COPOLYMER SEALANT COMPOSITIONS AND METHOD FOR MAKING

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ABSTRACT
Condensation curable poly(fluoroorgano)siloxane-poly(silarylene)siloxane block copolymer compositions having a glass transition temperature not exceeding about −54°C and excellent solvent resistance have been found useful as sealants. Polyaalkoxysilylorgano compounds, such as 1,4-bis[trimethoxysilyl(ethyl)]benzene have been found to be effective as cross-linkers.

34 Claims, No Drawings
COPOLYMER SEALANT COMPOSITIONS
AND METHOD FOR MAKING

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a divisional of application Serial No. 09/626,768, filed July 27, 2000, now 6,451,954, which is hereby incorporated by reference in its entirety.

The present invention is based on work sponsored under NASA’s High Speed Research Contract NAS 20-220, with Boeing under subcontract ZA0073 Task 22, Subtask 4.2.2.4.

BACKGROUND OF THE INVENTION

The present invention is directed to copolymer compositions useful in the preparation of fuel tank sealants. More particularly, the present invention relates to condensation curable poly(fluoroorganosiloxy-poly(silylene)siloxane block copolymer compositions and the use of polyalkoxyxilorganic compounds as cross-linkers to facilitate the condensation cure of poly(fluoroorganosiloxy-poly(silylene)siloxane block copolymers.

As shown by Smith, U.S. Pat. No. 3,109,826, bis (alkoxysilyl) hydrocarbons, such as 1,2-bis-(triethoxysilyl) ethane, can be used as cross-linkers in combination with a metal salt to effect the neutral condensation cure of hydroxy end-blocked polyorganosiloxanes. However, the resulting cured silicone compositions have been found to be problematic as aircraft fuel tank sealants, as they do not have the required solvent or fuel resistance. It is known that fluorosilicones, for example, made by polymerizing tris [trifluoropropyl)methyl)cyclotrisiloxane, can provide excellent fuel resistance. However, fluorosilicones often do not meet the wide temperature stability requirements needed in aircraft sealants, such as temperatures in a range between −54°C and 177°C over an extended period of time. In addition, fluorosilicones are subject to depolymerization which can result in the formation of low molecular weight cyclics.

In an effort to enhance the thermal stability of fluorosilicones, non-siloxane groups, such as p-silphenylene, have been inserted into the polyfluorosiloxane backbone, as shown by Grassie and Beattie, “The Thermal Degradation of Polyorganosiloxanes: Part 7”, Polymer Degradation and Stabilization 8:177–193 (1984). It is also reported by Dvornic and Lenz, Macromolecules, 25, 3769 (1992), that copolymers having a glass transition temperature (Tg) of −51°C can be made by reacting methyl(3,3,3-trifluoropropyl)silanediol and 1,4-bis(dimethylhydroxysilyl)benzene.

While fluorosilicones having improved thermal stability have been made by inserting non-siloxane groups, such as p-silphenylene into the polyfluorosiloxane backbone, such copolymers have been found to have a glass transition temperature which does not satisfy the minimum −54°C Tg flexibility requirements of aircraft fuel tank sealants.

Experience also has shown that in addition to being sensitive to depolymerization, condensation curable fluorosilicone compositions often suffer from an incomplete cure using a conventional curing catalyst, such as a tin salt, and a standard neutral condensation curable cross-linker, for example a polyalkoxyxiloxane. One possible explanation, as discussed by Fujiki, U.S. Pat. No. 5,236,997, is that the steric hindrance or electronic effects of bulky terminal trifluoropropyl groups inhibit crosslinking of the network.

Accordingly, depolymerization resistant silicone base copolymers which could be compounded to a fuel resistant condensation curable silicone composition convertible to the elastomeric state upon cure exhibiting stability over an operable temperature in a range between about −54°C or below and at least about 177°C, over an extended period of time are constantly being sought which also exhibit low temperature flexibility, in addition to high temperature stability.

BRIEF SUMMARY OF THE INVENTION

The present invention provides a condensation curable poly(fluoroorganosiloxy-poly(silylene)siloxane block copolymer exhibiting a glass transition temperature not exceeding about −54°C.

