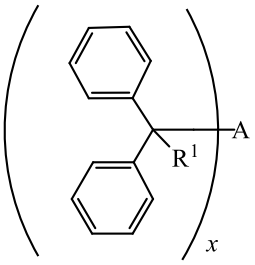
CLAIMS

We claim:

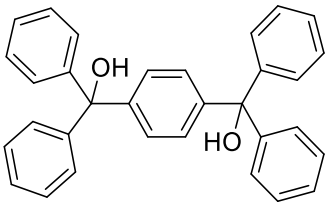
1. A cross-linking composition comprising a cross-linking compound for cross-linking an organic polymer and at least one organic polymer selected from poly(arylene ether)s, polysulfones, polyethersulfones, polyimides, polyamides, polyureas, polyurethanes, polyphthalamides, polyamide-imides, poly(benzimidazole)s, and polyaramids, wherein the cross-linking compound has the structure of formula (II):



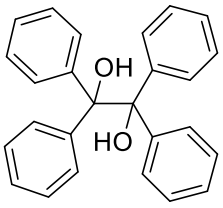
(II)

wherein A is a bond, an alkyl, an aryl, or an arene moiety having a molecular weight less than 10,000 g/mol, wherein R^1 has a molecular weight less than 10,000 g/mol, wherein R^1 is selected from the group consisting of hydrogen, hydroxyl (-OH), amine ($-NH_2$), halide, ether, ester, amide, aryl, arene, or a branched or straight chain, saturated or unsaturated alkyl group of one to six carbon atoms, and wherein *x* is 1.0 to 6.0.

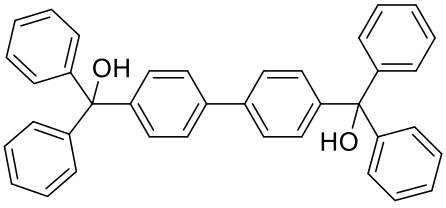
2. The cross-linking composition according to claim 1, wherein the cross-linking compound is selected from a group consisting of: compounds according to formulae (VIII), (IX), or (X):



, (VIII)

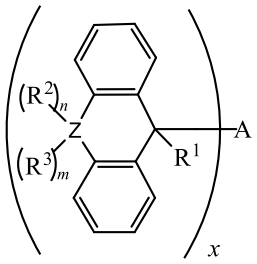


, and (IX)

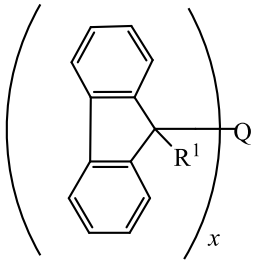


(X).

3. The cross-linking composition according to claim 1, further comprising one or more additional crosslinking compounds selected from the group consisting of:



, and (I)

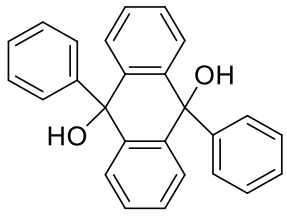


, (III)

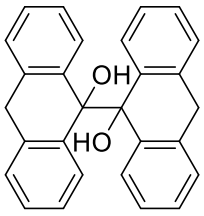
wherein Q is a bond, wherein A is Q, an alkyl, an aryl, or an arene moiety having a molecular weight less than 10,000 g/mol, wherein each of R^1, R^2, and R^3 has a molecular weight less than 10,000 g/mol, wherein R^1, R^2, and R^3 are the same or different and selected from the group consisting of hydrogen, hydroxyl (-OH), amine ($-NH_2$), halide, ether, ester, amide, aryl, arene, or a branched or straight chain, saturated or unsaturated alkyl group of one to six carbon atoms, wherein m is from 0 to 2, n is from 0 to 2, and m + n is greater than or equal to zero and less than or equal to two, wherein Z is selected from the group of oxygen, sulfur, nitrogen, and a branched or straight chain, saturated or unsaturated alkyl group of one to six carbon atoms, and wherein *x* is 1.0 to 6.0.

