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(71) Applicant(s)
Tremco Ltd.; The B.F. Goodrich Company

(72) Inventor(s)
Waldemar Kozakiewicz; David K Potter; Steven A Young

(74) Agent/Attorney
GRIFFITH HACK,GPO Box 1285K,MELBOURNE VIC 3001

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(71) Applicants: TREMCO, LTD. [CA/CA]; 220 Wicksteed Avenue, Leaside, Toronto, Ontario M4H 1G7 (CA). THE B.F. GOODRICH COMPANY [US/US]; 3935 Embassy Parkway, Akron, OH 44333-1799 (US).		Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>	
(72) Inventors: KOZAKIEWICZ, Waldemar; Apartment 403, 2 Park Vista, East York, Ontario M4B 1A1 (CA). POTTER, David, K.; 111 Sanderson Drive, Guelph, Ontario N1H 7K1 (CA). YOUNG, Steven, A.; R.R. 1, Hillsdale, Ontario L0L 1V0 (CA).			
(74) Agents: TUCKER, Mary, Ann et al.; The B.F. Goodrich Company, 9921 Brecksville Road, Brecksville, OH 44141-3289 (US).			
(54) Title: MOISTURE-CURABLE MODIFIED ACRYLIC POLYMER SEALANT COMPOSITION			
(57) Abstract <p>A cross-linkable acrylic copolymer having reduced amounts of silane functionalized monomeric units has been found to achieve unexpectedly superior adhesive, cohesive and flexural properties when used in a sealant formulation as compared with known silane functionalized acrylic copolymers. More particularly, it has been found that by reducing the amount of silane functionalized vinyl addition type monomer to less than 1 molar part per 100 molar parts of (meth)acrylate monomer, and reducing the amount of mercaptosilane chain transfer agent to less than 1 molar part per 100 molar parts of (meth)acrylate monomer, it is possible to obtain a copolymer which is capable of being used in a sealant formulation which exhibits vastly improved elastic properties, which are important for high movement sealant formulations, and improved adhesion to metal and glass substrates, while retaining other important sealant properties.</p>			

MOISTURE-CURABLE MODIFIED
ACRYLIC POLYMER SEALANT COMPOSITION

FIELD OF THE INVENTION

5 This invention relates to modified acrylic
copolymers suitable for formulating one-part, moisture
curable sealant compositions which are stable during
storage but which rapidly cures upon exposure to ambient
10 moisture, at about room temperature, to form a cured
sealant exhibiting superior strength, elastic recovery,
weatherability, and adhesion to a variety of substrate
materials. The invention further relates to a method for
15 preparing such modified acrylic copolymers, to room
temperature moisture curable sealant compositions utiliz-
ing the modified acrylic copolymers of the invention, and
to cured sealant compositions obtained by exposing the
sealant compositions of the invention to ambient condi-
tions for a time sufficient to effect the cure thereof.

BACKGROUND

20 Curable polyacrylate polymers incorporating
organosilane monomers capable of free radical polymeriza-
tion and containing hydrolyzable groups bonded to the
silicon atom are well known and have been used, for
25 example, as polymeric adhesion promoters and as primers
for coatings. After curing, these known polyacrylate-
organosilicon compositions, however, are generally tough,
often brittle materials, which are unsuitable for joint
sealing applications where elastic properties are re-
30 quired. Examples of such compositions are disclosed in
U.S. Patent Nos. 3,453,136; 3,951,893; 4,026,826 and
4,093,673.

 U.S. Patent No. 3,453,230 to Plueddemann relates
to acrylate-organosilicon compositions which are disclosed
35 as having "potential commercial utility as sealants,
coatings, and molding compounds" More specificall-
ly, the reference discloses a copolymer consisting essen-
tially of 100 molar parts of vinyl ester or acrylate

units; 1 to 8 molar parts of a (meth)acryloxyalkylsilane or vinylsilane; up to 50 molar parts of an optional vinyl monomer selected from the group generally consisting of ethylene, vinyl chloride, vinylidene chloride, vinyl acetate, styrene, acrylonitrile and butadiene; and from 0.5 to 4 molar parts of a mercaptosilane or mercaptan chain transfer agent. Sealant formulation utilizing the acrylate-organosilicon copolymers disclosed by the Plueddemann patent were found to be unacceptable for use as a high-movement sealant formulation on account of their poor cohesive and elongation properties.

The unsuitability of the known acrylate-organosilicon copolymers, for use in high-movement sealant formulations, such as those used, for example, to seal structural joints as between various building materials having different coefficients of thermal expansion, coupled with the availability of a variety of suitable alternatives, such as epoxy resin or polyurethane based formulations, have led to reduced interest in, and a slowing of further development of, effective acrylate-organosilicon copolymer based high-movement sealant formulations. Accordingly, despite their potential commercial utility in sealant formulations, which was recognized at least as early as 1964, acrylic copolymers containing reactive silyl groups and which are capable of being utilized in a high-movement sealant formulation which after curing exhibit superior elongation, elastic recovery and weatherability properties have not been previously disclosed.

In addition to having good physical properties after curing, such as high elongation, tensile strength, peel adhesion, weather resistance and flexibility, sealing formulations should desirably possess certain properties prior to curing, such as good long-term stability or shelf life when stored under normal conditions, good handling properties such as high extrudability rates, rapid cure and rapid attainment of the ultimate cured properties, and

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good anti-sag properties immediately after application to a vertically oriented substrate before curing is complete.

5 The Plueddemann patent discloses that the compositions taught therein remain relatively stable in a sealed vessel. However, it has been found that sealant formulations held in a sealed vessel and containing the acrylo-organosilane copolymers disclosed by Plueddemann experience a doubling of the viscosity index within 90 days in the absence of suitable stabilizing agents, 10 signifying a substantial loss of handling properties in a relatively short period of time.

