United States Patent

Hergenrother

[54] ETHYNYL AND SUBSTITUTED ETHYNYL-TERMINATED POLYSULFONES


[73] Assignee: The United States of America as represented by the Administrator of the National Aeronautics and Space Administration, Washington, D.C.

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Related U.S. Application Data


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[52] U.S. Cl. 556/436; 585/24; 260/544 D

[58] Field of Search 556/436; 585/24; 260/544 D

[56] References Cited

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Attorney, Agent, or Firm—Howard J. Osborn; John R. Manning; Wallace J. Nelson

[57] ABSTRACT

Ethynyl and substituted ethynyl-terminated polysulfones and a process for preparing the same are disclosed. These polysulfones are thermally cured to induce cross-linking and chain extension, producing a polymer system with improved solvent resistance and use temperatures. Also disclosed are substituted 4-ethynylbenzoyl chlorides as precursors to the substituted ethynyl-terminated polysulfones and a process for preparing the same.

2 Claims, No Drawings
ETHYNYL AND SUBSTITUTED ETHYNYL-TERMINATED POLYSULFONES

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

This is a division of application Ser. No. 433,598, filed Oct. 8, 1982, and now U.S. Pat. No. 4,431,761.

FIELD OF THE INVENTION

The present invention relates to a new class of sulfone polymers and oligomers. More particularly, it relates to a group of ethynyl and substituted ethynyl-terminated sulfone polymers and oligomers which cross-link and can be reformed upon heating, and which exhibit excellent solvent resistance and thermal stability.

BACKGROUND OF THE INVENTION

Polysulfones are commercially available thermoplastics which are widely used in a variety of applications such as adhesives, composites, or moldings for use in automobiles, household appliances and other applications. As thermoplastics, they are generally amorphous and creep under load at elevated temperatures. A more important use limitation is their sensitivity to various solvents, especially when the polymer is in a stressed condition. Because of this solvent sensitivity, conventional polysulfones cannot be used in many applications such as adhesives or composite matrices for use on commercial airplanes, which may be exposed to numerous solvents such as hydraulic and deicing fluids, fuel, and paint strippers. Composites from polysulfones, especially under load, exhibit pronounced crazing and cracking upon exposure to solvents, with loss of mechanical properties.

Various routes have been employed in an attempt to overcome the two major use limitations of polysulfones, creep at elevated temperature and solvent sensitivity. Each such attempt has not been entirely successful because either new difficulties were introduced or the original problem was not entirely solved. In one such application, polysulfones containing crystalline regions which serve as cross-links were employed to increase solvent resistance. The problem with using crystallinity to attain solvent resistance is that the material is more difficult to process and the physical properties of the polymer depend upon the amount or degree of crystallinity which is introduced into the polymer. The degree to which the polymer crystallizes is difficult to control and maintain, and when the degree of crystallinity changes, the physical properties change accordingly. This makes polymers of this type undesirable in certain applications, as in the design of airplane components which must be capable of performing for more than 50,000 hours in hostile environments.

An ethynyl-terminated sulfone monomer has been previously prepared and thermally polymerized to yield a brittle resin (elongation of approximately 6%) (see M. G. Maximovich, S. C. Lockerby, F. E. Arnold, and G. A. Loughran, Science of Advanced Material and Process Engineering Serries, vol. 23, p. 490 (1978)). The present invention differs from this in that higher molecular weight materials are used to retain toughness and the chemistry involved is entirely different (i.e., the synthesis is easier and less expensive). Propargyl terminated sulfone monomers and resins therefrom have also been disclosed. See U.S. Pat. No. 4,226,800 to Picklesimer. Once again, the chemistry involved is entirely different; propargyl (HC≡C-CH₂-) groups are used to introduce cross-linking versus the ethynyl and substituted ethynyl groups (-C≡C-X), employed in the present invention. The polymers in Picklesimer are thermosets, whereas the polymers of the present invention, depending on the molecular weight of the precursor polysulfone, are thermoplastics. Thermosets are generally high strength, brittle materials with low impact strength. Thermoplastics are relatively high strength, tough materials with high impact strength. Furthermore, thermosets cannot be reformed once they have cured whereas thermoplastics can be reformed as necessary. This feature makes thermoplastics commercially more attractive because scraps and faulted moldings can be reprocessed, thus reducing waste. There is thus a definite need in the art for a thermoplastic polysulfone exhibiting improved resistance to solvents and creep at elevated temperatures.

