Novel molecular weight controlled and endcapped polybenzimidazoles (PBI) are prepared by the aromatic nucleophilic displacement reaction of di(hydroxyphenylbenzimidazole) monomers with activated aromatic dihalides or activated aromatic dinitro compounds. The PBI are endcapped with mono(hydroxyphenyl)benzimidazoles. The polymerizations are carried out in polar aprotic solvents such as N-methyl-2-pyrrolidinone or N,N-dimethylacetamide using alkali metal bases such as potassium carbonate at elevated temperatures under nitrogen. Mono(hydroxyphenyl)benzimidazoles are synthesized by reacting phenyl-4-hydroxybenzoate with aromatic (o-diamine)s in diphenylsulfone. Molecular weight controlled and endcapped PBI of new chemical structures are prepared that exhibit a favorable combination of physical and mechanical properties.
FIG. 1

\[
\begin{align*}
\text{Diphenylsulfone / Toluene} & \\
\text{Nitrogen / Heat} & \\
\end{align*}
\]
Diphenylsulfone / Toluene
Nitrogen / Heat

\[
\begin{align*}
W \quad & \quad NH_2 \\
\text{+} \\
V \quad & \quad O - C - O - \\
\text{\downarrow} \\
W \quad & \quad NH \\
\end{align*}
\]

\[V = OH, F, Cl, NO_2\]
\[W = H, CH_3, CH_3O, \quad \text{, etc.}\]

FIG. 2
Fig. 4

$Z = \text{nil, } CO, SO_2, \text{ etc.}$

$W = H, CH_3, CH_3O,$

$X = CO, SO_2,$

$Y = F, Cl, NO_2,$

$W = H, CH_3, CH_3O,$

$X = CO, SO_2,$

$Y = F, Cl, NO_2,$

$Z = \text{nil, } CO, SO_2, \text{ etc.}$
FIG. 5
POLYBENZIMIDAZOLES VIA AROMATIC NUCLEOPHILIC DISPLACEMENT

CROSS REFERENCE TO RELATED APPLICATIONS


ORIGIN OF THE INVENTION

The invention described herein was jointly made by employees of the United States Government and a contract employee in the performance of work under NASA Grant No. NAG-1-448 and is subject to the provisions of Public Law 96-517 (35 USC 202) in which the contractor has elected not to retain title.

BACKGROUND OF THE INVENTION

The invention relates generally to heterocyclic polymers. In particular it relates to novel polybenzimidazoles and to a patent application Ser. No. 07/790,730, filed Oct. 30, 1991, entitled "Polybenzimidazoles Via Aromatic Nucleophilic Displacement".

POLYBENZIMIDAZOLES

Polybenzimidazoles (PBI) are heterocyclic polymers commonly prepared by the condensation reaction of aromatic bis(o-diamine)s with an aromatic diacid or derivative thereof and having a repeat unit of the general structure

where Ar is a tetravalent aromatic radical such as 1,2,4,5-tetrasubstituted benzene. Ar may also be a bis(o-diphenylene) having the general structure

where Z=ni1, O, S, SO2, O=C, CH2, or any other appropriate divalent radical. Ar' is a divalent aromatic radical which may be 1,3-phenylene, 1,4-phenylene, 4,4'-biphenylene, 4,4'-oxydiphenylene, 4,4'-sulfonyldiphenylene, or any other appropriate divalent radical.


To obtain polymer with low melt viscosity, the molecular weight of a polymer can be lowered and controlled by using a stoichiometric imbalance of one of the monomers. This is expressed mathematically by a modification of the Crouthers equation for AA-BB type monomers (Polymer Chemistry: An Introduction, 2nd Ed., M. P. Stevens, Oxford University, New York, 1990, 335-337).

\[
DP = \frac{(1+r)(1-r)}{r} \]

where

- DP: degree of polymerization
- r: stoichiometric imbalance; 0.5 < r < 1.0.

For r=1, there is no stoichiometric imbalance of monomers in the polymerization reaction. The calculated number average molecular weight can then be determined by

\[
M_n = \frac{0.50DP(MW \text{ of repeat unit})}{(1-\frac{1}{DP})}
\]

where

- \(M_n\): number average molecular weight
- MW of repeat unit= molecular weight of polymer repeat unit.