Sealant formulations used as joint fillers in the construction industry generally contain high molecular weight polymers or copolymers in order to satisfy movement requirements due to thermal expansion of the substrate materials. To meet extrudability requirements, sealant formulations containing high molecular weight polymers or copolymers must also contain relatively large amounts of solvent to reduce the viscosity of the sealant formula- 15 tion. High amounts of solvent are, however, undesirable in sealant formulations because they lead to pronounced shrinkage of the sealant formulation during curing, which, in turn, is recognized as being a potential source of sealant failure. 20

25

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide a sealant formulation containing a modified acrylic copolymer incorporating monomeric units having hydrolyzable silyl groups and having an average molecular weight such that relatively low quantities of solvent are 30 required to provide the desired extrudability, whereby sealant failure due to shrinkage during curing is substantially eliminated or at least significantly reduced.

35 The primary object of the invention is to provide a modified acrylic copolymer containing monomeric units having hydrolyzable silyl groups and which is

5 suitable for incorporation into a one-part, moisture curable sealant composition having an excellent balance of good stability, handling, and anti-sag properties prior to curing; having superior ultimate cured properties such as good elongation, suitable tensile strength, good adhesion to a variety of substrates, good weatherability and flexibility; and having a rapid cure time such that the ultimate cured properties are rapidly attained upon exposure to ambient moisture at about room temperature.

10 Another object of the invention is to provide a crosslinker/stabilizer system which is used in a sealant formulation containing the modified acrylic copolymers of the invention to prevent premature hydration, gelation and loss of handling properties during storage even when small quantities of water are inadvertently introduced into the sealant formulation.

15 It has been discovered that modified acrylic copolymers containing reduced levels of organosilane monomers incorporated into the copolymer backbone, when used in a sealant formulation in accordance with the invention, unexpectedly achieve improved elongation, modulus, and adhesion to various building material substrates, such as glass and aluminum, while retaining ultimate tensile strength. More particularly, it has been found that in order to achieve dramatic improvements in elongation, modulus and adhesion, while retaining often desirable properties, it is necessary to use an acrylic copolymer containing a lower level of total (meth)acryloxyalkylsilane monomer, vinyl silane monomer, and mercap-

20 tosilane chain transfer units than are specifically taught by U.S. Patent No. 3,453,230 to Plueddemann. Specifically, the acrylic copolymers of the invention contain less than 1 percent organosilane monomeric units on a molar basis, whereas the prior art teaches acrylic copolymers containing from 1 percent up to as much as about 11 percent organosilane monomeric units on a molar basis. It is speculated that the reduced levels of organosilane

25 30 35

monomeric units per acrylic copolymer molecule results in a lower crosslink density which yields a softer, more flexible sealant formulation which unexpectedly retains other desirable properties such as ultimate tensile strength as measured by stress to failure analysis.

5 In accordance with another aspect of the invention, the acrylic copolymers having reduced levels of organosilane monomeric units relative to the prior art are utilized in a sealant formulation containing a mixture of
10 di- and trifunctional organosilane crosslinkers which also serve as moisture scavengers to provide for a combination of improved storage stability and excellent sealant properties. The mixture of di- and trifunctional silane
15 crosslinkers is believed to result in lower crosslinking densities than would otherwise occur if, for example, only tri or tetrafunctional crosslinkers were used, thereby preventing over-crosslinking upon curing whereby an unexpectedly superior combination of cohesive strength, adhesive strength, flexibility, and high movement are
20 achieved in the cured sealant formulation.

In accordance with a further aspect of the invention, it has been discovered that lower molecular weight aliphatic monohydric alcohols when used with the acrylic copolymer and organosilane crosslinkers of the
25 invention as a solvent/additive achieve improved sealant properties. In particular, it was found that unexpected improvements in elastic recovery were realized without any accompanying deleterious effects on other important sealant properties when an alcohol was added as a solvent
30 or co-solvent additive.

The acrylic copolymers, organosilane crosslinkers and monohydric solvents of the invention individually and collectively contribute toward achievement of a high movement sealant formulation suitable for sealing
35 building joints and which exhibits superior cohesive strength, adhesive strength, elongation, elastic recovery, storage stability, anti-sag properties and handling

properties.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

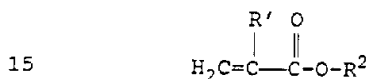
5 The acrylic copolymers of the invention are formed by any suitable free radical initiated chain polymerization process including bulk, solution, suspen-
10 sion or emulsion polymerization. However, because the acrylic copolymer of the invention includes organosilane monomers having hydrolyzable groups which serve as cross-linking sites upon exposure to moisture, it is important that the polymerization be performed in the absence of any significant quantity of water which would cause premature hydrolysis of the organosilanes and subsequent reaction with one another to form siloxane linkages. The acrylic
15 copolymers are most preferably formed by free radical initiated solution polymerization wherein the type of solvent and the amount of solvent are preferably selected such that the solvent is substantially unreactive with the monomers and does not significantly affect the polymeriza-
20 tion such as by contributing a significant chain transfer effect. Accordingly, solvent levels are preferably kept relatively low such as to constitute less than about 50 percent by weight of the reaction solution. Suitable solvents for the free radical initiated polymerization of
25 acrylic copolymers incorporating polymerizable monomers containing hydrolyzable groups bonded to a silicon atom are well known to the art and literature and include benzene, toluene, xylene, chloroform, carbon tetrachlo-
30 ride, methyl acetate, ethyl acetate, ethylene dichloride, acetone, dioxane, tertiary butyl alcohol and others, with the aromatic hydrocarbons, and aliphatic hydrocarbons.

The comonomers used to form the acrylic copoly-
mers of the invention include at least one acrylate or methacrylate monomer, at least one acryloxy alkyl silane,
35 methacryloxy alkyl silane or vinyl silane monomer contain-
ing up to three hydrolyzable groups bonded to the silicon atoms thereof, an optional, but highly desirable, vinyl

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addition type comonomer for modifying and enhancing physical properties such as cohesive strength, and an optional, but highly desirable, mercapto silane chain transfer agent having up to three hydrolyzable groups bonded to the silicon atom thereof.