Accordingly, it is an object of this invention to provide a new thermoplastic composition produced from polysulfones and containing various degrees of cross-linking.

Another object of the present invention is to provide a new thermoplastic composition that will chain extend upon curing.

It is yet another object of the present invention to provide novel thermoplastic polysulfones which exhibit improved use temperatures and solvent resistance.

It is a further object of the present invention to provide a high yield process for preparing thermoplastic polysulfones which exhibit improved use temperatures and solvent resistance.

SUMMARY OF THE INVENTION

According to the present invention, the foregoing and additional objects are attained by producing a class of polysulfones containing ethynyl and substituted ethynyl groups, which upon application of heat will cross-link and chain extend to produce highly solvent resistant and thermally stable polymer systems. The polymers are synthesized from the reaction of an hydroxy-terminated polysulfone with bromobenzoyl chloride to yield an intermediate which is then reacted with a substituted ethynyl compound to yield the product as shown in the following representative scheme:
where PS is a polysulfone with a molecular weight between 1000 and 50,000 and X is selected from the group consisting of:
- \( \text{Si(CH}_3\text{)}_3 \)
- straight or branched organic radicals having 4 to 10 carbon atoms
- substituted aromatic groups of the formula:
  \( \text{R}_n \cdot \text{C}_x \cdot \text{C}_y \cdot \text{C}_z \cdot \text{H} \)
  where \( \text{R} \) is selected from the group consisting of:
- straight or branched organic radicals having 1 to 12 carbon atoms,
- \( \text{H} \)
- and halogenated derivatives of all of the above.

As an alternative route, an ethynyl-substituted benzoyl chloride may be reacted directly with a hydroxy-terminated polysulfone to yield the product as represented in the following scheme:

\[
\text{HO-PS-OH} \xrightarrow{\text{Heat}} \text{solvent resistant cross-linked polysulfone}
\]

where PS is as defined above, and Z is selected from the group consisting of: X (as defined above) and H.

The molecular weight of the starting polysulfone may be varied according to the physical properties desired in the final polymer system. A low molecular weight starting material (depending upon the particular polysulfone selected, a molecular weight of approximately 3000 g/mole) will result in a more highly cross-linked product which is highly solvent resistant, but is also less thermoformable. A high molecular weight starting material (again depending upon the particular polysulfone, approximately 26,000 g/mole) will result in a product which has good thermoformability and improved solvent resistance, but will be susceptible to attack by certain solvents. A tabulation of the physical properties of the product resulting from various molecular weight starting polysulfones (PS), and a comparison with a commercially available polysulfone from Union Carbide Corporation, UDEL®, is shown in Table I. As shown therein, at comparable glass transition temperatures (Tg), the cross-linked polysulfones of the present invention show a marked improvement in solvent resistance over the commercially available polysulfone. The marked difference in Tg and solubility between the bromo-substituted and the ethynyl-substituted polymers highlights the dramatic improvement in the physical properties of a given PS when the cross-linking ethynyl groups are added.

