High temperature resins containing phenylethynyl groups that are processable by transfer molding have been prepared. These phenylethynyl containing oligomers were prepared from aromatic diamines containing phenylethynyl groups and various ratios of phthalic anhydride and 4-phenylethynylphthalic anhydride in glacial acetic acid to form a mixture of imide compounds in one step. This synthetic approach is advantageous since the products are a mixture of compounds and consequently exhibit a relatively low melting temperature. In addition, these materials exhibit low melt viscosities which are stable for several hours at 210–275°C, and since the thermal reaction of the phenylethynyl group does not occur to any appreciable extent at temperatures below 300°C, these materials have a broad processing window. Upon thermal cure at 300–350°C, the phenylethynyl groups react to provide a crosslinked resin system. These new materials exhibit excellent properties and are potentially useful as adhesives, coatings, films, moldings and composite matrices.
FIG. 1

Where PE=5.
Temp. °C

Viscosity, poise

Time, Minutes

FIG. 2
HIGH TEMPERATURE TRANSFER MOLDING RESINS

CROSS-REFERENCE

This patent application is related to commonly owned co-pending patent application Ser. No. 09/290,295, filed Apr. 13, 1999, entitled "PHENYLETHYNYL CONTAINING REACTIVE ADDITIVES".

ORIGIN OF THE INVENTION

The invention described herein was made by employees of the United States Government and may be manufactured and used by or for the Government or government purposes without payment of any royalties therein or thereof.

BACKGROUND OF THE INVENTION

In one aspect, the present invention is a mixture of imide oligomers containing phenylethynyl groups, in any proportion, and consisting of the general chemical formula

\[
\text{Ar} - \text{C} = \text{C} - \text{X}
\]

wherein Ar represents any aromatic group, PE is a radical represented by

\[
\text{O} - \text{C} - \text{C} - \text{Ar}
\]

wherein A is a group comprising O, CO, SO₂ or

\[
\text{C} - \text{C} - \text{X}
\]

X is a substituted or unsubstituted aryl, and R is a hydrogen or any phenylethynyl group represented by -C= C - X.

In another aspect the present invention is a process for synthesizing imide oligomers containing the phenylethynyl group by reacting 3,5-diamino-4'-phenylethynylbenzophenone and any proportion of a 4-phenylethynylphthalic anhydride and phthalic anhydride. By using this approach where ratios of PA and PEPA are used, a mixture of products is formed which consequently exhibit a lower melting temperature than that of the single product obtained by reacting the diamine with either PA or PEPA. For example, the product obtained from the reaction of the diamine with either PA or PEPA, for example, PA (1.5 mole) and PEPA (0.5 mole) or PA (0.5 mole) and PEPA (1.5 mole) were also prepared (designated TMR-2 and TMR-3, respectively).

All of above compounds exhibit relatively low melting temperatures. TMR-2 and TMR-3 exhibit two melting transitions by DSC. The onset of the thermal reaction of the phenylethynyl groups occurred -340 °C. and reached a maximum at -380 °C. After curing for one hour at 350 °C. in a sealed aluminum pan, no Tₘₜ were detectable by DSC. In addition, no residual exothermic transitions or crystalline melting transitions were detected. This information suggests that after this thermal cure, these materials had a moderate to high degree of crosslinking and were fully cured. Thermomechanical analyses (TMA) of a piece of molding prepared from TMR-1 that had been cured for 1 hour at 350 °C. indicated a Tₘₜ of -320 °C. Thermogravimetric analyses (TGA) of uncured imide powders of these materials indicated temperatures of 5% weight loss of -500 °C. in air and -525 °C. in nitrogen. These results are comparable to those typically exhibited by aromatic polyimides. Isothermal gravimetric analysis (ITGA) of a piece of molded prepared from TMR-1 and cured for one hour at 350 °C. in air indicated no weight loss after 132 hours at 265 °C. in flowing air. ITGA performed on this molding at 350 °C. in air indicated a 50% weight loss after 132 hours in flowing air. For comparative purposes, a phenylethynyl terminated imide oligomer with a number average molecular weight of 5000 g/mole exhibited a 10% weight loss after 132 hours at 350 °C. in air [See J. A. Hinkley and B. J. Jensen, High Perf. Polym. Vol. 7, 1-9 (1995)].

In addition, melt rheology was performed on the uncured powder of TMR-1.

The material was heated to -210 °C. and exhibited a complex melt viscosity of -10 poise. There was no change in the complex viscosity after a one hour hold at this temperature. The material was subsequently heated to 350 °C. over an additional 2 hour period. The complex melt viscosity decreased to less than 1.0 poise at -240 °C. and to zero at -270 °C. The complex melt viscosity did not increase until the temperature reached -325 °C. corresponding to a time of -2.5 hours after the material was first heated to 210 °C. A graph of the melt viscosity versus temperature and time is presented in FIG. 2.

Having generally described the invention, a more complete understanding thereof can be obtained by reference to the following examples, which are provided herein for purposes of illustration only and do not limit the invention.