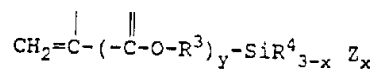
At least one acrylate monomer, methacrylate monomer or combinations thereof generally constitute the primary monomer or major portion of the copolymer and are primarily responsible for the properties thereof. Suitable acrylate and methacrylate monomers include those represented by the formula



where R' is either hydrogen or a methyl group, and R² is an alkyl group containing from 1 to about 9 carbon atoms. Examples include ethyl acrylate, 2-ethyl hexyl acrylate, ethyl methacrylate, butyl acrylate and the like. The particular monomer or combination of monomers employed depends primarily on the physical properties desired, especially upon the desired flexibility of the polymer, it being well known that polymer flexibility can be altered by varying the size of the alkyl substituent on the acrylate monomer. The preferred primary monomers for the acrylic copolymers of the invention include acrylates having from 2 to 6 atoms with the most preferred primary monomer being butyl acrylate, which at present is believed to provide the best overall combination or balance of desirable properties for use in a sealant composition.

The acryloxy alkyl silane, methacryloxy alkyl silane or vinyl silane addition monomers are utilized to provide sites for crosslinking along the backbone of the copolymer upon exposure to moisture such as ambient humidity. The silane functionalized addition monomers are generally represented by the formula





where R' is hydrogen or a methyl group, R³ is a divalent alkylene group, y is 0 or 1, R⁴ is an alkyl group, Z is a hydrolyzable group, and x is 1, 2 or 3. Alkylene groups represented by R³ in the above formula include methylene, ethylene, propylene, 2-methyl propylene, hexamethylene and the like. Suitable hydrolyzable groups include any of those known in the art and in the literature and include halogens such as chlorine or bromine, alkoxy groups such as methoxy or ethoxy, acyloxy groups such as acetoxymethyl or propionoxymethyl groups, ketoxymethyl groups such as methyl ethyl ketoxymethyl groups, alkoxyalkoxy groups and the like, with ketoxymethyl and alkoxy groups being preferred and with methoxy and ethoxy groups being most preferred. Because of their lower cost and greater availability, trifunctional silane functionalized addition monomers, i.e. those wherein x is equal to 3, are preferred. Suitable silane functionalized addition monomers include methacryloxypropyl trimethoxysilane, acryloxy propyl triethoxysilane, vinyl trimethoxysilane and the like, with vinyl trimethoxysilane being preferred for its lower reactivity during addition polymerization and hence its ability to provide long chains of nonreactive polymeric units between reactive silane functionalized monomer units containing hydrolyzable crosslinking sites, whereby reduced crosslink density using a readily available silane functionalized monomer having a trifunctional pendent silyl group is achieved.

The silane functionalized addition monomers are utilized in lower levels than previously disclosed by the prior art in order to increase the length of the nonreactive portion of the polymer chain to provide reduced levels of crosslinking and thereby achieve better properties for use in a sealant composition than have been heretofore attained. Specifically, the amount of silane functionalized addition monomer utilized in the copolymerization of the acrylic copolymers of the invention is less than 1 molar part, preferably from about 0.5 to about 0.95

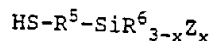
molar parts, and most preferably from about 0.5 to about 0.8 molar parts per 100 molar parts of the primary (meth)acrylate monomer.

5 The optional vinyl addition type comonomers are preferably utilized to impart enhanced properties such as improved tensile strength, shear strength and cohesive strength. The optional vinyl addition type comonomers are used in such amounts so as to achieve the foregoing enhancements, without seriously affecting other properties
10 such as handling properties, elasticity, modulus, and the like in a deleterious manner. The optional vinyl addition type comonomers can be generally characterized as mono-olefinically unsaturated addition monomers which are free of hydrolyzable groups bonded to a silane atom and are
15 generally unreactive to ambient moisture and constituents of the sealant formulation after incorporation into the acrylic copolymers of the invention. Suitable vinyl addition type comonomers for use with the invention include acrylonitrile, methacrylonitrile, vinyl substituted aromatics such as styrene, α -methyl styrene and the
20 like, as well as other well known addition type comonomers used to enhance physical properties. The preferred vinyl addition monomers include styrene and acrylonitrile with acrylonitrile being the most preferred. The amount of
25 optional vinyl addition type comonomers to be used depends primarily on the particular properties desired, the particular (meth)acrylate primary monomer, and the particular vinyl addition type comonomer selected. Suitable amounts of vinyl addition monomer range up to about 60
30 molar parts, more desirably from about 10 to about 50 molar parts, and most preferably from about 20 to about 40 molar parts per 100 molar parts of the (meth) acrylate primary monomer.

35 Chain transfer agents are preferably utilized during the free radical initiated polymerization of the acrylic copolymers of the invention to help control the number average molecular weight. Mercaptosilane chain

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transfer agents are preferably utilized to place crosslink sites at one end of the copolymer molecule in order to improve the cohesive strength of the cured sealant. Suitable mercaptosilane chain transfer agents for use with the invention have the general formula:



where R^5 is a divalent alkylene group, R^6 is an alkyl group, x is 1, 2 or 3, and Z is a hydrolyzable group. The alkylene groups, alkyl groups, and hydrolyzable groups are generally the same or similar to those set forth with respect to the silane functionalized addition monomers. Suitable mercaptosilane chain transfer agents include γ -mercapto propyl triethoxysilane, γ -mercaptopropyl trimethoxy silane, mercaptomethyl methyl dimethoxysilane and the like, with γ -mercaptopropyl trimethoxy silane being preferred. The quantities of chain transfer agents used are similar to those disclosed in the prior art.

The free radical initiated copolymerization can be carried out at temperatures and pressures which are generally well known in the art. To simplify the process and apparatus, the copolymerization is preferably done at or near atmospheric pressure. In order to maximize randomization of monomer addition, the polymerization is preferably conducted at a temperature which is as near to the ceiling temperature of the polymer being formed as is possible without actually risking depolymerization. Of course, the minimum effective temperature is dependent upon the dissociation temperature of the selected free radical initiator. Suitable temperatures generally range from about 25°C to about 200°C. The polymerization is preferably carried out at the reflux temperature of the reaction mixture.

