadhan Nair, Shape memory polymers based on cyanate ester-epoxy-poly (tetramethyleneoxide) co-reacted system, *European Polymer Journal*, Vol. 48, p. 499, 2012.
53. J.W. Cho, J.W. Kim, Y.C. Jung, and N.S. Goo, Electroactive shape-memory polyurethane composites incorporating carbon nanotubes, *Macromolecular Rapid Communications*, Vol. 26, p. 412, 2005.
54. I.H. Paik, N.S. Goo, Y.C. Jung, and J.W. Cho, Development and application of conducting shape memory polyurethane actuators, *Smart Materials and Structures*, Vol. 15, p. 1476, September 2006.

55. C. Zhang, X. Wen, N.R. Vyavahare, and T. Boland, Synthesis and characterization of biodegradable elastomeric polyurethane scaffolds fabricated by the inkjet technique, *Biomaterials*, Vol. 29, p. 3781, October 2008.
56. R.-Y. Ma and D.-S. Xiong, Synthesis and properties of physically crosslinked poly(vinyl alcohol) hydrogels, *Journal of China University of Mining and Technology*, Vol. 18, p. 271, June 2008.
57. Y. Bar-Cohen and Q. Zhang, Electroactive polymer actuators and sensors, *MRS Bulletin*, Vol. 33, p. 173, 2008.
58. J. Biggs, K. Danielmeier, J. Hitzbleck, J. Krause, T. Kridl, S. Nowak, E. Orselli, X. Quan, D. Schapeler, W. Sutherland, and J. Wagner, Electroactive polymers: Developments of and perspectives for dielectric elastomers, *Angewandte Chemie International Edition*, Vol. 52, p. 9409, 2013.
59. T. Rajan and J.M. Gladis, Smart electroactive polymers and composite materials in R. Francis and D.S. Kumar, (Eds.), *Biomedical Applications of Polymeric Materials and Composites*, chapter 5, pp. 125–140. Wiley-VCH, Weinheim, 2016.
60. T. Wang, M. Farajollahi, Y.S. Choi, I.-T. Lin, J.E. Marshall, N.M. Thompson, S. Kar-Narayan, J.D.W. Madden, and S.K. Smoukov, Electroactive polymers for sensing, *Interface Focus*, Vol. 6, p. 20160026, 2016.
61. M. Radosz and Y. Shen, Poly(ionic liquid)s as new materials for CO_2 separation and other applications, US Patent 8 449 652, assigned to University of Wyoming, May 28, 2013.
62. F. Robinson, Polymers useful as pH responsive thickeners and monomers therefor, US Patent 5 874 495, assigned to Rhodia Inc., February 23, 1999.
63. M. Kaushik, D. Zierer, K.L. Price, and J.L. Coleman, Polymer composition and articles for use in low temperature environments that are wear resistant, WO Patent 2 013 169 351, assigned to Ticona LLC, November 14, 2013.
64. M.J. Derry, T. Smith, P.S. O'Hora, and S.P. Armes, Block copolymer nanoparticles prepared via polymerization-induced self-assembly provide excellent boundary lubrication performance for next-generation ultralow-viscosity automotive engine oils, *ACS Applied Materials & Interfaces*, Vol. 11, p. 33364, 2019.
65. M. Jalaal and B. Stoeber, Controlled spreading of thermo-responsive droplets, *Soft Matter*, Vol. 10, p. 808, 2014.
66. K. Luetzow, T. Weigel, and A. Lendlein, Solvent-based fabrication method for magnetic, shape-memory nanocomposite foams, *MRS Advances*, Vol. 5, p. 785, 2020.