



US 20040053062A1

(19) **United States**

(12) **Patent Application Publication**

Nava

(10) **Pub. No.: US 2004/0053062 A1**

(43) **Pub. Date: Mar. 18, 2004**

(54) **RESINS FOR LINING SURFACES**

**Publication Classification**

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(51) **Int. Cl.<sup>7</sup> ..... C08F 2/00**

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(52) **U.S. Cl. .... 428/473.5; 525/123; 525/457;**

**427/239**

(57)

**ABSTRACT**

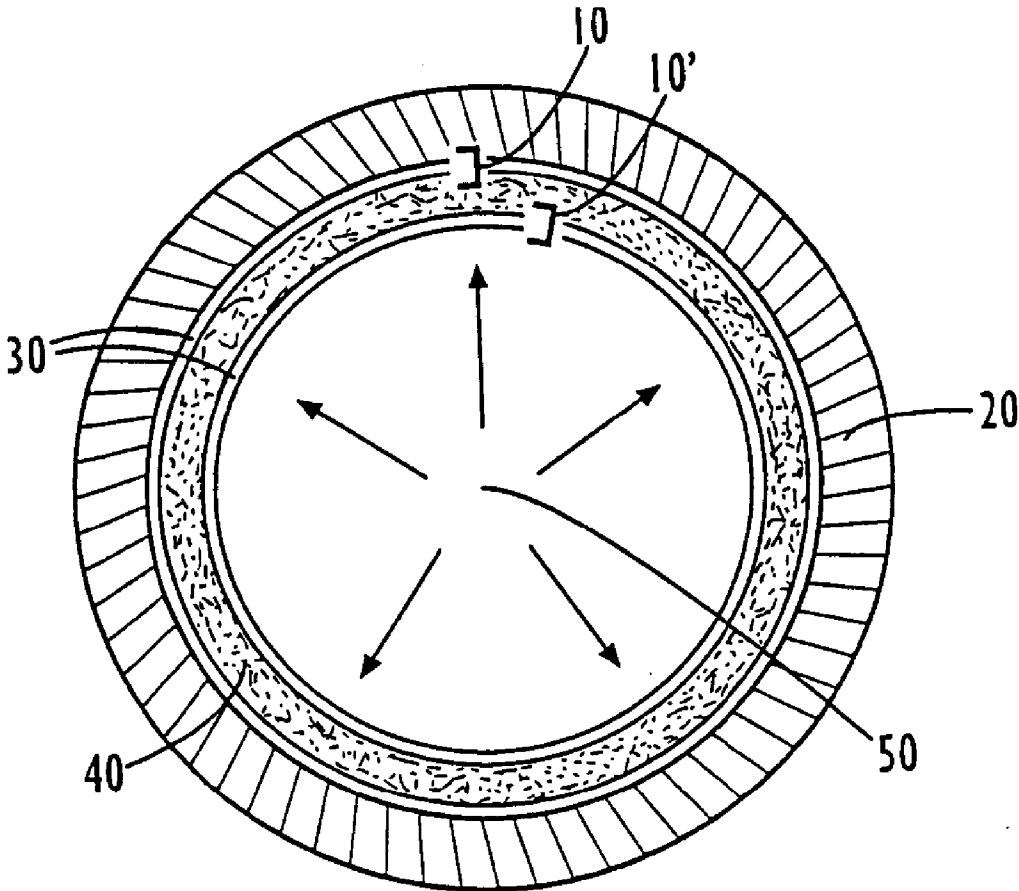
(21) Appl. No.: **10/622,394**

(22) Filed: **Oct. 31, 2003**

**Related U.S. Application Data**

(60) Continuation of application No. 09/519,924, filed on Mar. 7, 2000, which is a continuation of application No. 09/261,713, filed on Mar. 3, 1999, now abandoned, which is a division of application No. 08/919,090, filed on Aug. 27, 1997, now Pat. No. 5,925,409.

A method of lining a surface of a substrate comprises providing a reactive mixture which comprises (1) a resin containing active hydrogens; (2) a polycarbodiimide; and (3) an organic diluent; reacting the resin containing active hydrogens and the polycarbodiimide to chemically bind the resin and the polycarbodiimide; applying the chemically bound resin and polycarbodiimide to the surface of the substrate; and curing the chemically bound resin and polycarbodiimide in the presence of an initiator to form a cured resin material which lines the surface of the substrate.



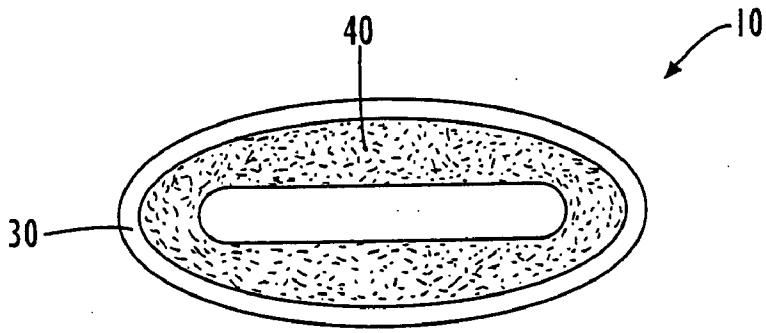


FIG. 1.

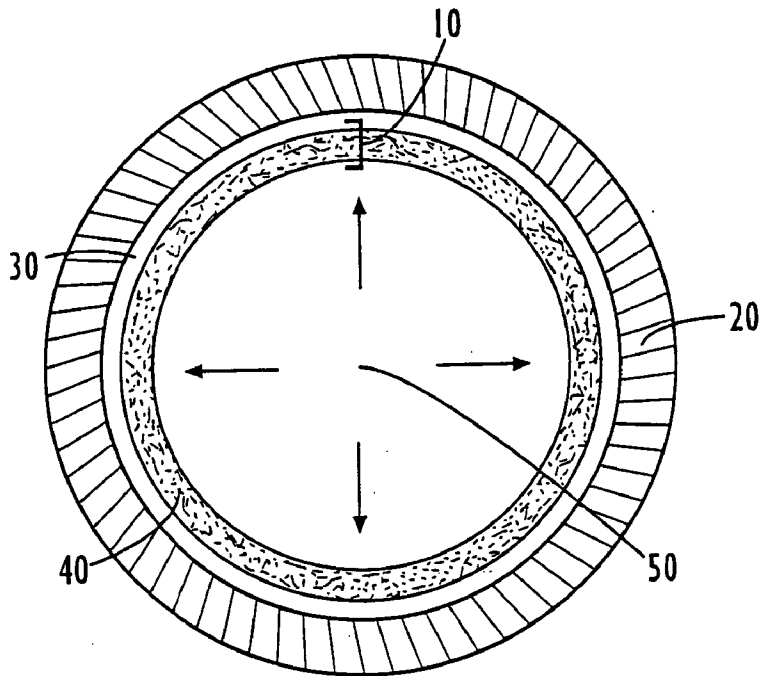


FIG. 2.

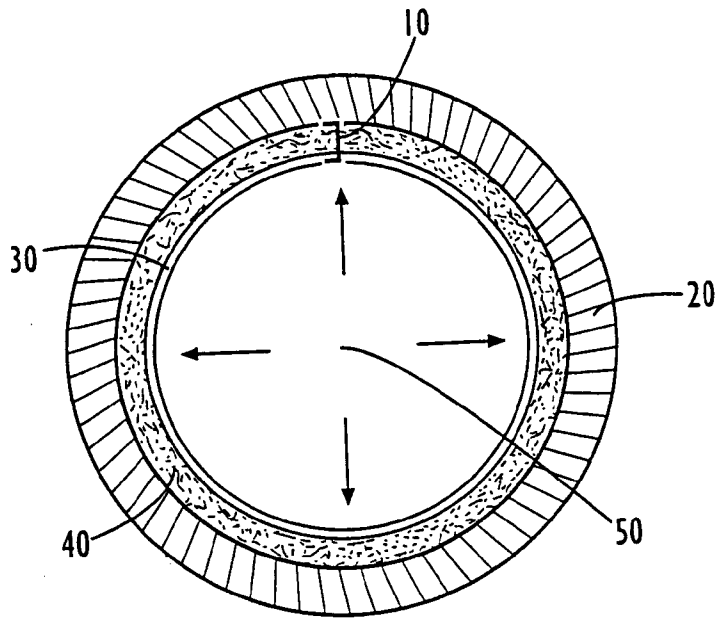


FIG. 3.

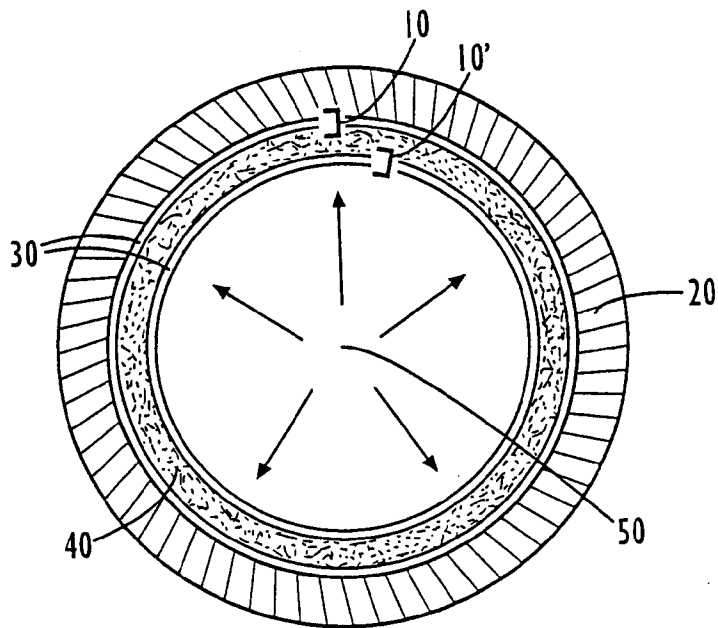


FIG. 4.