Generally, any of the free radical initiators known to the art can be utilized. Suitable free radical initiators include any of the acyl peroxides such as acetyl peroxide and benzoyl peroxide, alkyl peroxides such as *t*-amyl and *t*-butyl peroxides, hydroperoxides such as *t*-

butyl and cumyl hydroperoxides, peresters such as t-butyl perbenzoate, any of the various known azo initiators such as 2,2'-azobisisobutyronitrile, as well as disulfide initiators, tetrazenes and the like. Particularly preferred are t-amyl peroxides. The amount of initiator utilized is generally consistent with the amounts specified by the prior art, and appropriate amounts of free radical initiator can be readily determined by those of ordinary skill in the art by taking into consideration the particular reaction conditions and desired final properties including the monomers used, the desired molecular weight distributions, the amount, if any, of chain transfer agents utilized, etc. Suitable amounts of free radical initiators generally are within the range from about 0.01 percent to 1 percent by weight based upon the total weight of all monomers.

In accordance with a preferred aspect of the invention, the copolymerization is performed in a semi-batch made such that the monomers are fed into the reactor at a predetermined rate to compensate for differences in reactivity and thereby maintain substantially constant concentration ratios of the monomers during the copolymerization. Maintaining a constant monomer concentration ratio over the course of the polymerization will help to achieve a more uniform sequence length distribution. An appropriate monomer feed protocol for a given copolymerization system can be readily determined by those skilled in the art by observing the monomer concentrations for a batch process and appropriately adjusting the monomer feed rates to use an excess of the poorly reacting monomers early in the polymerization and add higher amounts of the more reactive monomers later in the polymerization. Further adjustments and refinements of the monomer feed protocol can be made if necessary.

In order to reduce the risk of premature hydrolysis of the hydrolyzable groups bonded to the mercaptosilane chain transfer agent and to the silane functional-

ized addition monomers due to inadvertent exposure to small or incidental quantities of water, and to eliminate the need for ensuring that all of the constituents of the copolymerization reaction mixture are absolutely, or at least very nearly, completely free of moisture, various crosslinkers/moisture scavengers are preferably introduced into the copolymerization reaction mixture. Suitable crosslinkers/moisture scavengers generally include polyfunctional organosilanes having from two to four hydrolyzable groups. Examples of suitable crosslinkers/moisture scavengers include methyltrimethoxysilane, tetraethyl orthosilicate, isobutyltrimethoxysilane, and dimethylmethylethyl ketoximosilane. While tetrafunctional organosilanes provide slightly better moisture scavenging efficiency, trifunctional organosilanes are preferred because they provide adequate moisture scavenging efficiency and provide better overall properties in cured sealant compositions primarily due to lower crosslinking densities. The preferred crosslinker/moisture scavenger for use during the copolymerization of the acrylic copolymers of the invention is iso-butyltrimethoxy silane. The crosslinkers/moisture scavengers are preferably used during the copolymerization in amounts ranging from about 0.5 parts to about 4 parts, and more preferably from 1 part to about 2 parts, per molar pair of radical polymerized silanes.

The reaction is generally allowed to proceed to at least 99 percent monomer conversion and more preferably from about 99 to about 99.99 percent monomer conversion. The amount of time needed to achieve the desired degree of conversion is dependent on the polymerization conditions including the temperatures, pressures, monomers, chain transfer agents, initiators, etc.; however, suitable conversions are generally achieved in from about 3 hours to about 10 hours.

The acrylic copolymers of the invention generally have a number average molecular weight of from

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about 5,000 to about 40,000 and more preferably from about 15,000 to about 25,000, and a weight average molecular weight of from 10,000 to about 200,000 and more preferably from about 25,000 to about 100,000. The copolymers on average generally contain from about 1 to about 4, and most preferably contain about 2 organosilane units per molecule, and from about 2 to about 12 and most preferably about 6 hydrolyzable groups per molecule on average.

The acrylic copolymers of the invention are expected to have properties which make them suitable in various adhesive and coating formulations. However, sealant formulation utilizing the acrylic copolymers disclosed herein have been found to exhibit properties which are unexpectedly superior to those exhibited by similar formulations utilizing previously known acrylic copolymers.

The moisture curable sealant formulations of the invention generally comprise a blend of the acrylic copolymer disclosed herein, crosslinkers/moisture scavengers, and various conventional additives including fillers, colorants, rheological modifiers, extenders, solvents, curing catalysts, and the like.

Any of the various crosslinking agents/moisture scavengers known to the art and literature such as methylmethoxysilane or tetraethylorthosilicate can be used. However, in accordance with a preferred aspect of the invention, it has been discovered that a surprisingly good combination of storage stability, fast curing rates and excellent cured sealant properties is achieved by utilizing a combination of both di- and tri-functional crosslinkers, without any substantial quantities of tetra-functional crosslinkers. The combination of di- and tri-functional silane crosslinkers is believed to provide a crosslink density in the cured sealant composition which contributes to superior elastomeric properties needed for high movement sealants while simultaneously achieving or retaining other good sealant properties such as cohesive

and adhesive strength, and good weatherability. The amount of difunctional crosslinker/moisture stabilizer used is generally from about 0.5 to about 4, and preferably from about 1.1 to about 2.0, per 100 parts by weight of polymer. The preferred difunctional crosslinker/moisture scavengers include dialkyl dialkoxy silanes such as dimethyl dimethoxysilane, or vinyl methyl dimethoxysilane. However, various other di and trifunctional silane crosslinks such as difunctional and trifunctional oximo curing agents, such as dimethyl dimethyl-ethyloximosilane can be used. Because dimethyl dimethylethylketoximosilane is highly susceptible to oxidation at elevated temperature, it is preferably added after copolymerization of the acrylic copolymer.