4. The cross-linking composition according to claim 3, wherein the additional crosslinking compounds are selected from the group consisting of:

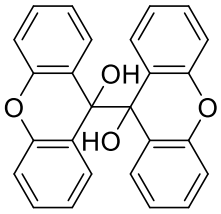
(a) a compound having a structure according to formula (I) that is selected from the group consisting of formulae (IV), (V), (VI), and (VII):

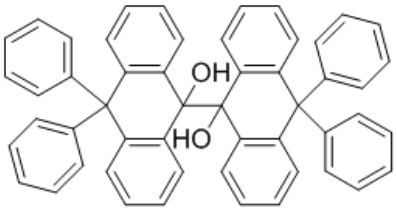


, (IV)



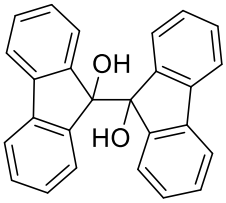
, (V)



, and (VI)


(VII); and

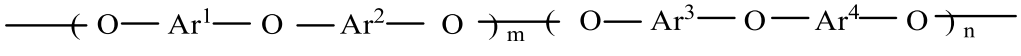
(b) a compound having a structure according to formula (III) that has formulae (XI):



(XI).

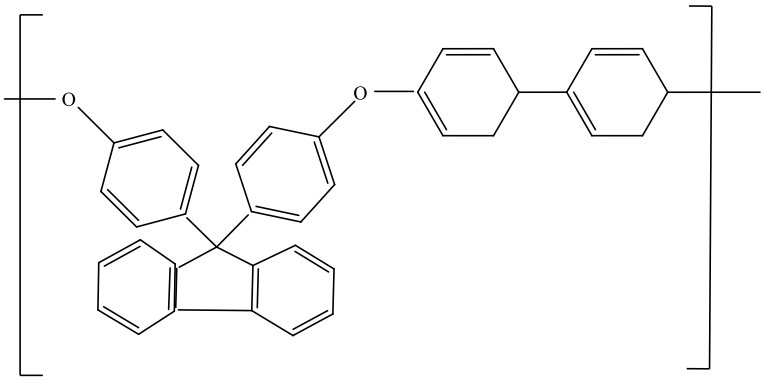
5. The cross-linking composition according to claim 1, wherein when A is not a bond, A has a molecular weight of 1,000 g/mol to 9,000 g/mol.

6. The cross-linking composition according to claim 1, wherein the organic polymer is a poly(arylene ether) including polymer repeating units having the following structure:


(XIII)

wherein Ar^1, Ar^2, Ar^3 and Ar^4 are identical or different aryl radicals, m = 0 to 1.0, and n = 1-m.

7. The cross-linking composition according to claim 6, wherein the organic polymer is a poly(arylene ether), m is 1 and n is 0 and the polymer has repeating units having the structure of formula (XIV):



(XIV).

8. The cross-linking composition according to claim 5, wherein the cross-linking composition further comprises at least one additive selected from continuous or discontinuous, long or short, reinforcing fibers selected from carbon fibers, glass fibers, woven glass fibers, woven carbon fibers, aramid fibers, boron fibers, polytetrafluorethylene fibers, ceramic fibers, polyamide fibers; and one or more fillers selected from carbon black, silicate, fiberglass, calcium sulfate,

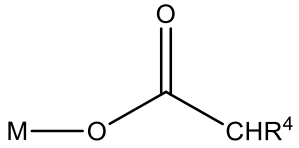
boron, ceramic, polyamide, asbestos, fluorographite, aluminum hydroxide, barium sulfate, calcium carbonate, magnesium carbonate, silica, alumina, aluminum nitride, borax (sodium borate), activated carbon, pearlite, zinc terephthalate, graphite, talc, mica, silicon carbide whiskers or platelets, nanofillers, molybdenum disulfide, fluoropolymer, carbon nanotubes and fullerene tubes.

9. The cross-linking composition according to claim 8, wherein the cross-linking composition comprises 0.5% to 65% by weight of the at least one additive.

10. The cross-linking composition according to claim 1, further comprising a rate controlling cross-linking reaction additive selected from an organic acid and/or an acetate compound, wherein the cross-linking reaction additive is capable of reacting with the cross-linking compound to form a reactive intermediate in the form of an oligomer, which reactive intermediate oligomer is capable of cross-linking an organic polymer.

11. The cross-linking composition according to claim 10, wherein the cross-linking reaction additive is an organic acid and the organic acid is selected from glacial acetic acid, formic acid, and/or benzoic acid.