## RESINS FOR LINING SURFACES

### FIELD AND BACKGROUND OF THE INVENTION

[0001] The present invention relates to a method of utilizing resins for lining substrate surfaces which are damaged or cracked.

[0002] Substrates which are exposed to outdoor conditions are utilized in, for example, sidewalks, roads, reservoirs, and the like. These substrates are typically formed from concrete, metals, and polymer composites. In addition to the above, the substrates are employed underground and used in a number of applications relating to the transport of petroleum, natural gas, chemicals, municipal water, and the like. Due to exposure to a number of influences over time such as, for example, temperature fluctuations, ground movements, corrosive fluids, etc., the pipes tend to crack and damage. As a result, the pipes often are unable to successfully transport the above mentioned fluids and thus become unsuitable for their intended use.

[0003] Various methods have been proposed to repair the pipes. One approach is presented in U.S. Pat. No. 4,009,063 to Wood, and involves lining the inside of the pipe with a tubular fibrous felt impregnated with a thermosetting resin which contains a catalyst. Wood teaches that the impregnated felt is inserted into the damaged pipe and is inflated using hot air or water. The expansion of the tubular felt molds it into the shape of the pipe. Heat from the hot air or water activates the catalyst causing the resin to cure and form a rigid liner.

[0004] Another approach involves utilizing glass fiber which is woven into a tubular shape. The glass fiber is impregnated with a thermosetting resin containing a catalyst, and the resin is then cured. Carbon fiber may be interwoven with the glass fiber such that curing may be accomplished by applying an electrical current to the carbon fibers to generate heat. As a result, the catalyst is activated and the resin cures forming a rigid pipe lining. In this instance, hot air or hot water is not required.

[0005] The use of thermally activated catalysts which is described above, however, present disadvantages. Since the catalysts typically require temperatures well above ambient, the viscosity of the impregnated resin decreases while in the pipe. As the viscosity decreases, the resin tends to sag. The resulting pipe lining formed from the resin is non-uniform in appearance and often possesses non-uniform physical properties.

[0006] In order to address the above difficulties, agents such as fumed silica have been added to the resins such that they become thixotropic. A thixotropic material is advantageous in that its flow at room temperature is limited in the absence of an applied shear force. Nonetheless, using thixotropic materials is problematic in that their viscosities are excessively high making them difficult to pump. Also, heating thixotropic materials reduces the resin viscosity such that the materials run off and are difficult to contain.

[0007] It would be desirable to provide a method of lining damaged surfaces such as those found in pipes or conduits which addresses the problems mentioned above.

### SUMMARY OF THE INVENTION

[0008] It is therefore an object of the present invention to provide a method for lining a surface with a resin which may

be transported more easily to the surface and provide more uniform physical properties to the surface.

[0009] To this end and others, the invention provides a method of lining a surface. The method comprises providing a reactive mixture which comprises (1) a resin containing active hydrogens; (2) a polycarbodiimide; and (3) an organic diluent; reacting the resin containing active hydrogens and the polycarbodiimide to chemically bind the resin and the polycarbodiimide; applying the chemically bound resin and polycarbodiimide to the surface of the substrate; and curing the chemically bound resin and polycarbodiimide to form a cured resin material which lines the surface of the substrate.

[0010] To cure the chemically bound resin, an initiator is employed. Additionally, in another embodiment, a promoter may be used in conjunction with the initiator.

[0011] The invention also provides a method of lining a surface which defines a conduit. The method comprises providing a reactive mixture which comprises (1) a resin containing active hydrogens; (2) a polycarbodiimide; and (3) an organic diluent; inserting the reactive mixture into a tube, the tube being defined by an inner membrane and an outer membrane; reacting the resin containing active hydrogens and the polycarbodiimide to chemically bind the resin and the polycarbodiimide; inserting the tube into a conduit having an inner surface; applying pressure to the tube such that the tube comes in contact with the inner surface of the conduit; and curing the chemically bound resin and polycarbodiimide to form a crosslinked resin material which lines the surface of the conduit.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0012] In the drawings which form an original portion of the disclosure as filed:

[0013] **FIG. 1** illustrates a tube filled with a resin according to the invention;

[0014] **FIG. 2** illustrates a tube filled with a resin according to the invention being present inside a conduit;

[0015] **FIG. 3** illustrates a tube filled with a resin according to the invention being urged by pressure against an inner surface of a conduit; and

[0016] **FIG. 4** illustrates a tube filled with a resin according to the invention being urged by pressure against a tube previously inserted and against an inner surface of a conduit.

### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0017] The present invention will now be described more fully hereinafter, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art.

[0018] In one aspect, the invention relates to a method for lining a surface of a substrate with a resin, typically the surface of a conduit such as a pipe. The method comprises providing a reactive mixture which comprises (1) a resin containing active hydrogens, (2) a polycarbodiimide, and (3)

an organic diluent. The polycarbodiimide is preferably dispersed or contained in the organic diluent during the providing step. The reaction mixture preferably contains greater than about 5 percent by weight of polycarbodiimides. The resin containing active hydrogens and the polycarbodiimide then react such that the resin and the polycarbodiimide become chemically bound, namely the resin becomes thickened. This step is preferably carried out at a temperature between about 5° C. and about 60° C. The chemically thickened resin preferably has a viscosity ranging from about 30,000 centipoise to about 50 million centipoise, and more preferably from about 100,000 centipoise to about 20 million centipoise.

[0019] The chemically bound resin and polycarbodiimide is then applied to the surface of the substrate. Subsequently, chemically bound resin and polycarbodiimide is cured to form a crosslinked resin material which lines the surface of the substrate. The curing step is preferably carried out at a temperature between about 40° C. and about 150° C., more preferably between about 50° C. and about 100° C. The curing step is performed in the presence of an initiator.

[0020] The invention is advantageous in that the glass transition temperature ( $T_g$ ) of the cured resin material may be enhanced by virtue of the method disclosed herein. Preferably, the  $T_g$  of the cured resin material increases from about 5 percent to about 600 percent, and more preferably from about 10 percent to about 300 percent. As a result of this elevation in  $T_g$ , the physical properties of the cured resin are believed to be enhanced.

[0021] As a result of this elevation in  $T_g$ , it is believed that the physical properties of the cured resin materials are enhanced. Preferably, the cured resin material has a flexural strength ranging from about 3000 psi to about 80,000 psi; a tensile strength ranging from about 1000 psi to about 50,000 psi; and a percent elongation ranging from about 1 to about 1000. In addition to the above, it should be appreciated that various types of resins may have differing preferred ranges of physical property values. For example, cured unsaturated polyester resins preferably have tensile strengths ranging from about 3000 psi to about 50,000 psi and elongations ranging from about 1 to about 10 percent, while cured polyurethanes preferably have tensile strengths ranging from about 800 to about 5000 psi and elongations ranging from about 70 to about 1000.

[0022] Preferably, the reactive mixture contains between about 3 to about 50 percent by weight of polycarbodiimide, more preferably between about 3 and about 20 weight percent polycarbodiimide, and most preferably between about 6 and about 12 weight percent polycarbodiimide.

[0023] The resin which contains active hydrogens may be selected from a number of resins well known to those skilled in the art. For the purposes of the invention, the term "resin containing active hydrogens" refers to any resin which contains functional groups containing active hydrogens. Functional groups containing active hydrogens can be defined as those which are capable of reacting with polycarbodiimide repeating units ( $N=C\uparrow N$ ). Suitable functional groups including, for example, hydroxyl, carboxyl, amino, phenol, silanol,  $-P-OH$ ,  $-P-H$ , as well as other appropriate substituents. Resins containing active hydrogens include, but are not limited to, saturated polyester resins (e.g., resins employed in hot melt adhesives and powder

coatings), unsaturated polyester resins (e.g., resins used in forming molded articles), aliphatic and aromatic polyethers, vinyl ester resins (e.g., resins used in filament winding and open and closed molding), polyurethanes, and mixtures of any of the above.

[0024] For the purposes of the invention, unsaturated polyester resins, saturated polyester resins, and vinyl ester resins are preferably employed. An unsaturated polyester resin may be formed from conventional methods. Typically, the resin is formed from the reaction between a polyfunctional organic acid or anhydride and a polyhydric alcohol under conditions known in the art. The polyfunctional organic acid or anhydride which may be employed are any of the numerous and known compounds. Suitable polyfunctional acids or anhydrides thereof include, but are not limited to, maleic acid, fumaric acid, citraconic acid, itaconic acid, glutaconic acid, phthalic acid, isophthalic acid, terephthalic acid, cyclohexane dicarboxylic acid, succinic anhydride, adipic acid, sebacic acid, azealic acid, malonic acid, alkenyl succinic acids such as n-dodecenylsuccinic acid, dococylsuccinic acid, octadecenylsuccinic acid, and anhydrides thereof. Lower alkyl esters of any of the above may also be employed. Mixtures of any of the above are suitable.

[0025] Additionally, polybasic acids or anhydrides thereof having not less than three carboxylic acid groups may be employed. Such compounds include 1,2,4-benzenetricarboxylic acid, 1,3,5-benzene tricarboxylic acid, 1,2,4-cyclohexane tricarboxylic acid, 2,5,7-naphthalene tricarboxylic acid, 1,2,4-naphthalene tricarboxylic acid, 1,3,4-butane tricarboxylic acid, 1,2,5-hexane tricarboxylic acid, 1,3-dicarboxyl-2-methyl-2-carboxymethylpropane, tetra(carboxymethyl)methane, 1,2,7,8-octane tetracarboxylic acid, and mixtures thereof.