The amount of trifunctional crosslinker/moisture scavenger used is generally from about 0.5 to about 10, and more preferably from about 1.5 to about 2.5, parts per 100 parts by weight of polymer. The preferred trifunctional crosslinker/moisture scavenger is iso-butyltrimethoxysilane which may be added wither to the sealant formulation after copolymerization of the acrylic copolymer or more preferably during the copolymerization of the acrylic copolymer to help prevent premature hydration of the hydrolyzable groups of the organosilane addition monomers and optional mercaptosilane chain transfer agents. In either case, the foregoing amounts refer to the total amounts of di- and tri-functional crosslinkers/moisture scavengers utilized without regard for whether they are added during the copolymerization of the acrylic copolymer or afterward.

In order to impart a desirable combination of handling, extrudability, and anti-sag properties, a rheological modifier, more specifically a thixotropic agent is preferably added to the sealant formulation. Preferred thixotropic agents include commercially available castor oil derivatives which are utilized in effective amounts such as from about 3 percent to about 8

percent, and more desirably from about 4 percent to about 6 percent by weight based on the total weight of the sealant formulation.

5 In order to improve adhesion between the sealant and a substrate such as glass or metal, any of various adhesion promoters known to bond tenaciously to non-porous substrates are preferably added to the sealant formulation. Suitable adhesion promoters contain polyfunctional silanes generally having three hydrolyzable groups which
10 react with hydroxy or other oxygen containing groups present on the substrate and also with each other and with the acrylic copolymer, either directly through a hydrolyzed silane or through a crosslinker to facilitate better adhesion between the acrylic copolymer and the substrate. Examples include methacryloxytrimethoxysilane, γ -
15 glicidoxypentyltrimethoxysilane, γ -aminopentyltriethoxysilane, γ -aminopentyltrimethoxysilane and aminoalkyltrimethoxy disilane. The preferred adhesion promoter for use in the sealant formulation of the invention is γ -
20 aminopentyltriethoxysilane or γ -aminopentyltrimethoxysilane. The amount of adhesion promoter used in the sealant formulation is generally from 0.1 to 0.5, and more preferably from 0.1 to 0.3 parts by weight per 100 parts by weight of polymer.

25 Various inorganic fillers and extenders can be added to the sealant formulation to improve anti-sag properties. Examples include such fillers as silica, alumina, titania, glass powder or fibers, carbon black, powdered metals, clay, talc, magnesium oxide, magnesium
30 hydroxide, calcium carbonate and the like. The presently preferred filler is calcium carbonate because it is commercially available in low moisture content form thereby avoiding drying requirements to prevent premature gelation of the acrylic copolymer whereas commercially
35 available talc and clay, for example, must generally be dried to prevent premature gelation. The amount of filler utilized in the sealant formulation depends on the various

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other components and on the desired properties, but generally ranges from about 30 to about 100, and more preferably from about 65 to about 80 parts by weight per 100 parts by weight of polymer.

5 To promote rapid cure upon exposure to moisture, it is generally desirable to add a condensation or curing catalyst to the sealant formulation. Suitable condensation catalysts for curing the silane functionalized acrylic copolymer of the invention are well known and
10 include any of the various alkali phenoxides, amines, carboxylic acid salts of metals, organic titanium compounds, and others disclosed, for example, in U.S. Patent No. 3,453,230 to Plueddemann, the entire contents of which are hereby incorporated by reference herein. The amount
15 of condensation catalyst used in the formulation should balance the rate of cure of the formulation against long term stability. It is, therefore, desirable to use the minimum amount of catalyst required to obtain the desired cure performance. The preferred cure or condensation
20 catalysts are dibutyl tin diacetate or dibutyl tin dilaurate which are preferably used in amounts ranging from 0.03 percent to 0.2 percent by weight based on the total weight of the sealant composition.

Any of various pigments or coloring agents can
25 be utilized as desired. For example, titanium dioxide can be utilized as a colorant in combination with a calcium carbonate filler to obtain a very light colored sealant formulation.

To obtain a workable viscosity the total solids
30 content of the sealant formulation can be adjusted by dilution using a solvent such as benzene, toluene, xylene, chloroform, carbon tetrachloride, methyl acetate, ethanol, isopropanol, or the like. The sealant formulations of the invention preferably have a total solids content of from
35 about 98 percent to about 90 percent by weight.

In accordance with a particularly preferred aspect of the invention, it has been discovered that when

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5 small quantities of a lower molecular weight monohydric alcohol are added to the sealant formulation, unexpected improvements in elastic recovery are achieved as compared to more conventional solvents such as xylene. The preferred monohydric solvent is isopropanol.

10 The amount of solvent used depends on the desired properties and other components of the sealant composition, but amounts of isopropanol in the range of 1 to 10 percent by weight based on the total weight of the sealant formulation have been observed to provide significant enhancement of the elastic recovery as compared with similar formulations utilizing xylene.

15 Sealant formulations made in accordance with the foregoing principles have been found to achieve excellent stability and handling properties; rapid cure times at temperature near ordinary room temperature, as demonstrated by short skin formation times, short tack free times, and rapid attainment of ultimate cured properties; and excellent cured properties including good weatherability, cohesive strength, adhesive strength, high movement, high elasticity, elastic recovery, etc.

20 The following examples are intended to further illustrate the invention and to provide a better understanding thereof, and should not be construed as limiting the invention thereto.

EXAMPLES

30 Polymers were prepared in stainless steel reactors equipped with reflux condensers. Monomer/initiator streams were fed to the reactors using appropriate pumps.

35 Molecular weight distributions were measured using a Waters SEC equipped with DRI and Viscotek detectors. Monomer analyses were obtained from a Hewlett Packard GC using an SPB-5 methyl phenyl silicone capillary column.

The polymerizations were achieved in suitable solvent medium, with a portion of the solvent charged

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initially to the reactor and the remainder distributed among monomer, initiator and scavenger feed streams. No special precautions to exclude moisture were taken in handling solvents, initiators and monomers, although silane monomers/crosslinkers were handled only under nitrogen blanket.

Polymers were prepared under reflux conditions or to a maximum temperature of 140°C. Monomer and initiator were fed into the reactor for two to three hours, dependent on protocol. The total process time was four and one half hours.