12. The cross-linking composition according to claim 10, wherein the cross-linking reaction additive is an acetate compound having a structure according to formula (XII):



(XII)

wherein M is a Group I or a Group II metal; and R^4 is an alkyl, aryl or aralkyl group, wherein the alkyl group comprises a hydrocarbon group of 1 to 30 carbon atoms which has from 0 to 10 ester or ether groups along or in a chain or structure of the group, and wherein R^4 comprises 0 to 10 functional groups selected from sulfate, phosphate, hydroxyl, carbonyl, ester, halide, mercapto or potassium.

13. The cross-linking composition according to claim 12, wherein the acetate compound is selected from lithium acetate hydrate, sodium acetate, and/or potassium acetate, and salts and derivatives thereof.

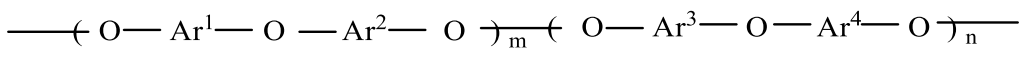
14. The cross-linking composition according to claim 10, wherein the weight percentage ratio of the cross-linking compound to the cross-linking reaction additive is 10:1 to 10,000:1.

15. The cross-linking composition according to claim 10, further comprising at least one organic polymer, wherein the cross-linking reaction additive is capable of reacting with the

cross-linking compound to form a reactive intermediate in the form of an oligomer, which reactive intermediate oligomer is capable of cross-linking the organic polymer.

16. The cross-linking composition according to claim 15, wherein the weight percentage ratio of the organic polymer to the combined weight of the cross-linking compound and the cross-linking reaction additive is 1:1 to 100:1.

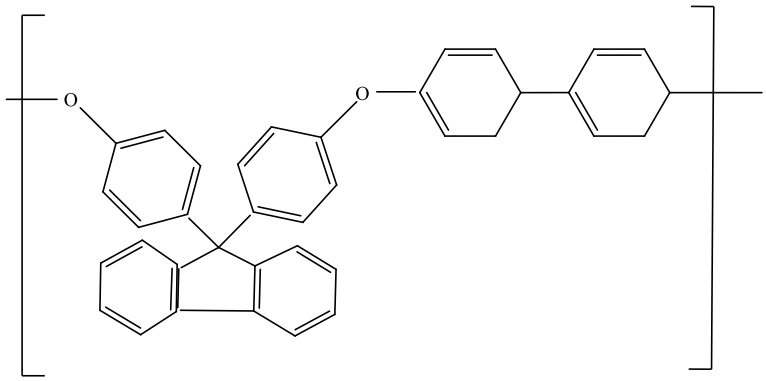
17. The cross-linking composition according to claim 16, wherein the organic polymer is a poly(arylene ether) including polymer repeating units having the following structure:



(XIII)

wherein Ar^1, Ar^2, Ar^3 and Ar^4 are identical or different aryl radicals, m = 0 to 1.0, and n = 1-m.

18.The cross-linking composition according to claim 17, wherein the organic polymer is a poly(arylene ether), m is 1 and n is 0 and the polymer has repeating units having the structure of formula (XIV):



(XIV).

19. The cross-linking composition according to claim 14, wherein the cross-linking composition further comprises at least one additive selected from continuous or discontinuous, long or short, reinforcing fibers selected from carbon fibers, glass fibers, woven glass fibers, woven carbon fibers, aramid fibers, boron fibers, polytetrafluorethylene fibers, ceramic fibers, polyamide fibers; and one or more fillers selected from carbon black, silicate, fiberglass, calcium sulfate, boron, ceramic, polyamide, asbestos, fluorographite, aluminum hydroxide, barium sulfate, calcium carbonate, magnesium carbonate, silica, alumina, aluminum nitride, borax (sodium borate), activated carbon, pearlite, zinc terephthalate, graphite, talc, mica, silicon carbide whiskers or platelets, nanofillers, molybdenum disulfide, fluoropolymer, carbon nanotubes and fullerene tubes.

20. The cross-linking composition according to claim 19, wherein the cross-linking composition comprises 0.5% to 65% by weight of the at least one additive.

21. The cross-linking composition according to claim 14, wherein the cross-linking composition further comprises one or more of a stabilizer, a flame retardant, a pigment, a plasticizer, a surfactant, and a dispersant.

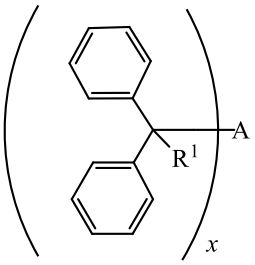
22. A molded article formed from the cross-linking composition according to claim 14.