[0026] Suitable polyhydric alcohols which may be used in forming the unsaturated polyester resin include, but are not limited to, ethylene glycol, diethylene glycol, propylene glycol, dipropylene glycol, 1,3-butanediol, 1,4-butanediol, 1,3 hexanediol, neopentyl glycol, 2-methyl-1,3-propanediol, 1,3-butylene glycol, 1,6-hexanediol, hydrogenated bisphenol "A", cyclohexane dimethanol, 1,4-cyclohexanol, ethylene oxide adducts of bisphenols, propylene oxide adducts of bisphenols, sorbitol, 1,2,3,6-hexatetrol, 1,4-sorbitan, pentaerythritol, dipentaerythritol, tripentaerythritol, sucrose, 1,2,4-butanetriol; 1,2,5-pentanetriol, glycerol, 2-methylpropanetriol, 2-methyl-1,2,4-butanetriol, trimethylol ethane, trimethylol propane, and 1,3,5-trihydroxyethyl benzene. Mixtures of the above alcohols may be used.

[0027] The vinyl ester resins employed in the invention include the reaction product of an unsaturated monocarboxylic acid or anhydride with an epoxy resin. Exemplary acids and anhydrides include (meth) acrylic acid or anhydride,  $\alpha$ -phenylacrylic acid,  $\alpha$ -chloroacrylic acid, crotonic acid, mono-methyl and mono-ethyl esters of maleic acid or fumaric acid, vinyl acetic acid, sorbic acid, cinnamic acid, and the like, along with mixtures thereof. Epoxy resins which may be employed are known and include virtually any reaction product of a polyfunctional halohydrin, such as epichlorohydrin, with a phenol or polyhydric phenol. Suitable phenols or polyhydric phenols include, for example, resorcinol, tetraphenol ethane, and various bisphenols such as Bisphenol "A", 4,4'-dihydroxydiphenyl sulfone, 4,4'-dihydroxy biphenyl, 4,4'-dihydroxydiphenyl methane, 2,2'-

dihydroxydiphenyl oxide, and the like. Novolac epoxy resins may also be used. Mixtures of any of the above may be used. Additionally, the vinyl ester resins may have pendant carboxyl groups formed from the reaction of esters and anhydrides and the hydroxyl groups of the vinyl ester backbone.

[0028] The resins containing reactive hydrogens may be used alone or in conjunction with other appropriate materials to help enhance physical properties of the resin. Suitable materials include, for example, fibrous reinforcements, fillers, flame retardants, woven and nonwoven fibrous sheets and mats, and the like. Any conventionally known fibrous reinforcement material may be used including fiberglass, polyester, carbon, metal, graphite, high modulus organic fibers (e.g., aromatic polyamides, polybenzimidazoles, and aromatic polyimides), other organic fibers (e.g., polyethylene, liquid crystals, and nylon), and natural fibers. The fibrous materials may be incorporated into the resin in accordance with techniques which are known in the art. Fillers may include but are not limited to calcium carbonate, aluminum oxide, aluminum hydroxide, silica gel, barite, graphite powder, and the like. Mixtures of the above may also be used.

[0029] Saturated polyester resins and polyurethanes which are thickened include, for example, those described in U.S. Pat. Nos. 4,871,811; 3,427,346; and 4,760,111; the disclosures of which are incorporated herein by reference in their entirety. The saturated polyester resins and polyurethanes are particularly useful in hot melt adhesives and pressure sensitive adhesive applications. Appropriate saturated polyester resins include, but are not limited to, crystalline and amorphous resins. The resins may be formed by any suitable technique. For example, the saturated polyester resin may be formed by polycondensating an aromatic or aliphatic di- or polycarboxylic acid and an aliphatic or alicyclic di- or polyol or its prepolymer. Optionally, either the polyols may be added in excess to obtain hydroxyl end groups or the dicarboxylic monomers may be added in excess to form carboxylic end groups. Suitable polyurethane resins may be formed by the reaction of diols or polyols as described in U.S. Pat. No. 4,760,111 along with diisocyanates. The diols are added in an excess to obtain hydroxyl end groups at the chain ends of the polyurethane.

[0030] Polycarbodiimides which may be employed in the present invention include those which are known in the art. Exemplary polycarbodiimides are described in U.S. Patent Nos. 5,115,072; 5,081,173; 5,008,363; and 5,047,588; the disclosures of which are incorporated herein by reference in their entirety. The polycarbodiimides can include aliphatic, cycloaliphatic, or aromatic polycarbodiimides.

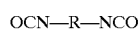
[0031] The polycarbodiimides can be prepared by a number of known reaction schemes. Preferably, the polycarbodiimides are synthesized by reacting an isocyanate-containing intermediate and a diisocyanate under suitable reaction conditions. The isocyanate containing intermediate is formed by the reaction between a component, typically a monomer, containing active hydrogens and a diisocyanate. Included are also polycarbodiimides prepared by the polymerization of isocyanates to form a polycarbodiimide, which subsequently react with a component containing active hydrogens.

[0032] Components containing active hydrogens, which may be employed are well known and numerous, with

monomers being typically utilized. Examples of such monomers include, but are not limited to, acrylates, alcohols, amines, esters, polyesters, thiols, phenols, aromatic and aliphatic polyethers, siloxanes, phosphorus-containing materials, olefins, unsaturated aromatic monomers, and mixtures thereof. Alcohols are typically used, with monofunctional alcohols being preferably employed. Monofunctional alcohols which may be used include, for example, ethanol, butanol, propanol, hexanol, octanol, ethylhexyl alcohol, and longer-chain alcohols (i.e., those alcohols containing up to 50 carbon atoms) and their isomers.

[0033] Other monomers having active hydrogens which may be used include, for example, acrylic acid, methacrylic acid, acetic acid, phenylacetic acid, phenoxyacetic acid, propionic acid, hydrocinnamic acid, and the like. Hydroxyalkyl acrylates or methacrylates such as hydroxyethyl acrylate, hydroxyethyl methacrylate, hydroxypropyl acrylate, hydroxypropyl methacrylate, hydroxybutyl acrylate, hydroxybutyl methacrylate, and the like may also be employed. Polyols can be additionally be used including, but not limited to, ethylene glycol; 1,2 and 1,3-propylene glycol; 1,4 and 2,3-butylene glycol; 1,5-pentanediol; 1,6-hexanediol; 1,8-octanediol; neopentyl glycol; 1,4-bis-hydroxymethyl cyclohexane; 2-methyl-1,3-propanediol; glycerol; trimethylolpropane; 1,2,6-hexanetriol; trimethylol ethane; pentaerythritol; quinitol; mannitol; sorbitol; diethylene glycol; triethylene glycol; tetraethylene glycol; 1,4-butanediol; polyethylene glycols having a molecular weight of up to 400; dipropylene glycol; ethoxylated and propoxylated bisphenol "A"; polybutylene glycols having a molecular weight of up to 400; methyl glucoside; diethanolamino-N-methyl phosphonic acid esters; castor oil; diethanolamine; N-methyl ethanolamine; and triethanolamine. Mixtures of any of the above may be used. Any of the above compounds may also include any one or a combination of halogens such as chlorine, fluorine, bromine, or iodine; or phosphorus, or silicon groups.

[0034] Diisocyanates which are used in the above reactions are well known to the skilled artisan. For the purposes of the invention, diisocyanates include aliphatic, cycloaliphatic, araliphatic, aromatic and heterocyclic diisocyanates of the type described, for example, by W. Siefken in *Justus Liebigs Annalen der Chemie*, 562, pages 75 to 136, (1949) for example, those corresponding to the following formula:



[0035] wherein R represents a difunctional aliphatic, cycloaliphatic, aromatic, or araliphatic radical having from about 4 to 25 carbon atoms, preferably 4 to 15 carbon atoms, and free of any group which can react with isocyanate groups. Exemplary diisocyanates include, but are not limited to, toluene diisocyanate; 1,4-tetramethylene diisocyanate; 1,4-hexamethylene diisocyanate; 1,6-hexamethylene diisocyanate; 1,12-dodecane diisocyanate; cyclobutane-1,3-diisocyanate; cyclohexane-1,3-diisocyanate; cyclohexane-1,4-diisocyanate; 1-isocyanato-3,3,5-trimethyl-5-isocyanatomethyl cyclohexane; 2,4-hexahydro-2,6-hexahydro-1,3-phenylene diisocyanate; 2,6-hexahydro-1,3-phenylene diisocyanate; per-hydro-2,4'-diphenyl methane diisocyanate; per-hydro-4,4'-diphenyl methane diisocyanate; 1,3-phenylene diisocyanate; 1,4-phenylene diisocyanate; 2,4-tolylene diisocyanate, 2,6-tolylene diisocyanates;

diphenyl methane-2,4'-diisocyanate; diphenyl methane-4,4'-diisocyanate; naphthalene-1,5-diisocyanate; 1,3-xylene diisocyanate; 1,4-xylene diisocyanate; 4,4'-methylene-bis-(cyclohexyl isocyanate); 4,4'-isopropyl-bis-(cyclohexyl isocyanate); 1,4-cyclohexyl diisocyanate; 3-isocyanatomethyl-3,5,5-trimethylcyclohexyl isocyanate (IPDI); 1-methoxy-2,4-phenylene diisocyanate; 1-chlorophenyl-2,4-diisocyanate; p-(1-isocyanatoethyl)-phenyl isocyanate; m-(3-isocyanatobutyl)-phenyl isocyanate; and 4-(2-isocyanate-cyclohexyl-methyl)-phenyl isocyanate. Mixtures of any of the above may be employed. When deemed appropriate, a diisocyanate may be employed which contains other functional groups such as hydroxy or amino functionality.