In yet another embodiment of the present invention, there is provided a neutral condensation curable poly(fluoroorganosiloxy-poly(silylene)siloxane block copolymer sealant composition comprising

(a) a poly(fluoroorganosiloxy-poly(silylene)siloxane block copolymer,
(b) a cross-linker, and
(c) a condensation catalyst.

In yet another embodiment of the present invention, there is provided a method for making a neutral condensation curable poly(fluoroorganosiloxy-poly(silylene)siloxane block copolymer sealant composition which comprises

(a) effecting reaction between bis(diorganohydroxysilyl)arylene and poly(fluoroalkylorganocyclopolsiloxane to form a condensation curable poly(fluoroorganosiloxy-poly(silylene)siloxane block copolymer,
(b) shearing the copolymer, and
(c) blending a cross-linker and a condensation catalyst with the copolymer to form a sealant.

DETAILED DESCRIPTION OF THE INVENTION

The poly(fluoroorganosiloxy-poly(silylene)siloxane block copolymer, or “block copolymers” within the scope of the present invention, can be used to make aircraft fuel tank sealants having property profiles which include a glass transition temperature (Tg) of about −54°C or below and can be made by the ring opening polymerization of a poly(fluoroalkylorganocyclopolsiloxane in the presence of a bis(diorganohydroxysilyl)arylene.

As used hereinafter, the term “bis(diorganohydroxysilyl) arylene”, or “bis(hydroxysilyl)arylene” is shown by the formula,

\[
[H(O)-(R)O]_2-SiO-(R)
\]

and the term “silylenesiloxysiloxy” can be represented by the formula,

\[
-(R)O-Si[O][O]_2Si(R)-O-
\]

where \(Q^1\) is a \(C_{(6-12)}\) divalent aromatic organic radical, and \(R\) is a \(C_{(1-4)}\) alkyl radical. Preferably, the bis (diorganohydroxysilyl)arylene is 1,4-bis(dimethylhydroxysilyl)benzene.

“Poly(fluoroalkylorganocyclopolsiloxane”, sometimes expressed as “poly(fluoroalkyl)cyclic siloxane” is shown by the following formula:
where \( R^1 \) is a \( C_{(1,8)} \) polyfluoroalkyl radical, \( R^2 \) is a \( C_{(1,12)} \) organic radical, and "a" is an integer in a range between about 3 and about 8 inclusive, and preferably 3 or 4. Poly[(fluorooalkyl]cyclosiloxane]cyclosiloxane can be used in a proportion in a range between about 0.5 and about 4 moles, and preferably in a range between about 1 and about 4 moles, per mole of bis(diorganohydroxysily1)arylene. Reaction to form the copolymer is typically effected with agitation under neat conditions or in the presence of an inert organic solvent, for example, toluene, at temperatures in a range between about 60°C and about 150°C. Reaction is typically effected for a time period in a range between about 30 minutes and about 2 hours, and preferably, in a range between about 45 minutes and about 1.5 hours. It is preferred to operate within an inert atmosphere, for example, under a nitrogen blanket. Typically, there is also present an initiator, for example, an alkali hydroxide (e.g. sodium hydroxide) or an alkali fluorosilanolate (e.g. sodium fluorosilanolate) in a range between about 5 parts per million (ppm) and about 50 ppm, based on the weight of reaction mixture, and a quencher, for example, phosphoric acid or silyl phosphate in a range between about 10 ppm and about 60 ppm, based on the weight of reaction mixture.

The cross-linker can be used in combination with an effective amount of a condensation catalyst, such as an acid catalyst or a base catalyst. Suitable condensation catalysts are present in a range between about 0.1 and about 10 parts by weight, per 100 parts of block copolymer. Suitable condensation catalysts are present in a range between about 0.1 and about 10 parts by weight, per 100 parts of block copolymer. A heat stabilizer, such as iron oxide, is preferred in a range between about 0.1 and about 10 parts by weight, per 100 parts of block copolymer. After blending of the masterbatch ingredients, the mixture can be degassed under reduced pressure, and the resulting paste can be stored.

The neutral condensation curable poly[(fluorooalkyl]siloxane-poly(silylene)siloxane]cyclosiloxane]cyclosiloxane sealant compositions can be made by blending the block copolymer masterbatch with an effective amount of a condensation catalyst and a suitable bis[(polyalkoxysilyl]methyl]cyclosiloxane]. "Neutral" as used herein refers to a sealant composition which is substantially acid-free and substantially base-free. Suitable condensation catalysts are present in a range between about 0.1 and about 2 parts, per 100 parts of block copolymer and include, for example, organometal compounds such as dibutyltin dilauroate, dimethyllithium neodecanoate, dibutyltin dilaurate, stannous octoate, dimethyllithium hydroxyoleate, or combinations thereof.