23. The molded article according to claim 22, wherein the molded article is molded using extrusion, injection molding, blow molding, blown film molding, compression molding, or injection/compression molding.

24. An article of manufacture formed from the composition according to claim 14, wherein the article of manufacture is selected from acid-resistant coatings, chemical-casted films, extruded films, solvent-casted films, blown films, encapsulated products, insulation, packaging, composite cells, connectors, and sealing assemblies in the shape of O-rings, V-rings, U-cups, gaskets, bearings, valve seats, adapters, wiper rings, chevron back-up rings, and tubing.

25. A method of controlling the cross-linking reaction rate of a cross-linking compound for use in cross-linking an organic polymer, comprising:

(a) providing a cross-linking composition comprising at least one organic polymer selected from poly(arylene ether)s, polysulfones, polyethersulfones, polyimides, polyamides, polyureas, polyurethanes, polyphthalamides, polyamide-imides, poly(benzimidazole)s, and polyaramids, at least one cross-linking compound and a rate controlling cross-linking reaction additive selected from an organic acid and/or an acetate compound, wherein the cross-linking compound has the following structure:



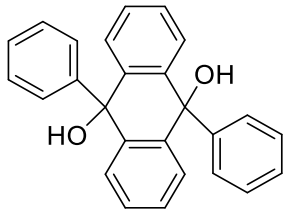
(II)

wherein A is a bond, an alkyl, an aryl, or an arene moiety having a molecular weight less than 10,000 g/mol, wherein R^1 has a molecular weight less than 10,000 g/mol, wherein R^1 is selected from the group consisting of hydrogen, hydroxyl (-OH), amine ($-NH_2$), halide, ether, ester, amide, aryl, arene, or a branched or straight chain, saturated or unsaturated alkyl group of one to six carbon atoms, and wherein *x* is 1.0 to 6.0; and

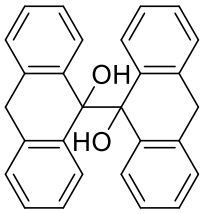
(b) heating the cross-linking composition such that oligomerization of the cross-linking compound occurs.

26. The method according to claim 25, wherein the cross-linking composition further comprises one or more additional cross-linking compounds selected from:

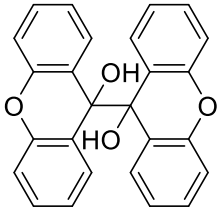
(a) a compound having a structure according to formula (I) that is selected from the group consisting of formulae (IV), (V), (VI), and (VII):



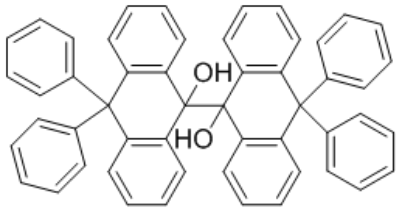
, (IV)



, (V)

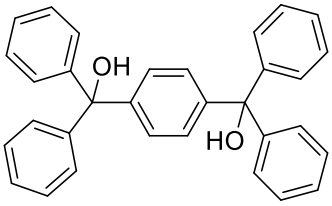


, and (VI)

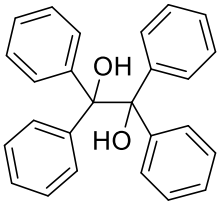


; (VII)

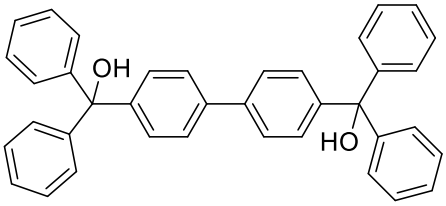
(b) a compound having a structure according to formula (II) that is selected from the group consisting of compounds according to formulae (VIII), (IX), or (X):



, (VIII)

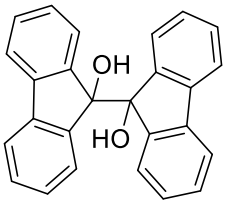


, and (IX)



; and (X)

(c) a compound having a structure according to formula (III) that has formulae (XI):



(XI).

27. The method according to claim 25, wherein step (b) further comprises heating the cross-linking composition before heat molding.

28. The method according to claim 27, wherein the cross-linking reaction additive is an organic acid selected from glacial acetic acid, formic acid and/or benzoic acid and/or an acetate compound selected from lithium acetate hydrate, sodium acetate, and/or potassium acetate, and salts and derivatives thereof.