Sealants were compounded using an Orbital Shaft Mixer. Additions of materials to the mixer were done under nitrogen atmosphere.

To the clean mixer the polymer and methyl trioximosilane were added and allowed to mix for 3 minutes at 900 RPM. Castor oil based thixotrope and titanium dioxide were then added and allowed to mix for 5 minutes, after which calcium carbonate was added. After 5 minutes of mixing the adhesion promoter and solvent (xylene) were added, followed by the DBTDA catalyst and the rest of the solvent after a further 5 minutes of mixing.

The contents of the mixer were heated to 65°C over a period of 20 to 25 minutes. After 10 minutes of mixing at temperatures between 65°C and 68°C, the batch was allowed to cool to 50°C.

At this temperature, vacuum would be applied for 5 minutes, while mixing, to deaerate the material. The mixer was then stopped and the vacuum broken using nitrogen gas. Scraping of the mixer was performed under the flow of nitrogen, and the material was filled to suitable cartridges using a hydraulic press.

Industry standard tests performed included:

- 1) Stability - by checking changes in the viscosity index over time (20 g of material extruded through 0.104" orifice under 60 psi measure).
- 2) Cure Rate - by checking tack free time

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(method 2.1; CAN2-19.0-M77, and ASTM C679), and by checking hardness (Shore "A") development over time using a "Zwick" Duromatic measuring device.

5 3) Sag - using Boeing Jig Assembly (ASTM D2202).

4) Adhesion to Glass, Mortar, and Aluminum - peel adhesion tests according to method 14.6; CAN2-19.0-M77.

10 5) H-Bead Tensile - using tensile tests (Instron) according to method 14.1; CAN2-19.0-M77.

6) Movement Capabilities on Glass, Primed and Unprimed Mortar - using cycling methods according to method 14.4, CAN2-19.0-M77, and ASTM C719.

15 7) Weathering - using Xenon Arc Weatherometer.

8) Elastic Recovery (ISO 7389).

Process Summary for Preparation of
Moisture Curable RTV Sealant Polymer

20 The reactor is initially purged with nitrogen, then charged with the xylene and the temperature is increased to 140°C at which point the solvent begins to boil at reflux.

25 The Silane and Main feeds are premixed in separate containers and then metered into the reactor according to individual feed rate protocols. The vinyl silane and acrylic monomers are metered separately to permit manipulation of the monomer distribution of the reactively dissimilar monomers. Polymerization commences within 5-10 minutes. At the end of the two feeds, the
30 conversion of monomer to polymer is about 90 percent complete.

35 To reduce residual monomers to less than 500 ppm (0.05 percent), the scavenger solution is metered to the reactor according to the prescribed protocol. The entire process has taken place at the reflux temperature of the mixture.

The contents of the reactor are then cooled to

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less than 100°C and the stabilizer is added in one shot, mixed and the mixture discharged into moisture tight containers.

5 An acrylic copolymer (designated P1) was prepared in accordance with the principles of the invention using the preferred monomers (butyl acrylate, acrylonitrile and vinyl trimethoxy silane), and the preferred chain transfer agent (mercaptopropyltrimethoxy silane).
10 The polymerization mixture also included xylene as a solvent, ethyl-3,3-di(t-amylperoxy)butyrate as the free radical initiator, and isobutyltrimethoxysilane (IBTMS) was used as a moisture scavenger during the polymerization. The IBTMS also acts as a crosslinker after polymerization when the copolymer is used in a sealant formulation.
15 Dimethylmethylethylketoximosilane was added immediately after the polymerization process was completed. The acrylic copolymer of the invention was prepared using the above-listed ingredients in the amounts shown in Table 1.



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TABLE I

	P1 Parts by Weight	Molar Basis	P2 Parts by Weight	Molar Basis	P3 Parts by Weight	Molar Basis
Butyl Acrylate	89.0	100	88.29	100	88.29	100
Acrylonitrile	10.0	27.1	10.00	27.2	10.00	27.2
Vinyltrimethoxy Silane	0.7	.68	1.03	1.00	1.03	1.0
Mercaptopropyl Trimethoxysilane	0.3	.22	0.68	0.50	0.68	0.50
Xylene	14.27	--	14.27	--	14.27	--
Initiator	0.17	--	0.17	--	0.17	--
Scavenger	0.75	--	0.75	--	0	--

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For purposes of comparison, a similar acrylic copolymer (designated P2) was prepared using the same monomers, solvents, initiator and scavengers, and using the identical apparatus and procedures, except that the amount of vinyltrimethoxy silane and mercaptopropyl trimethoxysilane was set at the lowest possible level suggested by the prior art.

A second comparative acrylic copolymer (designated P3) was prepared in an identical manner using the same components and amounts except without any moisture scavengers being added. The compositions of the comparative examples, P2 and P3, are also set forth in Table I.

Table II shows properties for the preferred copolymer of the invention and for comparative copolymers prepared in accordance with the closest prior art.

Each of the copolymers P1, P2 and P3 were used in a sealant formulation having the following composition:

	PARTS BY WEIGHT
Copolymer	49.5
Thixatrol ST	5.4
TiO ₂	4.4
Limestone	37.04
Methyltrimethylethylketoximosilane	0.9
γ-Aminopropyltrimethoxysilane	0.2
Dibutyltindiacetate	0.06
Xylene	2.5

Various properties for the above sealant formulations using P1, P2 and P3, respectively, (designated S1, S2 and S3, respectively) after curing, are shown in Table III. The results indicate that the sealant formulation (S3) utilizing the prior art copolymer without the preferred silane crosslinkers/moisture scavengers of the invention is relatively unstable as indicated by a doubling of the viscosity index in about 7 days. The results

indicate that the copolymer of the invention can be used to obtain a sealant formulation having excellent anti-sag properties and a suitable hardness. The results demonstrate that the copolymers of the invention can be used to
5 obtain sealant formulations having unexpectedly superior adhesion to glass and aluminum substrates as compared with the prior art. Mechanical testing also indicates that the sealant formulations utilizing the copolymer of the invention has excellent tensile strength for a cured
10 sealant and is comparable to the prior art in this regard. The results, however, demonstrate an unexpected improvement in strain and modulus, signifying vastly improved elastic properties which are highly desirable for high movement sealant formulations.