**[0036]** In the reaction involving the component containing active hydrogens and the diisocyanate, it is preferred to employ a catalyst. A number of catalysts known to the skilled artisan may be used for this purpose. Such catalysts include, but are not limited to, an organo tin catalyst such as dibutyl tin diacetate, dibutyl tin di-2-ethylhexoate, dibutyl tin dilaurate, dibutyl tin oxide, and the like. Tertiary amines, such as triethyl amine, tributylamine, triethylene-diamine tripropylamine, and the like may also be used. Mixtures of the above catalysts may be used. The catalyst may be used in various suitable amounts, preferably between about 0.005 and about 0.50 percent based on the weight of the component containing active hydrogens and the diisocyanate.

**[0037]** The reaction between the component containing reactive hydrogens and the diisocyanate forms a isocyanate-containing intermediate. The isocyanate-containing intermediate is then reacted with any of the diisocyanates described herein to form a poly-carbodiimide. The latter reaction described above is preferably carried out in the presence of a catalyst. Suitable catalysts which may be used include, for example, those described in U.S. Pat. No. 5,008,363; the disclosure of which is incorporated herein by reference in its entirety. Particularly useful classes of carbodiimide-forming catalysts are the phospholene-1-oxides and phospholene-1-sulfides. Representative compounds within these classes are triphenyl phosphine; 3-methyl-1-phenyl-3-phospholine 1-oxide; 1-ethyl-phenyl-3-phospholine 1-oxide; 3-(4-methyl-3-pentynyl)-1-phenyl-3-phospholine 1-oxide; 3-chloro-1-phenyl-3-phospholine 1-oxide; 1,3-diphenyl-3-phospholine 1-oxide; 1-ethyl-3-phospholine 1-sulfide; 1-phenyl-3-phospholine 1-sulfide; and 2-phenyliso-phosphindoline 2-oxide; 1-phenyl-2-phospholene 1-oxide; 3-methyl-phenyl-2-phospholene 1-oxide; 1-phenyl-2-phospholene 1-sulfide; 1-ethyl-2-phospholene 1-oxide; 1-ethyl-3-methyl-2-phospholene 1-oxide; and 1-ethyl-3-methyl-2-phospholene 1-oxide. Other isomeric phospholenes corresponding to all the above-named compounds also can be used. Mixtures of any of the above may be used. The catalyst may be used in various suitable amounts, preferably from about 0.005 to about 10 percent based on the weight of the reactants, more preferably from about 0.02 to about 5 weight percent, and most preferably from about 0.03 to about 2 weight percent.

**[0038]** A vinyl monomer may also be included as a diluent with the polycarbodiimide and the unsaturated and saturated resins. Suitable monomers may include those such as, for example, styrene and styrene derivatives such as alpha-methyl styrene, p-methyl styrene, divinyl benzene, divinyl toluene, ethyl styrene, vinyl toluene, tert-butyl styrene, monochloro styrene, dichloro styrene, vinyl benzyl chloride, fluorostyrene, and alkoxystyrenes (e.g., paramethoxy sty-

rene). Also, toluene, xylene, chlorobenzene, chloroform, tetrahydrofuran, ethyl acetate, isopropyl acetate, butyl acetate, butyl phthalate, acetone, methyl cellosolve acetate, cellosolve acetate, butyl cellosolve, methyl ethyl ketone, diethyl ketone, and cyclohexanone may be used. Other monomers which may be used include, for example, diallyl phthalate, hexyl acrylate, octyl acrylate, octyl methacrylate, diallyl itaconate, diallyl maleate, hydroxyethyl acrylate, hydroxyethyl methacrylate, hydroxypropyl acrylate, hydroxypropyl methacrylate, and mixtures thereof.

**[0039]** Any suitable polyfunctional acrylate may be used in the resin composition, including those described, for example, in U.S. Pat. No. 4,916,023 to Kawabata et al., the disclosure of which is incorporated by reference herein in its entirety. Such compounds include ethylene glycol dimethacrylate, butanediol dimethacrylate, hexanediol dimethacrylate, ethoxylated trimethylolpropane triacrylate, trimethylolpropane tri(meth)acrylate, trimethylolpropane triacrylate, trimethylolmethane tetramethacrylate, pentaerythritol tetramethacrylate, dipentaerythritol tetramethacrylate, dipentaerythritol pentamethacrylate, dipentaerythritol hexamethacrylate, ethoxylated polyhydric phenol diacrylates and dimethacrylates containing from 1 to 30 ethylene oxide units per OH group in the phenol, propoxylated polyhydric phenol diacrylates and dimethacrylates containing from 1 to 30 propylene oxide groups per OH groups in the phenol. Examples of some useful di- and polyhydric phenols include catechol; resorcinol; hydroquinone; 4,4'-biphenol; 4,4'-isopropylidenebis(o-cresol); 4,4'-isopropylidenebis(2-phenyl phenol); alkyldenediphenols such as bisphenol "A"; pyrogallol; phloroglucinol; naphthalene diols; phenol; formaldehyde resins; resorcinol/formaldehyde resins; and phenol/resorcinol formaldehyde resins. Mixtures of the above di- and polyacrylates may also be employed.

**[0040]** The vinyl monomers and polyfunctional acrylates may be used in varying amounts, preferably from about 20 to 50 based on the weight of the components which may be dissolved therein, and more preferably from about 30 to 45 weight percent.

**[0041]** The method of thickening a resin may be carried out using known equipment. Typically, for example, a resin containing active hydrogens is placed in a vessel, mixing tank, or other reactor along with a catalyst that will be mixed for a period lasting from about 5 to about 20 minutes. Subsequently, a polycarbodiimide which is present (typically dissolved) in an organic diluent is added to the above resin and is allowed to mix therein for a period lasting typically from about 3 to about 15 minutes. In general, the reactive mixture of resin containing active hydrogens and polycarbodiimide is applied to a surface of a substrate and the resin containing active hydrogens and the polycarbodiimide become chemically bound. An alternative way of mixing the resin containing active hydrogens and the polycarbodiimide may be accomplished by using a self balancing internal mix chopper system made commercially available from Magnum Industries from Clearwater, Fla.

**[0042]** The reactive mixture includes an initiator to facilitate curing of the chemically bound resin and polycarbodiimide. The initiator is typically added to the reactive mixture prior to the thickening of the resin. An example of an initiator is an organic peroxide compound. Exemplary

organic peroxides that may be used include, for example, cumene hydroperoxide; methyl ethyl ketone peroxide; benzoyl peroxide; acetyl peroxide; 2,5-dimethylhexane-2,5-dihydroperoxide; tert-butyl peroxybenzoate; di-tert-butyl perphthalate; dicumyl peroxide; 2,5-dimethyl-2,5-bis(tert-butylperoxy)hexane; 2,5-dimethyl-2,5-bis(tert-butylperoxy)hexyne; bis(tert-butylperoxyisopropyl)benzene; ditert-butyl peroxide; 1,1-di(tert-amylperoxy)-cyclohexane; 1,1-di-(tert-butylperoxy)-3,3,5-trimethylcyclohexane; 1,1-di-(tert-butylperoxy)-cyclohexane; 2,2-di-(tert-butylperoxy)butane; n-butyl-4,4-di(tert-butylperoxy butylperoxy)valerate; ethyl-3,3-di-(tert-amylperoxy)butyrate; ethyl-3,3-di(tert-butylperoxy)-butyrate; t-butyl peroxy-neodecanoate; di-(4-5-butyl-cyclohexyl)-peroxydicarbonate; lauryl peroxyde; 2,5-dimethyl-2,5-bis(2-ethyl-hexanoyl peroxy) hexane; t-amyl peroxy-2-ethylhexanoate; 2,2'-azobis(2-methylpropionitrile); 2,2'-azobis(2,4-methylbutanenitrile); and the like. Mixtures of any of the above may be used. The initiator is preferably employed in an amount from about 1 to 2.5 percent based on the weight of the thickened resin, more preferably from about 1 to 1.5 percent by weight, and most preferably from about 1 to 1.25 percent by weight.

[0043] Suitable initiators used in curing the thickened resin may also encompass photoinitiators which may be activated upon exposure to a source of energy such as infrared, visible, or ultraviolet radiation. Examples of suitable photoinitiators include, but are not limited to, an aliphatic or aromatic diketone and a reducing agent (e.g., benzil and dimethyl benzyl amine); vicinal polyketaldonol compounds (e.g., diacetyl benzil and benzil ketal);  $\alpha$ -carbonyl alcohols (e.g., benzoin); acyloin ethers (e.g., benzoin methyl ether); polynuclear quinones (e.g., 9,10-antraquinone), and benzophenone. Preferably, the amount of photoinitiator ranges from about 0.005 to 5 percent based on the weight of the thickened resin. Suitable commercial photoinitiators include those available from Ciba-Geigy Corporation sold under the tradenames Irgacure 500, Irgacure 369, Irgacure 1700, Darocur 4265, and Irgacure 819. It should be appreciated that other commercial photoinitiators may be used for the purposes of the invention.

[0044] Suitable curing accelerators or promoters may also be used and include, for example, cobalt naphthanate, cobalt octoate, N,N-dimethyl aniline, N,N-dimethyl acetamide, and N,Ndimethyl p-toluidine. Mixtures of the above may be used. The curing accelerators or promoters are preferably employed in amounts from about 0.05 to about 1.0 percent by weight, more preferably from about 0.1 to 0.5 percent by weight, and most preferably from about 0.1 to 0.3 percent by weight of the thickened resin.