Some of the preferred bis[(polyalkoxysilyl]methyl]cyclosiloxane]cyclosiloxane]cyclosiloxane]cyclosiloxane cross-linkers included within formula (I) are, for example, 1,2-bis[(trimethoxysilyl]methyl]benzene, 1,2-bis[(methyldiethoxysilyl]oxy]benzene, and 1,6-bis[(methyltriethoxysilyl]hexane. The cross-linkers are present in a range between about 1 and about 20 parts, per 100 parts of block copolymer. In order that skilled in the art will be better able to practice the present invention, the following examples are given by way of illustration and not by way of limitation. All parts are by weight unless otherwise indicated.

**EXAMPLE 1**

A poly[(fluoroalkoxy)siloxane-poly[(silylene)siloxane]-siloxane]cyclosiloxane]cyclosiloxane]cyclosiloxane]cyclosiloxane block copolymer useful in making a condensation curable sealant composition was prepared as follows:

A mixture of 2.26 grams (g) (0.010 mole) of 1,4-bis(dimethyldiethoxysilyl]benzene and 9.42 g (0.020 mole) of tris[(fluorooalkyl)propyl]methyl]cyclosiloxane was heated with stirring to about 150°C. under a nitrogen atmosphere. There was then added 0.04 g of sodium fluorosilanolate. After 60 minutes at 150°C, there was added to the mixture 0.065 g of a silyl phosphate. The reaction mixture was maintained with stirring for an additional 150°C and then allowed to cool. Based on method of preparation, there was obtained a block copolymer, including chemically combined blocks of 1,4-dimethylsilylephylphenylenesiloxane units and blocks of...
based on the use of 1324 parts of block copolymer, 105 parts of a bis(polyalkoxysilyl) cross-linker, and 0.5 part of dibutyltindiacetate, or "DBTA", as a condensation catalyst. Another test period, "B", was heat aging at 177°C for 7 days after standard cure. The following results were obtained, where the respective catalyzed formulations at ambient temperatures: Tensile strength (psi), elongation (%), and 100% modulus of each of the respective condensation curable compositions were identified in the tables below by the particular bis(polyalkoxysilyl) cross-linker, where Q is as previously defined. More particularly, the bis(polyalkoxysilyl)Q cross-linkers include 1,2-bis(triethoxysilyl)ethane, or "BTSE", 1,6-bis(trimethoxysilyl)hexane, or “BTMSSH”, and 1,4-bis(trimethoxysilyl)(ethyl)benzene, or “BTMSEB”.

There was also mixed with the respective red sealant paste blends of block copolymer and cross-linker, 0.5 part of dibutyltindiacetate, or “DBTA”, as a condensation catalyst. Test specimens were prepared by compression molding at 150°C. The viscous red sealant paste was then discharged while slightly above room temperature into a 4 liter (L) Semco® 1350 apparatus of PRC Desoto Inc of Mount Laurel, N.J. and then dispensed into 6 ounce Semco cartridges. Several neutral condensation curable sealant compositions were prepared by blending in a Semco 388 mixer, 4 parts of a bis(polyalkoxysilyl)C(12,10) hydrocarbon cross-linker and 100 parts of the above block copolymer red sealant paste contained in a Semco cartridge. The respective neutral condensation curable sealant compositions are identified in the tables below by the particular bis(polyalkoxysilyl)Q cross-linker, where Q is as previously defined. More particularly, the bis(polyalkoxysilyl)Q cross-linkers include 1,2-bis(triethoxysilyl)ethane, or “BTSE”, 1,6-bis(trimethoxysilyl)hexane, or “BTMSSH”, and 1,4-bis(trimethoxysilyl)(ethyl)benzene, or “BTMSEB”.