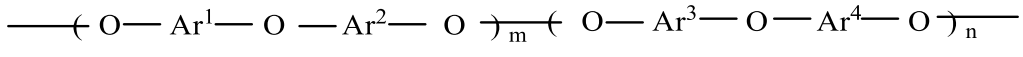
29. The method according to claim 25, further comprising combining the cross-linking compound and the cross-linking reaction additive in a solvent in step (a) and reacting the cross-linking compound and the cross-linking reaction additive to form a reactive oligomerized cross-linking compound.

30. The method according to claim 29, further comprising:

(c) adding the reactive oligomerized cross-linking compound to an organic polymer to form a cross-linkable composition, and

(d) cross-linking the organic polymer composition to form a cross-linked organic polymer.

31. The method according to claim 25, wherein the organic polymer is a poly(arylene ether) including polymer repeating units having the following structure:



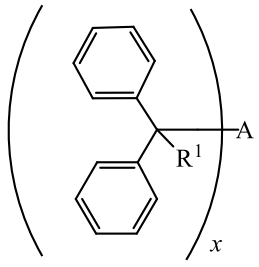
(XIII)

wherein Ar^1, Ar^2, Ar^3 and Ar^4 are identical or different aryl radicals, m = 0 to 1.0, n = 1-m.

32. An organic polymer composition for use in forming a cross-linked organic polymer, comprising:

a dehalogenated organic polymer, and

at least one cross-linking compound having a structure of formula (II):



(II)

wherein A is a bond, an alkyl, an aryl, or an arene moiety having a molecular weight less than 10,000 g/mol, wherein R^1 has a molecular weight less than 10,000 g/mol, wherein R^1 is selected from the group consisting of hydrogen, hydroxyl (-OH), amine ($-NH_2$), halide, ether, ester, amide, aryl, arene, or a branched or straight chain, saturated or unsaturated alkyl group of one to six carbon atoms and wherein *x* is 1.0 to 6.0; and

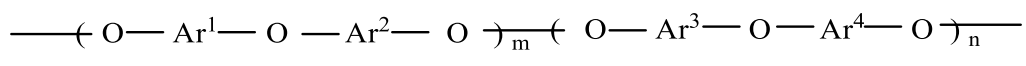
wherein the dehalogenated organic polymer is formed by a process comprising reacting an organic polymer having at least one halogen-containing reactive group with an alkali metal compound to break a bond between the organic polymer having the at least one halogen-containing reactive group and a halogen atom in the at least one halogen containing reactive group to form an intermediate.

33. The organic polymer composition according to claim 32, wherein the dehalogenated organic polymer is a debrominated organic polymer.

34. The organic polymer composition according to claim 32, further comprising a cross-linking reaction additive selected from an organic acid and/or an acetate compound, wherein the cross-linking reaction additive is capable of reacting with the cross-linking compound to form a reactive intermediate in the form of an oligomer, which reactive intermediate oligomer is capable of cross-linking the dehalogenated organic polymer.

35. The organic polymer composition according to claim 32, wherein the dehalogenated organic polymer is a polymer selected from poly(arylene ether)s, polysulfones, polyethersulfones, polyimides, polyamides, polyureas, polyurethanes, polyphthalamides, polyamide-imides, poly(benzimidazole)s and polyaramids.

36. The organic polymer composition according to claim 35, wherein the dehalogenated organic polymer is a poly(arylene ether) including polymer repeating units in its backbone having the following structure:



(XIII)

wherein Ar^1, Ar^2, Ar^3 and Ar^4 are identical or different aryl radicals, *m* = 0 to 1.0, and *n* = 1-*m*.

37. The organic polymer composition according to claim 32, wherein the dehalogenated organic polymer is formed by reacting the intermediate with acetic acid to form the dehalogenated organic polymer.

38. The organic polymer composition according to claim 37, wherein the alkali metal compound is selected from the group consisting of R^5-M', wherein M' is an alkali metal and R^5 is H or a branched or straight chain organic group selected from alkyl, alkenyl, aryl and aralkyl

groups of from 1 to 30 carbon atoms having from 0 to 10 ester or ether groups along or in a chain or structure of the group, and wherein R^5 may be substituted or unsubstituted.

39. The organic polymer composition according to claim 38, wherein the alkali metal compound is *t*-butyllithium.

40. The organic polymer composition according to claim 37, wherein the halogen-containing reactive group is a bromine-containing reactive group.