[0045] Additional additives known by the skilled artisan may be employed in the thickened resin composition of the present invention including, for example, paraffins, fatty acids, fatty acid derivatives, lubricants, and shrink-reducing additives. Various percentages of these additives can be used in the resin composition.

[0046] As recited herein, the invention relates to a method of lining the surfaces of substrates. For the purposes of the invention, the term "surfaces" is to be broadly construed and includes, but is not limited to, those which are typically exposed to conditions which may cause damage such as temperature fluctuations, earth movement, and the like. The

substrates may be formed from a number of materials such as, but not limited to, concrete, metals, polymeric composites, and mixtures thereof. Flat and contoured surfaces may be encompassed within the scope of the invention. In one embodiment, the invention relates to lining a surface which forms a conduit. The term "conduit" is to be broadly interpreted and includes, for example, pipes. One example involves the lining of a surface which forms a conduit as described in U.S. Pat. No. 4,009,063 to Wood, the disclosure of which is incorporated herein by reference in its entirety.

[0047] In general, the resin may be applied to the conduit surface using any of the known and accepted techniques. For the purposes of the invention, the term "lining" substrate surfaces should be construed broadly, and includes employing the resin alone or in conjunction with other materials. For example, as illustrated in FIG. 1, the resin may be inserted into a tube denoted by **10**. The tube depicted in this instance is defined by an outer membrane **30** and an inner membrane **40** which may contain conventional fibrous reinforcement materials such as, but not limited to, fiberglass, polyester, carbon, metal, high modulus organic fibers (e.g., aromatic polyamides, polybenzimidazoles, and aromatic polyimides), other organic fibers (e.g., polyethylene, liquid crystals, and nylon), and natural fibers. The tube **10** may be constructed out of any of a number of appropriate materials known to one skilled in the art including suitable polymeric materials, and is fabricated by conventional methods. As discussed below, since the tube **10** is made to conform to the shape and size of the conduit **20** as illustrated in FIG. 2, it is desirable that the outer membrane **30** be formed from materials which possess a certain degree of elasticity. Examples of suitable materials include, but are not limited to, polyethylene, polyvinylchloride, rubber, cellophane nitrate, neoprene, and polyester film. The dimensions of the tube may be configured in a manner such that the tube fits within a variety of conduits.

[0048] The reactive mixture may be inserted into the tube **10** using known procedures, typically involving the impregnation of membrane **40**. The insertion of the reactive mixture typically taking place prior to placing the tube **10** in conduit **20**. For example, the reactive mixture may be pumped or injected into tube **10** through one end or at puncture ports located at several intervals along the tube **10**. Additional materials may be present along with the reactive mixture in tube **10**. Specifically, tube **10** may include those materials which are typically used in conjunction with resins such as, for example, fibrous reinforcement material, woven and nonwoven fibrous sheets or mats, fillers, fire retardants, colorants, and the like. The selection of these materials is known to one who is skilled in the art.

[0049] At this point, the reactive mixture is a viscous material in tube **10**, and it is allowed to thicken for 1 to 24 hours or longer to become a gel-like substance which remains flexible. Preferably, the process occurs between about 5° C. and about 60° C., and more preferably between about 10° C. and about 35° C. Tube **10** remains flexible and can allow for good control for its insertion into conduit **20**.

[0050] The insertion of tube **10** into conduit **20** may be carried out using various techniques. For example, as shown in FIG. 2, the tube **10** may be drawn into the conduit **20** and expanded or inflated by air pressure such that it fills conduit channel **50** and conforms to the shape of conduit **20**. In



another embodiment, illustrated in FIG. 3, the tube 10 may be inverted during insertion into the conduit 20 using, for example, water pressure. As a result, the inner membrane 40 may contact the inner surface of conduit 20. Moreover, the tube 10 may be inserted by employing an approach which combines both of the above methods. As shown in FIG. 4, a tube 10 is drawn into the conduit 20. Next, a second tube 10' which contains a thin inner membrane 40 is inverted into the first tube 10 which is drawn into conduit 20 as described herein above.

[0051] The curing of the thickened resin which is present in tube 10 contained in conduit 20 may occur using known techniques. For example, hot air, hot water, or other means such as electricity, radiation, and the like may be employed. The temperature under which the curing takes place preferably ranges from about 40° C. to about 150° C. The cured crosslinked resin material serves to line the conduit 20. In addition to the tube described above, it should be noted that other tubes, membranes, and the like may be utilized in conjunction with tube 10 to form a multi-layer composite liner structure within conduit 20.

[0052] The following examples are provided to illustrate the present invention, and should not be construed as limiting thereof.

#### EXAMPLES 1-20

##### Polycarbodiimide Preparation Using a Neat Preparation

[0053] Examples 1-20 represent polycarbodiimides prepared by using a neat preparation which is described herein below. Table 1 lists the compositions for the polycarbodiimides.

[0054] Toluene diisocyanate is placed in a reactor and n-butanol is added at a rate to maintain the reaction temperature below 120° C. The temperature is then increased to 120° C. and maintained for thirty minutes to complete the first step of the reaction. Next, a carbodiimide forming catalyst, 3-methyl-1-phenyl-2-phospholene-1-oxide, is added and the reaction is continued at 140° C. to complete the second step of the reaction. Once a small amount of unreacted isocyanate groups remain, as detected by infrared spectroscopy, a second charge of n-butanol is added to the reaction mixture. After 15 to 60 minutes, when no unreacted isocyanate groups are detected, the temperature is decreased to 100° C. Styrene containing an inhibitor is then added. The reaction is cooled continuously until room temperature is reached, thus completing the reaction.

[0055] Table 2 describes the resulting molecular weights (Mn and Mw) and polydispersity (D) for these examples as measured by gel permeation chromatography. Also listed are the viscosities determined by a Brookfield viscometer (LVF #3 spindle at 30 rpm) and percent solids.

#### EXAMPLES 21 THROUGH 27

##### Polycarbodiimide Preparation in the Presence of Styrene

[0056] Examples 21-27 are polycarbodiimides which are prepared in the presence of styrene. Specifically, toluene diisocyanate, styrene, and p-benzoquinone are placed in a reactor, and n-butanol is added at a rate to maintain a

reaction temperature below 120° C. The temperature is then increased to 120° C. and maintained for thirty minutes to complete the first step of the reaction. Next, a carbodiimide forming catalyst, 3-methyl-1-phenyl-2-phospholene-1-oxide, is added and the reaction is continued at 140° C. to complete the second step of the reaction. Once a small amount of unreacted isocyanate groups remain, as detected by infrared spectroscopy, a second charge of n-butanol is added to the reaction. After 15 to 60 minutes, when no more unreacted isocyanate groups are detected, the temperature is decreased to 100° C. and additional styrene is added to the reaction. The reaction is cooled continuously until room temperature is reached, and thus completing the reaction.

[0057] Table 3 describes the resulting molecular weights (Mn and Mw) and polydispersity (D) as measured by gel permeation chromatography. Also listed are the viscosities determined by a Brookfield viscometer (LVF #3 spindle at 30 rpm) and percent solids.

##### [0058] Resins Thickened Using Polycarbodiimides

[0059] Described below are resins which have been thickened using the polycarbodiimides referred to above. All resins are available from Reichhold Chemicals, Inc., Durham, N.C.

[0060] The resins are as follows. DION® 6694 is a corrosion resistant modified bisphenol fumarate. Polylyte® 31612 types are unsaturated polyesters containing propylene glycol and maleic anhydride. Polylyte® 31013-00 contains 2-methyl-1,3-propanediol, ethylene glycol, terephthalic acid, and maleic anhydride. Polylyte® 31830-00 is an unsaturated polyester containing diethylene glycol, adipic acid, isophthalic acid and maleic anhydride. Polylyte® 31506-00 is an unsaturated polyester containing propylene glycol, isophthalic acid, terephthalic acid, and maleic anhydride.

[0061] The following catalysts are used in the curing process. Superox® 46744 is a pourable, pumpable BPO dispersion available from Reichhold Chemicals, Inc., Durham, N.C. Trigonox® 21 is a t-butyl peroxy-2-ethylhexanoate catalyst available from Akzo Chemicals, Inc., Chicago, Ill.

[0062] The procedure for thickening a resin begins by placing an unsaturated polyester in a container and mixing a catalyst with the resin for five to ten minutes. The polycarbodiimide is then added and mixed for one minute. The percentage of polycarbodiimide used can be varied to achieve the desired viscosity at the required time interval. Viscosities in the following tables are measured with a Brookfield viscometer RVF#4 at 10 rpm if the reported viscosity is below 20,000 cps and with a Brookfield viscometer HBT TC spindle at 1 rpm for viscosities exceeding 20,000 cps.

##### [0063] Description of Data

[0064] Table 4 illustrates the chemical thickening profile of DION® 6694 using the polycarbodiimide described in Example 18. A general procedure to line a pipe is described below. FIGS. 1 and 3 illustrate the lining of the pipe. In one embodiment, unsaturated polyester resin Don® 6694 is mixed with Superox® 46744 for about 10 minutes and then the polycarbodiimide described in Example 18 is added in the amount described in Table 4. The reactive mixture is pumped into tube 10 through one end or at several puncture

ports located along tube **10**. The reactive mixture is allowed to thicken for 24 hours at room temperature to become a gel-like substance that remains flexible to allow for good control during insertion into conduit **20**. As shown in **FIG. 3**, tube **10** is inverted during insertion into conduit **20** by using water pressure. As a result, inner membrane **40** is forced inside-out and contacts the inner surface of conduit **20**. After inversion of tube **10**, one of the ends is sealed so that water remains in the inner portion of the tube. The temperature of the water is then gradually increased to about 90° C. for about 1 to about 4 hours. At the end of this period, the impregnated tube **10** becomes a hardened material lining conduit **20**.