Synthesis of Transfer Molding Resins (TRMs)

EXAMPLE 1

Synthesis of TRM-1 from 3,5-diamino-4'-phenylethynylbenzophenone (1.0 mole), phthalic anhydride (1.0 mole) and 4-phenylethynylphthalic anhydride (1.0 mole)

Into a 3 L three-necked round-bottom flask equipped with a mechanical stirrer, thermometer and reflux condenser was placed 3,5-diamino-4'-phenylethynylbenzophenone (187.4 g, 0.60 mole), phthalic anhydride (88.9 g, 0.60 mole), 4-phenylethynylphthalic anhydride (148.9 g, 0.60 mole) and glacial acetic acid (785 mL, 34% solids). The mixture was heated to reflux (-120 °C.) to give a dark brown solution. After -2 hours at this temperature a large amount of light tan
precipitate formed making stirring impossible. Heating was continued for 1 additional hour and the reaction mixture was cooled to room temperature. The product was isolated by filtration and washed three times in warm water to remove residual acetic acid. The solid was air dried overnight and most of the next day and subsequently placed in a forced air oven at 125 °C overnight. The light tan powder (397 g, 98% of theoretical yield), exhibited a melting transition at ~182 °C, and an exothermic transition due to the thermal reaction of the phenylethynyl groups beginning at 346 °C and peaking at 381 °C as determined by DSC. The heat of reaction was ~275 J/g.

EXAMPLE 2

Synthesis of TRM-2 from 3,5-diamino-4'-phenylethynylbenzophenone (1.0 mole), phthalic anhydride (1.5 mole) and 4-phenylethynylphthalic anhydride (0.5 mole)

Into a 500 mL three-necked round-bottom flask equipped with a mechanical stirrer, thermometer and reflux condenser was placed 3,5-diamino-4'-phenylethynylbenzophenone (23.43 g, 75.0 mmole), phthalic anhydride (16.66 g, 112.5 mmole), 4-phenylethynylphthalic anhydride (9.31 g, 37.5 mmole) and glacial acetic acid (125 mL, 30% solids). The mixture was heated to reflux (~120 °C) to give a dark brown solution. After ~2 hours at this temperature a large amount of light tan precipitate formed making stirring impossible. Heating was continued for 1 additional hour and the reaction mixture was cooled to room temperature. The product was isolated by filtration and washed three times in warm water to remove residual acetic acid. The solid was air dried overnight and subsequently placed in a forced air oven at 130 °C for six hours. The light tan powder (45.0 g, 96% of theoretical yield), exhibited a melting transition at ~179 °C and 235 °C, and an exothermic transition due to the thermal reaction of the phenylethynyl groups beginning at 346 °C and peaking at 383 °C as determined by DSC. The heat of reaction was ~209 J/g.

EXAMPLE 3

Synthesis of TRM-3 from 3,5-diamino-4'-phenylethynylbenzophenone (1.0 mole), phthalic anhydride (0.5 mole) and 4-phenylethynylphthalic anhydride (1.5 mole)

Into a 500 mL three-necked round-bottom flask equipped with a mechanical stirrer, thermometer and reflux condenser was placed 3,5-diamino-4'-phenylethynylbenzophenone (21.98 g, 70.4 mmole), phthalic anhydride (5.21 g, 35.2 mmole), 4-phenylethynylphthalic anhydride (26.20 g, 105.5 mmole) and glacial acetic acid (200 mL). The mixture was heated to reflux (~120 °C) to give a dark brown solution. After ~2 hours at this temperature a large amount of light tan precipitate formed making stirring impossible. Heating was continued for 1 additional hour and the reaction mixture was cooled to room temperature. The product was isolated by filtration and washed three times in warm water to remove residual acetic acid. The solid was air dried overnight and subsequently placed in a forced air oven at 130 °C for six hours. The light tan powder (50.2 g, 99% of theoretical yield), exhibited a melting transition at ~191 °C and 230 °C, and an exothermic transition due to the thermal reaction of the phenylethynyl groups beginning at 340 °C and peaking at 374 °C as determined by DSC.

While the invention has been described in terms of its preferred embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the appended claims. We claim:

1. An imide compound having the general chemical formula:

   ![](image)

   wherein Ar represents any aromatic group, wherein PE is radical represented by

   ![](image)

   wherein A is a radical selected from the group consisting of O, CO, SO₂ and

   ![](image)

   wherein X is selected from the group consisting of substituted aryl group and unsubstituted aryl group, wherein R is selected from the group consisting of hydrogen and any phenylethynyl group represented by

2. An imide compound obtained by reacting an aromatic diamine containing phenylethynyl groups having the general chemical formula

   ![](image)

   wherein Z is a radical selected from the group consisting of

   ![](image)

   wherein Ar represents any aromatic group, with any proportion of a phenylethynyl containing anhydride and a non-phenylethynyl containing anhydride.

3. A mixture of imide compounds obtained by reacting 3,5-diamino-4'-phenylethynylbenzophenone and any proportion of a 4-phenylethynyl phthalic anhydride and phthalic anhydride.
4. The mixture of imide compounds of claim 3, wherein the reaction is carried out in glacial acetic acid.

5. A process of synthesizing a mixture of imide compounds containing at least one phenylethynyl group and having the general structural formula according to claim 1, which process comprises the reaction between 3,5-diamino-4'-phenylethynylbenzophenone and any proportion of a 4-phenylethynylphthalic anhydride and phthalic anhydride.

6. A process of synthesizing a mixture of imide compounds containing at least one phenylethynyl group and having the general structural formula according to claim 1, which process comprises the reaction between 3,5-diamino-4'-phenylethynylbenzophenone and any proportion of a 4-phenylethynylphthalic anhydride and phthalic anhydride in glacial acetic acid.

7. A composite prepared from the imide compound according to claim 1.

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