41. The organic polymer composition according to claim 38, wherein the organic polymer having at least one halogen-containing end group is reacted with the alkali metal compound in a solvent and the organic polymer having the at least one halogen-containing end group is dried prior to reacting in the solvent.

42. A molded article formed using the organic polymer composition of claim 32.

43. The molded article of claim 42, wherein the molded article is formed using extrusion, injection molding, blow molding, blown film molding, compression molding, or injection/compression molding.

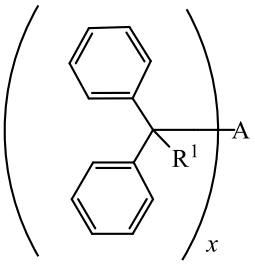
44. An article of manufacture formed from the composition according to claim 32, wherein the article of manufacture is selected from acid-resistant coatings; chemical-casted films; extruded films; solvent-casted films; blown films; encapsulated products; insulation; packaging; composite cells; connectors; sealing assemblies, including O-rings, V-rings, U-cups, gaskets; bearings; valve seats; adapters; wiper rings; chevron back-up rings; and tubing.

45. A method of controlling the cross-linking reaction rate of an organic polymer having at least one halogen-containing reactive group during a cross-linking reaction, comprising:

(a) reacting the organic polymer having at least one halogen-containing reactive group with an alkali metal compound to break a bond between the organic polymer having the at least one halogen-containing reactive group and a halogen atom in the at least one halogen-containing reactive group, and to form an intermediate having a carbocation;

(b) reacting the intermediate having the carbocation with acetic acid to form a dehalogenated organic polymer; and

(c) cross-linking the dehalogenated organic polymer using a cross-linking reaction comprising a cross-linking compound of formula (II):



(II)

wherein A is a bond, an alkyl, an aryl, or an arene moiety having a molecular weight less than 10,000 g/mol, wherein R^1 has a molecular weight less than 10,000 g/mol, wherein R^1 is selected from the group consisting of hydrogen, hydroxyl (-OH), amine ($-NH_2$), halide, ether, ester, amide, aryl, arene, or a branched or straight chain, saturated or unsaturated alkyl group of one to six carbon atoms, and wherein *x* is 1.0 to 6.0.

46. The method according to claim 45, wherein the at least one halogen-containing reactive group is represented by $-R^6-(X)_p$, wherein R^6 is carbon or a branched or straight chain organic group selected from alkyl, alkenyl, aryl and aralkyl groups of from 1 to 30 carbon atoms having from 0 to 10 ester or ether groups along or in a chain or structure of the group, and wherein R^6 may be substituted or unsubstituted; and X is a halogen atom and *p* is an integer that is 1 or 2.

47. The method according to claim 45, wherein the alkali metal compound is selected from the group consisting of R^5-M', wherein M' is an alkali metal and R^5 is H or a branched or straight chain organic group selected from alkyl, alkenyl, aryl and aralkyl groups of from 1 to 30 carbon atoms having from 0 to 10 ester or ether groups along or in a chain or structure of the group, and wherein R^5 may be substituted or unsubstituted.

48. The method according to claim 45, wherein the organic polymer having the at least one halogen-containing end group is reacted with the alkali metal compound in a solvent, wherein the solvent is selected from a heptanes, tetrahydrofuran, and a diphenyl ether.

49. The method according to claim 45, wherein the organic polymer having the at least one halogen-containing end group is dried prior to reacting with the alkali metal compound in the solvent.

50. The method according to claim 45, wherein step (a) occurs at a temperature of less than -20°C.

51. The method according to claim 50, wherein step (a) occurs at a temperature of less than -70°C for a period of about 2 hours.

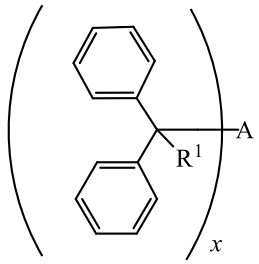
52. The method according to claim 45, wherein step (c) further comprises providing a rate controlling cross-linking reaction additive selected from an organic acid and/or an acetate compound, wherein the cross-linking reaction additive is capable of reacting with the cross-linking compound to form a reactive intermediate in the form of an oligomer, which reactive intermediate oligomer is capable of cross-linking the dehalogenated organic polymer.