[**0065**] Table 5 illustrates the chemical thickening profiles of PolyLite® 31612 types using two different polycarbodiimide concentrations: (1) 8 weight percent of Example 10 and (2) 10 weight percent of Example 26. Table 6 illustrates the chemical thickening profiles of PolyLite® 31013-000 at two different polycarbodiimide concentrations: (1) 8 weight percent of Example 3 and (2) 10 weight percent of Example 9. Table 7 illustrates the chemical thickening profiles for PolyLite® 31013-00 and PolyLite® 31830-00 blend, 75/25 weight percent respectively, using 8 weight percent of polycarbodiimides prepared in (1) Example 10 and (2) Example 18.

[**0066**] Table 8 illustrates two hour chemical thickening profiles using PolyLite® 31506-00 with polycarbodiimides described in Examples 3, 4, 6, and 7. Table 9 illustrates chemical thickening profiles using PolyLite® 31506-00 with polycarbodiimides described in Examples 3, 4, 5, 8, 9, 16, 17, 19, and 20. Table 10 illustrates chemical thickening profiles for PolyLite® 31506-00 containing styrene-prepared polycarbodiimides described in Examples 21 and 25. Table 11 illustrates the effect of polycarbodiimide concentration on the chemical thickening profile using PolyLite® 31506-00 with the polycarbodiimide prepared in Example 9. Table 12 illustrates batch-to-batch variation with polycarbodiimides prepared in Examples 7 and 18 and two batches of PolyLite® 31506-00: A and B. Table 13 details the effect of temperature on the chemical thickening profile of PolyLite® 31506-00 and the polycarbodiimide prepared in Example 8.

[**0067**] Comparison of Chemical Thickening Processes

[**0068**] Table 14 compares four different chemical thickening systems. The polycarbodiimide system according to the invention was prepared by mixing 2 g of Superox® 46744 with 180 g of PolyLite® 31612-10 for two minutes. The polycarbodiimide prepared in Example 18 was then added in the amount of 20 g and mixed for one minute.

[**0069**] A magnesium oxide system was prepared by mixing 2 g of Superox® 46744 with 200 g PolyLite® 31612-10 for two minutes. Maglite D® (C. P. Hall Company, Chicago, Ill.) in the amount of 8 g was then added and mixed for one minute.

[**0070**] A combination magnesium oxide and polycarbodiimide system was prepared by mixing 2 g of Superox® 46744 with 190 g of PolyLite® 31612-10 for two minutes. Maglite D® was then added in the amount of 6 g as well as 10 g of Example 18. The material was mixed for one minute.

[**0071**] A Rubinate M® (ICI, Sterling Heights, Mich.) system was made by mixing 2 g of Superox® 46744 with 200 g of PolyLite® 31612-10 for two minutes. Rubinate M®

in the amount of 10 g and 1 g of dibutyl tin dilaurate were added and mixed for one minute.

TABLE 1

General Polycarbodiimide Production		
Raw Material	Total Charge Weight Percent	
	Neat Preparation	Sytrene Preparation
Toluene diisocyanate	48.78	48.78
Styrene	0	20.00
p-benzoquinone	0.0112-0.0300	0.0300
n-butanol	13.835	13.835
Phospholene oxide*	0.03-0.05	0.03-0.05
Sytrene	37.31-37.34	17.31-17.33

\*3-methyl-1-phenyl-2-phospholene-1-oxide

[**0072**]

TBALE 2

Polycarbodiimide Production							
Neat Preparation							
Example	Molecular			Physical Properties		n-Butanol Charge	
	Weight Data			Viscosi-	Percent	Percent	Percent
	Mn	Mw	D	ty cps	Solids	1 <sup>st</sup> Add	2 <sup>nd</sup> Add
1	1570	23600	15	260	58.1	86.7	13.3
2	1650	30300	18	310	57.6	86.7	13.3
3	1460	14400	10	364	57.1	86.7	13.3
4	1440	13100	9	324	57.5	86.7	13.3
5	1430	10500	7.4	204	56.2	86.7	13.3
6	1370	11500	8.4	420	57.4	95	5
7	1210	7240	6.0	224	57.2	97.5	2.5
8	1110	4280	3.8	180	58.6	98.5	1.5
9	1210	5780	4.8	228	59.2	97.5	2.5
10	1500	9200	6.1	320	59.2	97.5	2.5
11	1270	6310	5	328	59.6	97.5	2.5
12	1290	5960	4.6	284	59.5	97.5	2.5
13	1210	5070	4.2	260	59.8	97.5	2.5
14	1210	5040	4.2	280	59.2	97.5	2.5
15	1170	4370	3.7	240	59.5	97.5	2.5
16*	1190	5040	4.2	380	59.4	97.5	2.5
17	1420	9420	6.6	480	59.4	97.5	2.5
18	1440	9230	6.4	560	59.2	97.5	2.5
19	1200	4680	3.9	344	58.5	97.5	2.5
20	1200	5800	4.8	440	58.6	97.5	2.5

\*Example 16 is a composite of Examples 11 through 15.

[**0073**]

TABLE 3

Polycarbodiimide Production							
Styrene Preparation							
Example	Molecular			Physical Properties		n-Butanol Charge	
	Weight Data			Viscosi-	Percent	Percent	Percent
	Mn	Mw	D	ty cps	Solids	1 <sup>st</sup> Add	2 <sup>nd</sup> Add
21	1170	4630	3.9	268	60.2	90	10
22	1350	10400	7.7	344	61.6	90	10
23	1470	14500	9.9	400	61.4	90	10
24	1530	15600	10	432	60.4	90	10
25	1230	5490	4.5	392	60.9	100	0

TABLE 3-continued

Polycarbodiimide Production Styrene Preparation								
Example	Molecular Weight Data			Physical Properties		n-Butanol Charge		Percent
	Mn	Mw	D	ty cps	Solids	1 <sup>st</sup> Add	2 <sup>nd</sup> Add	
26	1100	5620	5.1	336	59.8	98.5	1.5	
27	1140	5640	5	480	61.3	98	2	

[0074]

TABLE 4

Chemical Thickening Profile DION @ 6694		
Blend Component	Weight Percent	
6694	92	
Example 18	8	
Superox @ 46744	1 g/100 g mix	
Time from Mixing Minutes	Viscosity cps	
0	1000	
15	1660	
30	3120	
45	6640	
60	14400	
90	1.44 × 10 <sup>6</sup>	
120	2.08 × 10 <sup>6</sup>	
24 hours	3.86 × 10 <sup>6</sup>	
Gel Time Data		
Gel time at 90° C.	29.5 min	
Peak exotherm	205.7° C.	
Total time to peak	47.4 min	

[0075]

TABLE 5

Chemical Thickening Profiles Polylite @ 31612 Types		
Blend Component	Weight Percent	
31612-10	92	
Example 10	8	
Trigonox @ 21	1 g/100 g mix	
Time from Mixing Minutes	Viscosity cps	
0	1200	
15	2150	
30	3300	
45	4600	
60	5700	
90	7700	
120	9100	
150	10400	

TABLE 5-continued

Chemical Thickening Profiles Polylite @ 31612 Types	
180	10800
24 hours	13140
Gel Time Data	
Gel time at 90° C.	6.8 min
Peak exotherm	221.0° C.
Total time to peak	9.0 min
Blend Component	Weight Percent
31612-25	90
Example 26	10
Time from Mixing Minutes	Viscosity cps
0	3600
2	4480
4	5240
6	6310
8	7770
10	9620
15	19400
20	30000
25	70000
45	6.44 × 10 <sup>6</sup>
120	6.72 × 10 <sup>6</sup>

[0076]

TABLE 6

Chemical Thickening Profiles Polylite @ 31013-00		
Blend Component	Weight Percent	
31013-00	69	
Styrene	23	
Example 3	8	
Time from Mixing Minutes	Viscosity cps	
0	500	
2	540	
4	600	
6	660	
8	720	
10	800	
15	1000	
20	1200	
25	1440	
30	1640	
45	2420	
60	3280	
70	3880	
80	4500	
90	5280	
100	5940	
110	6500	
120	6920	

TABLE 6-continued

Chemical Thickening Profiles Polylite ® 31013-00	
270	12320
360	15660
Blend Component	Weight Percent
31013-00	67.5
Styrene	22.5
Example 9	10
Time from Mixing Minutes	Viscosity cps
0	740
15	1200
30	2000
45	2880
60	4560
90	8040
120	14300
20 hours	$1.96 \times 10^6$

[0077]

TABLE 7

Chemical Thickening Profiles Polylite ® 31013-00 and Polylite ® 31830-00 Blend	
Blend Component	Weight Percent
31013-00	69
31830-00	23
Example 10	8
Trigonox ® 21	1 g/100 g mix
Time from Mixing Minutes	Viscosity cps
0	760
15	1100
30	1500
45	1960
60	2480
90	3340
120	4160
24 hours	8540
Gel Time Data	
Gel Time at 90° C.	6.3 min
Peak exotherm	236.7° C.
Total time to peak	15.7 min
Blend Component	Weight Percent

TABLE 7-continued

Chemical Thickening Profiles Polylite ® 31013-00 and Polylite ® 31830-00 Blend	
31013-00	69
31830-00	23
Example 18	8
Time from Mixing Minutes	Viscosity cps
0	980
15	1540
30	2260
45	3280
60	4060
90	5580
120	6860
24 hours	13200