TABLE I

<table>
<thead>
<tr>
<th>Mₙ of Starting</th>
<th>Substituent (Y)</th>
<th>Tg of Cured Resin, °C</th>
<th>Chloroform Solubility</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS</td>
<td>DSQA</td>
<td>TBA₃</td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>Br⁻</td>
<td>161 163</td>
<td>sol.</td>
</tr>
<tr>
<td>(CH₃)SiCl⁻</td>
<td>207 207</td>
<td>insol.</td>
<td></td>
</tr>
<tr>
<td>HC⁻</td>
<td>209 207</td>
<td>insol.</td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>Br⁻</td>
<td>177 178</td>
<td>sol.</td>
</tr>
<tr>
<td>(CH₃)SiCl⁻</td>
<td>204 205</td>
<td>sl. swelling</td>
<td></td>
</tr>
<tr>
<td>HC⁻</td>
<td>203 203</td>
<td>sl. swelling</td>
<td></td>
</tr>
<tr>
<td>9000</td>
<td>Br⁻</td>
<td>183 182</td>
<td>sol.</td>
</tr>
<tr>
<td>(CH₃)SiCl⁻</td>
<td>201 201</td>
<td>sl. swelling</td>
<td></td>
</tr>
<tr>
<td>HC⁻</td>
<td>202 202</td>
<td>sl. swelling</td>
<td></td>
</tr>
<tr>
<td>12000</td>
<td>Br⁻</td>
<td>180 181</td>
<td>sol.</td>
</tr>
<tr>
<td>(CH₃)SiCl⁻</td>
<td>197 192</td>
<td>swells</td>
<td></td>
</tr>
<tr>
<td>HC⁻</td>
<td>198 195</td>
<td>swells</td>
<td></td>
</tr>
<tr>
<td>12000</td>
<td>Br⁻</td>
<td>187 187</td>
<td>sol.</td>
</tr>
<tr>
<td>(CH₃)SiCl⁻</td>
<td>196 194</td>
<td>swells</td>
<td></td>
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<tr>
<td>HC⁻</td>
<td>197 198</td>
<td>swells</td>
<td></td>
</tr>
<tr>
<td>25000</td>
<td>Br⁻</td>
<td>192 192</td>
<td>sol.</td>
</tr>
<tr>
<td>(CH₃)SiCl⁻</td>
<td>193 188</td>
<td>pron. swelling</td>
<td></td>
</tr>
<tr>
<td>HC⁻</td>
<td>195 194</td>
<td>pron. swelling</td>
<td></td>
</tr>
</tbody>
</table>

1 Differential scanning calorimetry at heating rate of 20°C/min.
2 Torsional braid analysis at heating rate of 3°C/min.
3 Direct route using bethynylbenzoyl chloride, see Eq. (2).

The cross-linked polysulfones of the present invention also exhibit superior mechanical stability at elevated temperatures. As shown in Table II, the ethynyl-terminated polysulfone loses only 2.5% of the flexural strength as the temperature is increased from ambient to 93°C; this is a 60% improvement over the loss of strength in UDEL®, and a similar improvement is realized in the flexural modulus. While the improvement in shear strength is not as dramatic, it remains significant. The polymer of the present invention exhibits an 8.5% improvement over UDEL® in loss of shear strength as the temperature rises from ambient to 93°C.
Having generally described the invention, a more complete understanding thereof can be obtained by reference to the following specific examples which are provided herein for purposes of illustration only and are not to be limiting on the invention.

**EXAMPLE I**

**Trimethylsilylethynylbenzoate-Terminated Polysulfones**

The hydroxy-terminated PS of various molecular weights were converted to trimethylsilylethynylbenzoate-terminated PS as shown in Eq. (1) by the following representative procedure. Hydroxy-terminated PS [30 g, Mn = 12,000, Tg = 183°C] was dissolved in DMAC (100 ml) and powdered potassium carbonate (1.5 g) was added. The light brown reaction mixture was vigorously stirred at 40°C for two hours and subsequently poured into dilute aqueous hydrochloric acid in a blender. The light tan precipitate was thoroughly washed successively with water and twice with hot methanol to yield 4-ethynylbenzoate-terminated PS as a light tan solid (11.7 g) (IR essentially identical to that of the 4-bromobenzoate-terminated PS except for a weak sharp band at 3300 cm⁻¹ attributed to H—C≡C stretch).