53. The method according to claim 52, further comprising before step (c) heating the cross-linking compound and the cross-linking reaction additive in a separate composition such that oligomerization of the cross-linking compound occurs to form the reactive intermediate oligomer.

54. A method of preparing an elastomeric material, comprising

(a) providing an aromatic polymer which is nonelastomeric at room temperature;

(b) cross-linking the aromatic polymer using a cross-linking compound to form a cross-linked aromatic polymer that is substantially cured, wherein the cross-linking compound has a structure of formula (II):



(II)

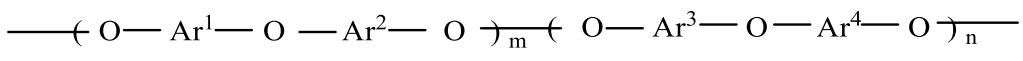
wherein A is a bond, an alkyl, an aryl, or an arene moiety having a molecular weight less than 10,000 g/mol, wherein R^1 has a molecular weight less than 10,000 g/mol, wherein R^1 is selected from the group consisting of hydrogen, hydroxyl (-OH), amine ($-NH_2$), halide, ether, ester, amide, aryl, arene, or a branched or straight chain, saturated or unsaturated alkyl group of one to six carbon atoms, and wherein *x* is 1.0 to 6.0; and

(c) heating the cross-linked aromatic polymer to a temperature at or above a glass transition temperature of the cross-linked aromatic polymer.

55. The method of preparing an elastomeric material according to claim 54, wherein, in step (b), the aromatic polymer is at least 80% cured.

56. The method of preparing an elastomeric material according to claim 55, wherein the aromatic polymer is at least 90% cured.

57. The method of preparing an elastomeric material according to claim 54, wherein the aromatic polymer is a poly(arylene ether) including polymer repeating units having the following structure:



(XIII)

wherein Ar^1, Ar^2, Ar^3 and Ar^4 are identical or different aryl radicals, m = 0 to 1.0, and n = 1-m.

58. The method of preparing an elastomeric material according to claim 54, wherein step (b) further comprises cross-linking the organic polymer with the cross-linking compound and a rate controlling cross-linking reaction additive selected from an organic acid and/or an acetate compound, wherein the cross-linking reaction additive is capable of reacting with the cross-linking compound to form a reactive intermediate in the form of an oligomer, which reactive intermediate oligomer is capable of cross-linking the organic polymer.

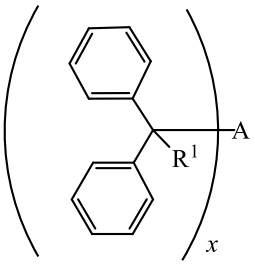
59. The method of preparing an elastomeric material according to claim 54, wherein the method further comprises forming a composition comprising the cross-linked organic polymer and heating the composition to form a molded article and step (c) further comprises placing the molded article in use at a temperature at or above the glass transition temperature of the cross-linked organic polymer.

60. An elastomeric article formed by the method of claim 54.

61. The elastomeric article according to claim 60, selected from the group consisting of an O-ring, a V-ring, a U-cup, a gasket, at least one component of a seal stack, a packer element, a diaphragm, a thee seal, a bearing, a valve seat, an adapter, a wiper ring, a chevron seal back-up ring, and tubing.

62. A method of using an organic polymer that is not elastomeric at room temperature in an elastomeric application, comprising

cross-linking the organic polymer using a cross-linking compound to form a cross-linked organic polymer to substantially cure the aromatic polymer, wherein the cross-linking compound has a structure of:



(II)

wherein A is a bond, an alkyl, an aryl, or an arene moiety having a molecular weight less than 10,000 g/mol, wherein R^1 has a molecular weight less than 10,000 g/mol, wherein R^1 is selected from the group consisting of hydrogen, hydroxyl (-OH), amine ($-NH_2$), halide, ether, ester, amide, aryl, arene, or a branched or straight chain, saturated or unsaturated alkyl group of one to six carbon atoms, and wherein *x* is 1.0 to 6.0; and

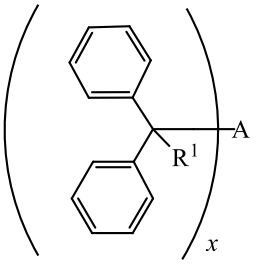
heating the cross-linked polymer in use at or above a glass transition temperature of the cross-linked polymer such that it becomes elastomeric.