[0078]

TABLE 8

Chemical Thickening Profiles Polylite ® 31506-00				
Blend Component	Weight Percent	Weight Percent	Weight Percent	Weight Percent
31506-00	92	92	92	92
Polycarbodiimide	8	8	8	8
Polycarbodiimide	Example 3	Example 4	Example 6	Example 7
Time from Mixing Minutes	Viscosity cps	Viscosity cps	Viscosity cps	Viscosity cps
0	900	850	700	700
2	980	920	800	800
4	1080	1020	850	800
6	1160	1060	900	800
8	1260	1200	1000	825
10	1360	1300	1000	850
15	1700	1600	1150	1100
20	2240	2120	1350	1200
25	3080	2600	1600	1400
30	4280	3450	18000	1600
40	7020	6300	—	—
45	—	—	300	2400
50	240000	50000	—	—
60	$1.12 \times 10^6$	$1.44 \times 10^6$	5150	3650
70	$1.96 \times 10^6$	$2.16 \times 10^6$	7400	4800
80	$2.48 \times 10^6$	$2.60 \times 10^6$	10950	7200
90	$3.08 \times 10^6$	$2.92 \times 10^6$	>100000	8600
120	$4.40 \times 10^6$	$4.12 \times 10^6$	—	—

[0079]

TABLE 9

Chemical Thickening Profiles Polylite ® 31506-00				
Blend Component	Weight Percent	Weight Percent	Weight Percent	Weight Percent
31506-00	92	92	92	92
Polycarbodiimide	8	8	8	8
Polycarbodiimide	Example 3	Example 4	Example 5	Example 9

TABLE 9-continued

Chemical Thickening Profiles Polylite ® 31506-00					
Time from Mixing Minutes	Viscosity cps	Viscosity cps	Viscosity cps	Viscosity cps	Viscosity cps
0	—	—	—	700	700
15	1640	1686	1608	1080	1060
30	10	3390	2780	1760	1640
45	—	—	—	2560	2620
60	100000	1.34 × 10 <sup>6</sup>	42400	3660	4020
75	—	—	—	5940	5800
90	2.40 × 10 <sup>6</sup>	4.00 × 10 <sup>6</sup>	2.40 × 10 <sup>6</sup>	8720	11560
120	—	—	—	40000	120000
150	4.00 × 10 <sup>6</sup>	5.20 × 10 <sup>6</sup>	4.08 × 10 <sup>6</sup>	1.28 × 10 <sup>6</sup>	1.80 × 10 <sup>6</sup>
24 Hours	6.70 × 10 <sup>6</sup>	6.20 × 10 <sup>6</sup>	8.60 × 10 <sup>6</sup>	4.84 × 10 <sup>6</sup>	5.52 × 10 <sup>6</sup>

Blend Component	Weight Percent	Weight Percent	Weight Percent	Weight Percent
31506-00	92	92	92	92
Polycarbodiimide	8	8	8	8
Polycarbodiimide	Example 16	Example 17	Example 19	Example 20
Time from Mixing Minutes	Viscosity cps	Viscosity cps	Viscosity cps	Viscosity cps
0	780	720	750	700
15	1000	1040	1000	1000
30	1260	1460	1400	1500
45	1740	1940	1900	2000
60	2200	2600	2450	2800
90	3280	4320	4200	4100
120	4600	6300	5500	4800
150	—	10780	—	—
24 Hours	1.00 × 10 <sup>6</sup>	1.48 × 10 <sup>6</sup>	2.40 × 10 <sup>6</sup>	2.88 × 10 <sup>6</sup>

[0080]

TABLE 10

Chemical Thickening Profiles: Styrene Preparations Polylite ® 31506-00		
Blend Component	Weight Percent	Weight Percent
31506-0	92	92
Polycarbodiimide	8	8
Polycarbodiimide	Example 21	Example 25
Time from Mixing Minutes	Viscosity cps	Viscosity cps
0	760	860
2	840	900
4	880	940
6	920	980
8	1000	1020
10	1060	1060
15	1300	1200
20	1600	1380
25	1860	1520
30	2500	1720
45	4780	2460
60	12800	3240
70	0.48 × 10 <sup>6</sup>	4740
80	2.84 × 10 <sup>6</sup>	5620
90	4.16 × 10 <sup>6</sup>	7540
120	—	16000
240	6.64 × 10 <sup>6</sup>	—
24 Hours	—	3.76 × 10 <sup>6</sup>

[0081]

TABLE 11

Chemical Thickening Profiles: Effect of Polycarbodiimide Concentration				
Blend Component	Weight Percent	Weight Percent	Weight Percent	Weight Percent
31506-00	96	95	94	93
Example 9	4	5	6	7
Time from Mixing Minutes	Viscosity cps	Viscosity cps	Viscosity cps	Viscosity cps
0	700	640	660	700
15	900	940	1120	1300
30	1200	1440	2100	3000
45	1600	2420	4360	120000
60	1900	3440	—	880000
90	2800	8260	1.12 × 10 <sup>6</sup>	1.52 × 10 <sup>6</sup>
120	3800	80000	1.24 × 10 <sup>6</sup>	1.84 × 10 <sup>6</sup>

[0082]

TABLE 12

Chemical Thickening Profiles Batch to Batch Variation				
Blend Component	Weight Percent	Weight Percent	Weight Percent	Weight Percent
31506-00	92	92	92	92
Polycarbodiimide	8	8	8	8

TABLE 12-continued

Chemical Thickening Profiles Batch to Batch Variation				
31506-00 Batch	Example 7		Example 18	
	A	B	A	B
Times from Mixing Minutes	Viscosity cps	Viscosity cps	Viscosity cps	Viscosity cps
0	800	1400	700	1560
15	1100	2150	1000	2880
30	1640	3550	1300	5460
45	2460	5600	1900	10240
60	4120	9600	2500	20000
90	8020	80000	3900	2.04 × 10 <sup>6</sup>
120	120000	2.04 × 10 <sup>6</sup>	5800	3.28 × 10 <sup>6</sup>
150	1.24 × 10 <sup>6</sup>	—	8200	—
24 hours	4.96 × 10 <sup>6</sup>	3.00 × 10 <sup>6</sup>	3.44 × 10 <sup>6</sup>	3.60 × 10 <sup>6</sup>

[0083]

TABLE 13

Chemical Thickening Profiles - Effect of Temperature				
Blend Component	Weight Percent	Weight Percent	Weight Percent	Weight Percent
31506-00	92	92	92	92
Example 8	8	8	8	8
Time from Mixing minutes	Viscosity cps 50° F.	Viscosity cps 77° F.	Viscosity cps 90° F.	Viscosity cps 90° F.
0	600	600	600	600
15	1300	900	920	920
30	1700	1300	1400	1400
45	2100	1900	2000	2000
60	2600	2600	3700	3700
90	3100	4000	6200	6200
120	3800	5800	13600	13600
150	4900	8600	80000	80000
24 hours	1.16 × 10 <sup>6</sup>	1.14 × 10 <sup>6</sup>	0.68 × 10 <sup>6</sup>	0.68 × 10 <sup>6</sup>

[0084]

TABLE 14

Comparison of Chemical Thickening Processes				
Blend Component	Weight Percent	Weight Percent	Weight Percent	Weight Percent
31612-10	90	100	95	100
Example 18	10	—	5	—
Maglite D	—	4 g/100 g resin	3 g/100 g mix	—
Rubinate M	—	—	—	5 g/100 g resin
Dibutyl tin dilaurate	—	—	—	0.5 g/100 g resin
Superox ® 46744	1 g/100 g mix	1 g/100 g resin	1 g/100 g mix	1 g/100 g
Time from Mixing Minutes	Viscosity Cps	Viscosity Cps	Viscosity Cps	Viscosity Cps
0	800	1140	900	620
15	1200	1140	1800	740
30	2400	1200	2500	980
45	4600	1200	3100	1300
60	5700	1460	41000	1920

TABLE 14-continued

Comparison of Chemical Thickening Processes				
Blend Component	Weight Percent	Weight Percent	Weight Percent	Weight Percent
60	5700	1460	4000	1920
90	7700	2480	6300	3720
120	9100	5200	10400	8380
24 hours	4.22 × 10 <sup>6</sup>	3.84 × 10 <sup>6</sup>	3.20 × 10 <sup>6</sup>	7.60 × 10 <sup>6</sup>
Gel Time Data				
Gel time at 90° C.	18.1 min	14.6 min	13.2 min	15.0 min
Peak exotherm	215.9° C.	238.5° C.	226.4° C.	200.8° C.
Total time to peak	27.8 min	19.5 min	18.0 min	22.0 min

[0085] The invention has been described in detail with reference to its preferred embodiments and its examples. However, it will be apparent that numerous variations and modifications can be made without departure from the spirit and scope of the invention as described in the foregoing specification and claims.

That which is claimed:

1. A method of lining a surface of a substrate, said method comprising:

providing a reactive mixture which comprises (1) a resin containing active hydrogens; (2) a polycarbodiimide; and (3) an organic diluent;

reacting the resin containing active hydrogens and the polycarbodiimide to chemically bind the resin and the polycarbodiimide;

applying the chemically bound resin and polycarbodiimide to the surface of the substrate; and

curing the chemically bound resin and polycarbodiimide in the presence of a initiator to form a cured resin material which lines the surface of the substrate.

2. The method according to claim 1, wherein the substrate is a conduit.

3. The method according to claim 1, wherein the reactive mixture comprises greater than about 5 percent by weight of polycarbodiimide.