**EXAMPLE II**

**Ethynylbenzoate-Terminated Polysulfones**

Trimethylsilylethynyl benzoate-terminated PS (12.0 g) from the preceding procedure was dissolved in DMAC (100 ml) and powdered potassium carbonate (1.5 g) was added. The light brown reaction mixture was vigorously stirred at 40°C for two hours and subsequently poured into dilute aqueous hydrochloric acid in a blender. The light tan precipitate was thoroughly washed successively with water and twice with hot methanol to yield 4-ethynylbenzoate-terminated PS as a light tan solid (11.7 g) (IR essentially identical to that of the 4-bromobenzoate-terminated PS except for a weak sharp band at 3300 cm⁻¹ attributed to H—C≡C stretch).

**EXAMPLE III**

An alternate and more direct approach to the preparation of the ethynylbenzoate-terminated PS involved the reaction of the hydroxy-terminated PS with 4-ethynylbenzoic acid as in Eq. 2. The 4-ethynylbenzoic acid was prepared as follows: 4-Bromobenzoic acid (11.0 g, 0.055 mole; source, Aldrich Chemical Company), dichlorobis(triphenylphosphine)palladium (0.3 g; source, Strem Chemical, Inc.), pyridine (60 ml), triethylamine (40 ml), and trimethylsilylacetylene (8.3 g, 0.085 mole; source, Silar Laboratories Inc.) were stirred in DMAC (300 ml) under nitrogen at 70°C for six hours. The yellow solution turned brown and a precipitate appeared (presumably triethylammonium bromide). The reaction mixture was poured into cold dilute aqueous hydrochloric acid (10°C–20°C) to yield 4-ethynylbenzoylethenylbenzoic acid as a crude tan solid (11.0 g, m.p. 175°C–185°C. [lit. m.p. 181°C–182.5°C]). The tan solid was dissolved in dilute aqueous sodium hydroxide solution, filtered, and the filtrate acidified to yield a light tan solid (9.6 g). Recrystallization twice from toluene provided 4-ethynylbenzoic acid as golden needles (4.3 g, m.p. 222°C–223°C. [Sample introduced in a preheated melting point apparatus at 220°C].[lit. m.p. 218°C. C. decomp.] [IR, strong sharp absorption at 3300 cm⁻¹ characteristic of H—C≡C stretch. Mass spectroscopy (MS), molecular ion (M⁺) at 146 [4-ethynylbenzoic acid (mol. wt. 146)], major fragments m/e 129 (HC≡C—C₆H₄—CO⁺) and 101 (HC≡C—C₆H₄—).] 4-Ethynylbenzoic acid (4.2 g) was stirred in thionyl chloride (30 ml) containing a few drops of N,N-dimethylformamide at ambient temperature overnight (8–20 hours). The light orange solution was concentrated to dryness at temperature <40°C in vacuo to yield an orange crystalline solid which was thoroughly washed with cold n-hexane (5°C–10°C C.). The resultant yellow crystalline solid (3.1 g) was dissolved in warm n-hexane (30 ml) and the solution cooled to 5°C to 10°C. Since no solid appeared, the solution was partially concentrated to yield 4-ethynylbenzoyl chloride as crude yellow
neatly 316° C. and pressure applied for 15 minutes. The precipitated product need not be further cured to exhibit the superior solvent and thermal qualities. The above specific examples are considered illustrative of the invention and there may be variations in the substituted acetylene or substituted ethynylbenzoyl chloride that will be apparent to those skilled in the art without departing from the spirit and scope of the invention.

It is recognized, for instance, that where chloroform has been used in the examples, other chlorinated or aromatic solvents such as methylene chloride, symmetric tetrachloroethane and possibly others, could be used. Likewise, where triethylamine has been used in the examples, other organic bases such as diethylamine, tripropylamine and possibly others could be used as well. Similarly, where methanol has been employed as a precipitating agent, it is recognized that other non-solvents such as ethanol, propanol, and possibly other liquids in which the precipitate would not be soluble could also be employed. Also, other highly polar solvents which could be substituted for N,N-dimethylformamide, or possibly others, could also be employed. Also, other highly polar solvents such as ethanol, propanol, and possibly others, could also be employed. 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