15 The above copolymer of the invention (P1) was used in two substantially identical sealant formulations except that isopropyl alcohol was used in one of the sealant formulations (S5) as the solvent instead of xylene which was used in the other sealant formulation (S4).
20 Each of the sealant formulations using the copolymer of the invention exhibited excellent handling and anti-sag properties, excellent peel adhesion properties, good mechanical properties, and each passed the ASTM C719 movement tests at ± 25 percent movement for aluminum, glass and primed mortar substrates, as shown in Table IV.
25 However, the sealant formulation wherein isopropyl alcohol was used as the solvent showed unexpectedly superior elastic recovery properties when subjected to ISO 7389 wherein the cured samples were stretched to 100 percent of
30 their original length. The sealant formulation containing the isopropyl alcohol achieved 72 percent elastic recovery, whereas the other sealant containing the xylene solvent, but otherwise identical, experienced cohesive failure prior to 100 percent elongation.

35 From the foregoing descriptions and examples, it has been shown that the objects of the invention have been achieved with respect to particular embodiments thereof;

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however, various modifications and equivalents which will be apparent to those skilled in the art are considered to be within the spirit and scope of the invention as defined by the appending claims.

TABLE II

TABLE II												
Polymer I.D. No.		Crosslinker %		RTI Viscosity (Pa s)	Polymer Solids %	Gel Permeation Chromatography Results						Comments
						Mn	Mw 000's	Mz	MW /Mn	Skew		
										(N)	(W)	
P1	0.75	1.31	64.3	83.2	16.1	53.1	110.2	3.29	4.4	2.56	example of the present invention	
P2	0.75	1.31	37.8	83.1	15.3	45.0	86.8	2.94	3.65	2.09	lowest described functional monomer	
P3	0	0	46.4	85.1	13.9	51.0	117.6	3.67	5.05	2.83	no moisture scavenger or stabilizer	

TABLE III

COMPARISON OF THE PRESENT POLYMER TO DOW PATENT VERSIONS IN THE STANDARD SEALANT FORMULATION									
Sealant	Polymer	Viscosity(s)	Sag (inches)	Shore "A"	Peel Adhesion on Glass (kN/m)	Peel Adhesion on Aluminum (kN/m)	Tensile Stress to Failure (MPa)	Elongation at Failure Strain (%)	Modulus (MPa)
S1	P1	81	0.03"	31	2.86	2.18	1.47	1.46	1.01
S2	P2	31	0.02"	41	1.12	1.81	1.50	98	1.53
S3	P3	93 (7 days 190)	0.05"	47	1.19	1.26	1.41	91	1.55

TABLE IV

FORMULATION COMPONENTS	STANDARD:	IMPROVED
Polymer	47.50%	47.50%
Triaxtol ST	6.40%	6.40%
TiO ₂	4.60%	4.60%
Xylene	2.60%	
Isopropyl Alcohol		2.60%
A-1100 (Union Carbide) (γ -aminopropyltrimethoxysilane)	0.20%	0.20%
OS-1000 (Allied-Signal) (Methytrimethylethy/ketoximosilane)	0.90%	0.90%
Limestone	34.73%	34.73%
Dibutyltin Diacetate	0.07%	0.07%
Diethyladipate	3.00%	3.00%
VISCOSITY INDEX(S):	28	25
BOEING JIG SAG (INCHES):	0.03	0.02

TABLE IV (CONT)

FORMULATION COMPONENTS	STANDARD:	IMPROVED
PEEL ADHESION (kN/m):		
GLASS	2.3 C/F	2.5 C/F
ALUMINUM	1.8 C/F	2.0 C/F
MORTAR	2.2 C/F	2.0 S/F
D-BELL MAX STR. (MPa)	0.95	0.83
D-BELL MAX STN.:	179%	181%
MOVEMENT: +/-25% ASTM C719	PASS: G,A,Pm	PASS: G,A,Pm
ELASTIC RECOVERY: ISO 7389	C/F	72%
SHORE "A":	28	21

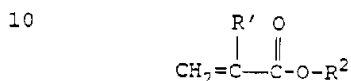
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While in accordance with the Patent Statutes, a preferred embodiment and best mode has been presented, the scope of the invention is not limited thereto, but rather is measured by the scope of the attached claims.

Claims:

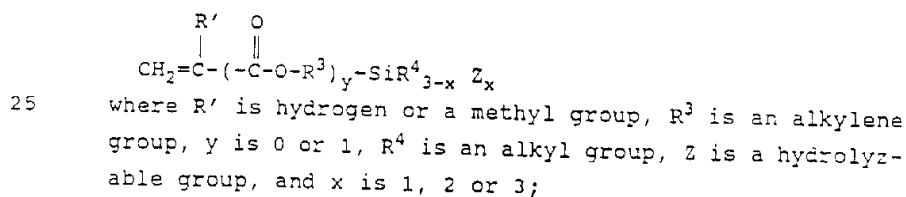
1. An acrylic copolymer comprising the free
5 radical initiated copolymerization product of:

a) at least one acrylate monomer, methacrylate
monomer, or combination thereof, represented by the
formula



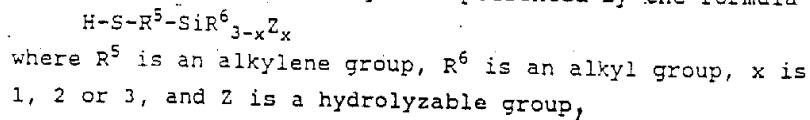
where R' is hydrogen or a methyl group, and R² is an alkyl
group containing from 1 to ~~about~~ 9 carbon atoms;