There was also mixed with the respective red sealant paste blends of block copolymer and cross-linker, 0.5 part of dibutyltindiacetate, or “DBTA”, as a condensation catalyst. Test specimens were prepared by compression molding the respective catalyzed formulations at ambient temperatures into 4 inch x 5 inch x 0.08 inch sheets. The sheets were allowed to cure to the elastomeric state for a minimum of 7 days at 25°C. and 50% relative humidity (RH). Tensile properties, such as tensile strength (psi), elongation (%), and 100% modulus (psi) of each of the respective compression molded elastomeric sheets were then measured after a series of seven day test periods. The initial test period, "A", was standard cure at room temperature at 50% RH. Another test period, "B", was heat aging at 177°C for 7 days after standard cure. There was also included, "C", immersion in Jet A fuel at 60°C for 7 days after standard cure, and, "D", 2 days in Jet A at 60°C. followed by 5 days in air at 177°C after standard cure. The following results were obtained, where the respective cross-linked condensation cured compositions are denoted by their previously identified cross-linkers, namely BTMSEB, BTSE and BTMSSH:

<table>
<thead>
<tr>
<th>7 Day Test Periods</th>
<th>Tensile Strength (psi)</th>
<th>Elongation (%)</th>
<th>100% Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>BTMSEB 250</td>
<td>196</td>
<td>104</td>
</tr>
<tr>
<td></td>
<td>BTSE 227</td>
<td>212</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>BTMSSH 227</td>
<td>178</td>
<td>110</td>
</tr>
<tr>
<td>B</td>
<td>BTMSEB 273</td>
<td>213</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>BTSE 239</td>
<td>185</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>BTMSSH 268</td>
<td>196</td>
<td>114</td>
</tr>
<tr>
<td>C</td>
<td>BTMSEB 151</td>
<td>139</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>BTSE 146</td>
<td>145</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>BTMSSH 192</td>
<td>92</td>
<td>—</td>
</tr>
<tr>
<td>D</td>
<td>BTMSEB 291</td>
<td>212</td>
<td>111</td>
</tr>
<tr>
<td></td>
<td>BTSE 253</td>
<td>186</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td>BTMSSH 275</td>
<td>191</td>
<td>121</td>
</tr>
</tbody>
</table>

The above results show that the copolymers of the present invention are depolymerization resistant and provide neutral condensation curable compositions which are useful as solvent resistant sealants.

The crosslinker in the present invention can be employed in non-corrosive cure systems to fabricate elastomers useful as fuel resistant sealing materials, electronic encapsulation, and in applications requiring chemically resistant materials. Particularly, the crosslinkers can be used for preparation of fuel tank sealants.

While typical embodiments have been set forth for the purpose of illustration, the foregoing description should not be deemed to be a limitation on the scope of the invention. Accordingly, various modifications, adaptations, and alternatives may occur to one skilled in the art without departing from the spirit and scope of the present invention.

What is claimed:

1. A method for making a neutral condensation curable poly(fluoroorganosiloxane-siloxysiloxane-siloxane block copolymer sealant composition which comprises the following steps:
   (a) effecting reaction between a bis(diorganosilyl)arylene and a poly(diorganosilyl)cyclopolsiloxane to form a condensation cureable poly(fluoroorganosiloxane-siloxane-poly(arylene)siloxane) block copolymer,
   (b) shearing the copolymer, and
   (c) blending a cross-linker and a condensation catalyst with the copolymer to form a sealant.

2. The method in accordance with claim 1, wherein the method further comprises blending a filler with the copolymer.

3. The method in accordance with claim 2, wherein the filler is present in a range between about 0 parts and about 10 parts by weight per 100 parts of copolymer.

4. The method in accordance with claim 3, wherein the filler is present in a range between about 1 parts and about 10 parts by weight per 100 parts of copolymer.

5. The method in accordance with claim 2, wherein the filler comprises fumed silica.

6. The method in accordance with claim 1, wherein the method further comprises blending a heat stabilizer.

7. The method in accordance with claim 6, wherein the heat stabilizer is present in a range between about 0.1 parts and about 10 parts by weight per 100 parts of copolymer.
8. The method in accordance with claim 6, wherein the heat stabilizer comprises iron oxide.
9. The method in accordance with claim 1, wherein the cross-linker comprises the formula

\[(RO)z(XSiOlQ,\]