63. The method of using an organic polymer in an elastomeric composition according to claim 62, further comprising forming a composition comprising the cross-linked organic polymer, molding the composition into a molded article, placing the molded article in use and heating the molded article in use so as to heat the cross-linked polymer at or above the glass transition temperature of the cross-linked polymer.

64. A method of preparing an elastomeric material, comprising:

(a) providing an aromatic polymer which is non-elastomeric at room temperature;

(b) cross-linking the aromatic polymer using a cross-linking compound to form a cross-linked aromatic polymer, wherein the cross-linking compound has a structure of:



(II)

wherein A is a bond, an alkyl, an aryl, or an arene moiety having a molecular weight less than 10,000 g/mol, wherein R^1 has a molecular weight less than 10,000 g/mol, wherein R^1 is selected from the group consisting of hydrogen, hydroxyl (-OH), amine ($-NH_2$), halide, ether, ester, amide, aryl, arene, or a branched or straight chain, saturated or unsaturated alkyl group of one to six carbon atoms, and wherein *x* is 1.0 to 6.0;

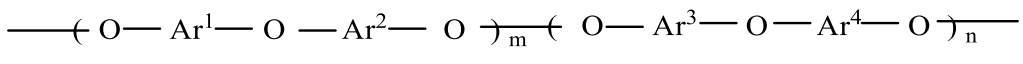
(c) heating the cross-linked aromatic polymer to a temperature at or above a glass transition temperature of the cross-linked aromatic polymer.

65. The method of preparing an elastomeric material according to claim 64, wherein, in step (b), the aromatic polymer is at least 80% cured.

66. The method of preparing an elastomeric material according to claim 65, wherein the aromatic polymer is at least 90% cured.

67. The method of preparing an elastomeric material according to claim 64, wherein the aromatic polymer is selected from the group consisting of a poly(arylene ether)s, polysulfones, polyethersulfones, polyarylene sulfides, polyimides, polyamides, polyureas, polyurethanes, polyphthalamides, polyamide-imides, poly(benzimidazole)s, polyarylates, liquid crystalline polymers (LCPs) and polyaramids.

68. The method of preparing an elastomeric material according to claim 67, wherein the aromatic polymer is a poly(arylene ether) polymer including polymer repeating having units of structure according to formula (XIII) below:



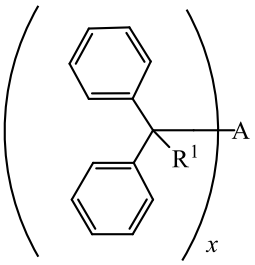
(XIII)

wherein Ar^1, Ar^2, Ar^3 and Ar^4 are identical or different aryl radicals, m is 0 to 1, and n is 1 - m.

69. The method of preparing an elastomeric material according to claim 68, wherein step (b) further comprises cross-linking the aromatic polymer with the cross-linking compound and a rate controlling cross-linking reaction additive selected from an organic acid and/or an acetate compound, wherein the cross-linking reaction additive is capable of reacting with the cross-linking compound to form a reactive intermediate in the form of an oligomer, which reactive intermediate oligomer is capable of cross-linking the organic polymer.

70. A method of improving extrusion- and creep-resistance of a component for use in a high temperature sealing element or seal connector, comprising,

providing a composition comprising an aromatic polymer and a cross-linking compound, wherein the cross-linking compound has a structure of:



(II)

wherein A is a bond, an alkyl, an aryl, or an arene moiety having a molecular weight less than 10,000 g/mol, wherein R^1 has a molecular weight less than 10,000 g/mol, wherein R^1 is selected from the group consisting of hydrogen, hydroxyl (-OH), amine ($-NH_2$), halide, ether, ester,

amide, aryl, arene, or a branched or straight chain, saturated or unsaturated alkyl group of one to six carbon atoms, and wherein *x* is 1.0 to 6.0; and

subjecting the composition to a heat molding process to form the component and cross-link the aromatic polymer.

71. The method according to claim 70, wherein the composition is unfilled.

72. The method according to claim 70, wherein the aromatic polymer is selected from the group consisting of a polyarylene polymer, a polysulfone, a polyphenylene sulfide, a polyimide, a polyamide, a polyurea, a polyurethane, a polyphthalamide, a polyamide-imide, an aramid, a polybenzimidazole, and blends, copolymers and derivatives thereof.

73. A sealing component formed by the method of claim 70.

74. The sealing component according to claim 73, wherein the composition is unfilled.