15 b) from ~~about~~ 0.05 to ~~about~~ 0.95 molar parts,
per 100 molar parts of the at least one acrylate monomer,
methacrylate monomer, or combination thereof, of at least
one silane functionalized addition monomer having at least
one hydrolyzable group, said silane functionalized addi-
20 tion monomer being represented by the formula



c) up to ~~about~~ 60 molar parts, per 100 molar
parts of the at least one acrylate monomer, methacrylate
30 monomer, or combination thereof, of a monoolefinically
unsaturated addition monomer free of hydrolyzable groups
bonded to a silicon atom; and

d) up to an amount less than 1 molar part, per
100 molar parts of the at least one acrylate monomer,
35 methacrylate monomer, or combination thereof, of a mercap-
tosilane chain transfer agent represented by the formula



e) 0.5 parts to 4 parts, per molar pair of radical polymerized silanes, of at least one polyfunctional organosilane introduced into the copolymerization reaction mixture during copolymerization and having from two to four hydrolyzable groups to reduce premature hydrolysis of the hydrolyzable groups bonded to said mercaptosilane chain transfer agent (d) and to said silane functionalized addition monomer (b).

2 An acrylic copolymer according to claim 1, wherein the amount of component (c) is from 20 to 50 molar parts per 100 molar parts of component (a), and wherein component (c) is a vinyl substituted aromatic, acrylonitrile or methacrylonitrile.

3 An acrylic copolymer according to claim 1 or 2, wherein the amount of component (b) is from 0.05 to 0.95 molar parts per 100 molar parts of component (a), and wherein the amount of component (d) is from 0.05 to 0.95 molar parts per 100 molar parts of component (a).

4 An acrylic copolymer according to any preceding claim wherein the hydrolyzable groups of components (b) and (d) are methoxy groups, ethoxy groups or methylethylketoximo groups.

5 An acrylic copolymer according to any preceding claim wherein component (a) is an acrylate having an alkyl group containing 2 to 9 carbon atoms or a combination thereof.



6 An acrylic copolymer according to any preceding claim wherein component (b) is a vinyl alkyl alkoxy silane.

7 An acrylic copolymer according to claim 6,
5 wherein component (a) includes butyl acrylate, component (b) includes a vinyl trialkoxysilane, component (c) includes acrylonitrile and component (d) includes a mercapto alkylene trialkoxy silane.

10 8 An acrylic copolymer according to any preceding claim wherein component (e) is methyltrimethoxy-silane, tetraethylorthosilicate, isobutyltrimethoxysilane or dimethyl methylethyl ketoxymosilane.

15 9 A moisture curable sealant formulation comprising:

A) the acrylic copolymer as defined in any one of claims 1 to 8,

20 B) from 0.5 to 4 parts by weight per 100 parts by weight of acrylic copolymer, of a difunctional silane crosslinker, and

C) from 0.5 to 10 parts by weight per 100 parts by weight of acrylic copolymer, of a trifunctional silane crosslinker.

25

10 A sealant formulation according to claim 9, wherein the difunctional silane crosslinker is a dialkyldialkoxy silane or a dialkyl diketoximosilane, and wherein the trifunctional crosslinker is an alkyl



triketoximosilane or an alkyl trialkoxysilane.

11 A sealant formulation according to claim 9 or 10
wherein the amount of component (c) of the acrylic
5 copolymer is from 20 to 50 molar parts per 100 molar parts
of component (a), and wherein component (c) of the acrylic
copolymer is a vinyl substituted aromatic, acrylonitrile,
or methacrylonitrile.

10 12 A sealant formulation according to claim 11,
wherein the amount of component (b) of the acrylic
copolymer is from 0.5 to 0.8 molar parts per 100 molar
parts of component (a), the amount of component (d) of the
15 acrylic copolymer is from 0.3 to 0.7 molar parts per 100
molar parts of component (a), and wherein component (a)
includes butyl acrylate, component (b) includes a vinyl
trialkoxysilane, component (c) includes acrylonitrile and
component (d) includes a mercaptoalkylenetrialkoxysilane.

20 13 A sealant formulation according to claim 12,
wherein the difunctional silane crosslinker is a
dialkyldialkoxysilane or dialkyldiketoximosilane and the
trifunctional crosslinker is an alkyltrialoxysilane or an
alkyltriketoximosilane.

25 14 A sealant formulation according to any one of
claims 9 to 13, further comprising from 1 to 10 parts by
weight per 100 parts by weight of acrylic copolymer, of an
aliphatic monohydric alcohol.

30



15 A sealant formulation according to claim 14, wherein the aliphatic monohydric alcohol is isopropyl alcohol.

5 16 A cured sealant formulation in accordance with any one of claims 9 to 15, which has a tensile strength of at least 1.4 MPa, and an elongation at failure of at least 140 percent.

10 17 A cured sealant formulation in accordance with any one of claims 9 to 16, having a peel adhesion of at least 2 kN/m on both glass and aluminum substrate surfaces.

15 18 A cured sealant formulation in accordance with claim 17, which passes the ASTM C719 test for ± 25 percent movement on glass, aluminum and primed mortar surfaces.

19 A cured sealant formulation in accordance with claim 14 having a tensile strength of at least 1.4 MPa, an
20 elongation at failure of at least 140 percent, a peel adhesion of at least 2 kN/m on both glass and aluminum substrate surfaces, which passes the ASTM C719 test for ± 25 percent movement on glass, aluminum and primed mortar surfaces, and which upon 100 percent elongation exhibits an
25 elastic recovery of at least 70 percent.

20 An acrylic copolymer comprising the free radical initiated copolymerization product substantially as herein described with reference to the accompanying examples.



21 A moisture curable sealant formulation
substantially as herein described with reference to the
accompanying examples.

5

Dated this 21st day of December 1998

TREMCO LTD and THE B.F. GOODRICH COMPANY

By their Patent Attorneys

GRIFFITH HACK

10 Fellows Institute of Patent

Attorneys of Australia

A 10x10 grid of dots forming a stylized letter 'A'. The 'A' is composed of black dots on a white background. The top part of the 'A' is a triangle of dots, and the bottom part is a horizontal bar. The dots are arranged in a way that the 'A' is centered and occupies most of the grid.