where Q is a C(2-12) divalent organic radical, R is a C(1-4) alkyl radical, and X is a member selected from the group consisting of R and RO.
10. The method in accordance with claim 9, wherein the cross-linker comprises 1,4-bis(trimethoxysilyl)benzene, 1,2-bis(triethoxysilyl)ethane, 1,6-bis(trimethoxysilyl)hexane, or combinations thereof.
11. The method in accordance with claim 10, wherein the cross-linker comprises 1,2-bis(triethoxysilyl)ethane.
12. The method in accordance with claim 1, wherein the cross-linker is present in a range between about 1 parts and about 25 parts by weight per 100 parts of copolymer.
13. The method in accordance with claim 1, wherein the condensation catalyst is present in a range between about 0.1 parts and about 2 parts by weight per 100 parts of copolymer.
14. The method in accordance with claim 1, wherein the condensation catalyst comprises an organo-metal compound.
15. The method in accordance with claim 14, wherein the organo-metal compound comprises dibutyltin diacetate, dimethyltin neodecanoate, dibutyltin dilaurate, stannous octoate, dimethyltin hydroxylolate, or combinations thereof.
16. The method in accordance with claim 15, wherein the organo-metal compound comprises dibutyltin dilaurate.
17. The method in accordance with claim 1, wherein the reaction of step (a) is conducted at a temperature in a range between about 60°C and about 110°C.
18. The method in accordance with claim 1, wherein the reaction of step (a) further comprises an initiator.
19. The method in accordance with claim 18, wherein the initiator is present in a range between about 1 parts and about 2 parts by weight per 100 parts of copolymer.
20. The method in accordance with claim 18, wherein the initiator comprises an alkali fluorosilanolate.
21. The method in accordance with claim 1, wherein the reaction further comprises a quencher.
22. The method in accordance with claim 21, wherein the quencher is present in a range between about 10 parts per million and about 60 parts per million.
23. The method in accordance with claim 21, wherein the quencher comprises a silyl phosphate.
24. The method in accordance with claim 1, wherein shearing occurs at a temperature in a range between about 25°C and about 200°C.
25. The method in accordance with claim 24, wherein the shearing occurs at a temperature in a range between about 100°C and about 150°C.
26. The method in accordance with claim 1, wherein the shearing occurs for a period of time in a range between about 15 minutes and about 4 hours.
27. The method in accordance with claim 26, wherein the shearing occurs for a period of time in a range between about 1 hour and about 2 hours.
28. The method in accordance with claim 1, wherein the poly(fluoroalkylorganosiloxane) is present in a range between about 0.5 moles and about 4 moles, per mole of bis(diorganohydroxysilyl)arylène.
29. The method in accordance with claim 28, wherein the poly(fluoroalkylorganosiloxane) is present in a range between about 1 moles and about 2 moles, per mole of bis(diorganohydroxysilyl)arylène.
30. The method in accordance with claim 1, wherein the poly(fluoroalkylorganosiloxane) is present in a range between about 1 moles and about 2 moles, per mole of bis(diorganohydroxysilyl)arylène.
31. The method in accordance with claim 30, wherein the poly(fluoroalkylorganosiloxane) is present in a range between about 1 moles and about 2 moles, per mole of bis(diorganohydroxysilyl)arylène.
32. The method in accordance with claim 1, wherein the poly(fluoroalkylorganosiloxane) is present in a range between about 1 moles and about 2 moles, per mole of bis(diorganohydroxysilyl)arylène.
33. The method in accordance with claim 32, wherein the poly(fluoroalkylorganosiloxane) is present in a range between about 1 moles and about 2 moles, per mole of bis(diorganohydroxysilyl)arylène.
34. A method for making a neutral condensation curable poly(fluoroorganosiloxane)-poly(silylarylène)-siloxane block copolymer sealant composition which comprises the following steps:

(a) effecting reaction between 1,4-bis(dimethylhydroxysilyl)benzene and tris[(trifluoropropyl)methyl]cyclosiloxane in the presence of sodium fluorosilanolate and silyl phosphate at a temperature in a range between about 60°C and about 150°C to form a condensation curable poly(fluoroorganosiloxane)-poly(silylarylène)-siloxane block copolymer, (b) shearing the copolymer at a temperature in a range between about 100°C and about 150°C, for a period of time in a range between about 1 hour and about 2 hours, and (c) blending the copolymer with 1,2-bis(triethoxysilyl)ethane, dibutyltin diacetate, fumed silica, and iron oxide to form the copolymer sealant.

* * * * *