4. The method according to claim 1, wherein the resin containing active hydrogens is selected from the group consisting of saturated polyester resins, unsaturated polyester resins, vinyl ester resins, polyurethane resins, and mixtures thereof.

5. The method according to claim 1, wherein the organic diluent is selected from the group consisting of toluene, xylene, chlorobenzene, chloroform, tetrahydrofuran, ethyl acetate, isopropyl acetate, butyl acetate, butyl phthalate, acetone, methyl cellosolve acetate, cellosolve acetate, butyl cellosolve, methyl ethyl ketone, diethyl ketone, cyclohexanone, styrene, alphas-methylstyrene, p-methyl styrene, divinyl benzene, vinyl toluene, divinyl toluene, ethyl styrene, tert-butyl styrene, monochloro styrene, dichloro styrene, vinyl cyclohexane, vinyl cyclopentane, vinyl toluene, vinyl anthracenes, 3-vinyl benzyl chloride, 4-vinyl biphenyl, 4-vinyl-1-cyclohexene, vinyl cyclooctane, 2-vinyl naphthalene, 5-vinyl-2-norbornene, 1-vinylimidazole, 2-vinyl pyridine, 4-vinyl pyridine, 1-vinyl-2-pyrrolidinone, 9-vinyl carbazole,

ethylene glycol dimethacrylate, butanediol dimethacrylate, hexanediol dimethacrylate, and mixtures thereof.

6. The method according to claim 1, wherein the organic diluent comprises a polyfunctional acrylate component.

7. The method according to claim 1, wherein the polycarbodiimide is formed from a reaction between an isocyanate-containing intermediate and a diisocyanate.

8. The method according to claim 7, wherein the isocyanate-containing intermediate is formed from a reaction between a component containing active hydrogens and a diisocyanate.

9. The method according to claim 8, wherein the component containing active hydrogens is selected from the group consisting of alcohols, amines, thiols, phenols, silanol, —P—OH, —P—H, and mixtures thereof.

10. The method according to claim 8, wherein the component containing active hydrogens is an alcohol.

11. The method according to claim 1, wherein the initiator is an organic peroxide selected from the group consisting of cumene hydroperoxide; methyl ethyl ketone peroxide; benzoyl peroxide; acetyl peroxide; 2,5-dimethylhexane-2,5-dihydroperoxide; tert-butyl peroxybenzoate; di-tert-butyl perphthalate; dicumyl peroxide; 2,5-dimethyl-2,5-bis(tert-butylperoxy)hexane; 2,5-dimethyl-2,5-bis(tert-butylperoxy)hexyne; bix(tert-butylperoxyisopropyl)benzene; ditert-butyl peroxide; 1,1-di(tert-amylperoxy)-cyclohexane; 1,1-di-(tert-butylperoxy)-3,3,5-trimethylcyclohexane; 1,1-di-(tert-butylperoxy)-cyclohexane; 2-di-(tert-butylperoxy)butane; n-butyl-4,4-di(tert-butylperoxy)valerate; ethyl-3,3-di-(tert-amylperoxy)butyrate; ethyl-3,3-di(tert-butylperoxy)-butyrate; t-butyl peroxy-neodecanoate; di-(4-5-butylcyclohexyl)-peroxydicarbonate; lauryl peroxyde; 2,5-dimethyl-2,5-bis(2-ethyl-hexanoyl peroxy) hexane; t-amyl peroxy-2-ethylhexanoate; 2,2'-azobis(2-methyl-propionitrile); 2,2'-azobis(2,4-methylbutanenitrile); and mixtures thereof.

12. The method according to claim 1, wherein the initiator is a photoinitiator.

13. The method according to claim 1, wherein said curing step is carried out in the presence of a promoter.

14. The method according to claim 1, wherein said reactive mixture further comprises fibrous reinforcement material.

15. The method according to claim 14, wherein the fibrous reinforcement material is selected from the group consisting of fiberglass, polyester, carbon, metal, organic fibers, and mixtures thereof.

16. The method according to claim 1, wherein said reacting step is carried out at a temperature ranging from about 5° C. to about 60° C.

17. The method according to claim 1, wherein said curing step is carried out at a temperature ranging from about 40° C. to about 150° C.

18. A method of lining a surface of a conduit comprising:

providing a reactive mixture which comprises (1) a resin containing active hydrogens; (2) a polycarbodiimide; and (3) an organic diluent;

inserting the reactive mixture into a tube, the tube being defined by an inner membrane and an outer membrane;

reacting the resin containing active hydrogens and the polycarbodiimide to chemically bind the resin and the polycarbodiimide;

inserting the tube into a conduit having an inner surface; applying pressure to the tube such that the tube comes in contact with the inner surface of the conduit; and

curing the chemically bound resin and polycarbodiimide in the presence of an initiator to form a cured resin material which lines the surface of the conduit.

19. The method according to claim 18, wherein the reactive mixture comprises greater than about 5 percent by weight of polycarbodiimide.

20. The method according to claim 18, wherein the resin containing active hydrogens is selected from the group consisting of saturated polyester resins, unsaturated polyester resins, vinyl ester resins, polyurethane resins, and mixtures thereof.

21. The method according to claim 18, wherein the organic diluent is selected from the group consisting of toluene, xylene, chlorobenzene, chloroform, tetrahydrofuran, ethyl acetate, isopropyl acetate, butyl acetate, butyl phthalate, acetone, methyl cellosolve acetate, cellosolve acetate, butyl cellosolve, methyl ethyl ketone, diethyl ketone, cyclohexanone, styrene, alphasethylstyrene, p-methyl styrene, divinyl benzene, vinyl toluene, divinyl toluene, ethyl styrene, tert-butyl styrene, monochloro styrene, dichloro styrene, vinyl cyclohexane, vinyl cyclopentane, vinyl toluene, vinyl anthracenes, 3-vinyl benzyl chloride, 4-vinyl biphenyl, 4-vinyl-1-cuclohexene, vinyl cyclooctane, 2-vinyl naphthalene, 5-vinyl-2-norbormene, 1-vinylimidazole, 2-vinyl pyridine, 4-vinyl pyridine, 1-vinyl-2-pyrrolidinone, 9-vinyl carbazole, ethylene glycol, dimethacrylate, butanediol dimethacrylate, hexanediol dimethacrylate, and mixtures thereof.

22. The method according to claim 18, wherein the organic diluent comprises a polyfunctional acrylate component.

23. The method according to claim 18, wherein the polycarbodiimide is formed from a reaction between an isocyanate-containing intermediate and a diisocyanate.

24. The method according to claim 23, wherein the isocyanate-containing intermediate is formed from a reaction between a component containing active hydrogens and a diisocyanate.

25. The method according to claim 24, wherein the component containing active hydrogens is selected from the group consisting of alcohols, amines, thiols, phenols, silanol, —P—OH, —P—H, and mixtures thereof.

26. The method according to claim 24, wherein the component containing active hydrogens is an alcohol.

27. The method according to claim 18, wherein the reactive mixture further comprises fibrous reinforcement material.

28. The method according to claim 27, wherein the fibrous reinforcement material is selected from the group consisting of fiberglass, polyester, carbon, metal, organic fibers, and mixtures thereof.

29. The method according to claim 18, wherein the initiator is an organic peroxide initiator selected from the group consisting of cumene hydroperoxide; methyl ethyl ketone peroxide; benzoyl peroxide; acetyl peroxide; 2,5-dimethylhexane-2,5-dihydroperoxide; tert-butyl peroxybenzoate; di-tert-butyl perphthalate; dicumyl peroxide; 2,5-dimethyl-2,5-bis(tert-butylperoxy)hexane; 2,5-dimethyl-2,5-bis(tert-butylperoxy)hexyne; bix(tert-butylperoxyisopropyl)benzene; ditert-butyl peroxide; 1,1-

di(tert-amylperoxy)-cyclohexane; 11-di-(tert-butylperoxy)-3,3,5-trimethylcyclohexane; 1,1-di-(tert-butylperoxy)-cyclohexane; 2,2-di-(tert-butylperoxy)butane; n-butyl-4,4-di(tert-butylperoxy)valerate; ethyl-3,3-di-(tert-amylperoxy)butyrate; ethyl-3,3-di(tert-butylperoxy)-butyrate; t-butyl peroxy-neodecanoate; di-(4-5-butyl-cyclohexyl)-peroxydicarbonate; lauryl peroxyde; 2,5-dimethyl-2,5-bis(2-ethyl-hexanoyl peroxy) hexane; t-amyl peroxy-2-ethylhexanoate; 2,2'-azobis(2-methyl-propionitrile); 2,2'-azobis(2,4-methylbutanenitrile); and mixtures thereof.

**30.** The method according to claim 18, wherein the initiator is a photoinitiator.

**31.** The method according to claim 18, wherein the reaction mixture further comprises a promoter.

**32.** The method according to claim 18, wherein said reacting step is carried out at a temperature ranging from about about 5° C. to about 60° C.

**33.** A lined substrate comprising:

a cured resin material comprising a resin chemically bound to a polycarbodiimide; and

a surface of said substrate which contains said cured resin material thereon.

**34.** The lined substrate according to claim 33, wherein the resin chemically bound to a polycarbodiimide is selected from the group consisting of saturated polyester resins, unsaturated polyester resins, vinyl ester resins, polyurethane resins, and mixtures thereof.

**35.** The lined substrate according to claim 32, wherein said substrate is a conduit.

**36.** The lined substrate according to claim 32, wherein said cured resin material further comprises fibrous reinforcement material selected from the group consisting of fiberglass, polyester, carbon, metal, organic fibers, and mixtures.

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