Endcapping the polymer is achieved by using 2x(1-r) of a monofunctional reagent in the polymerization reaction based on monofunctional endcapping technology [D. Progar, T. S. Clair, H. Burks, C. Gautreau, A. Tamaguchi, and M. Ohta, SAMPE J., 52 (Jan/Feb 1990)]. An endcapped version of poly[2,2'-(m-phenylene-5,5'-dibenzimidazole)] has recently been reported [M. Jaffe, E. C. Cheney, W. M. Cooper, M. Glick, and I. Taider, Polym. Prepr., 32(2), 207 (1991)].

SUMMARY OF THE INVENTION

A primary object of the present invention is to provide novel polybenzimidazole (PBI) compositions of matter. Another object is to provide a new process to prepare molecular weight controlled and endcapped PBI. Yet another object is to provide new molecular weight controlled and endcapped PBI that are useful as adhesives, coatings, films, fibers, membranes, moldings, and composite matrices.
According to the present invention, the foregoing and additional objects were obtained by synthesizing molecular weight controlled and endcapped PBI by nucleophilic displacement reaction of di(hydroxyphenyl)benzimidazole monomers with activated aromatic dihalides. Endcapping of the molecular weight controlled polymer was achieved by using a mono(hydroxyphenyl)benzimidazole. The inherent viscosities (η\text{inh}) of the molecular weight controlled and endcapped PBI ranged from 0.55 to 1.65 dL/g and the glass transition temperatures (T\text{g}) ranged from 266°-274°C. An unendcapped, uncontrolled molecular weight PBI polymer (no stoichiometric imbalance) had an inherent viscosity of 2.00 dL/g and a glass transition temperature of 276°C. Thermogravimetric analysis (TGA) at a heating rate of 2.5°C/min showed no weight loss occurring below 300°C in air or nitrogen with a 5% weight loss occurring at about 470°C in air and about 490°C in nitrogen.

The synthesis of molecular weight controlled and endcapped PBI involved the use of di(hydroxyphenyl) benzimidazoles and mono(hydroxyphenyl)benzimidazoles. The monomers were prepared from phenyl-4-hydroxybenzoate and aromatic bis(o-diamine)s. The catenation of the hydroxy groups may be meta-meta, para-para, or para-meta. The monofunctional benzimidazole, used as an endcapping agent, was prepared from phenyl-4-hydroxybenzoate and o-phenylene diamine. The catenation of the functional group may be para or meta.

**BRIEF DESCRIPTION OF THE DRAWINGS**

For a more complete understanding of the present invention including its objects and benefits, reference should be made to the Description of the Preferred Embodiments, which is set forth below. This description should be read together with the accompanying drawings, wherein:

FIG. 1 is an equation showing the preparation of monomers according to the present invention from phenyl-4-hydroxybenzoate and aromatic bis(o-diamine)s;

FIG. 2 is an equation showing the preparation of an endcapping agent according to the present invention from phenyl-4-hydroxybenzoate and o-phenylene diamine;

FIGS. 3 and 4 are equations showing the general reaction sequence for the synthesis of molecular weight controlled and endcapped polybenzimidazoles according to the present invention; and

FIGS. 5 and 6 are equations showing the general reaction sequence for the synthesis of molecular weight controlled and unendcapped PBI according to the present invention.

**DESCRIPTION OF THE PREFERRED EMBODIMENTS**

In one aspect, the present invention is a molecular weight controlled and endcapped poly(benzimidazole) consisting of repeat units having the general structural formula

\[
\begin{align*}
\text{Ar} + \text{N} = \text{N} + \text{O} + \text{N} - \text{N} + \text{Ar}
\end{align*}
\]

wherein the catenation of oxygen is selected from the group consisting of meta-meta, para-para, and para-meta. Ar is a radical selected from the group consisting of

\[
\begin{align*}
\text{CH}_2, \text{O}, \text{S}, \text{O} = \text{C}, \text{SO}_2
\end{align*}
\]
etc.

$X$ is a radical selected from the group consisting of

\[-SO_2-\]

$EC$ is a radical selected from the group consisting of:

The monomer ratio ($r$) is $0.5 \leq r \leq 1$, and $n$ is an integer between 4 and 1000.

An especially preferred embodiment of a molecular weight controlled and endcapped poly(benzimidazole) is presented when $Ar$ is a radical represented by

$X$ is a radical represented by

$EC$ is a radical represented by

$W$ is a radical represented by $H$, and the monomer ratio ($r$) is $0.93$, $0.97$, $0.985$ and $1$. 
In another aspect, the present invention is a process for synthesizing molecular weight controlled and endcapped poly(benzimidazoles) by aromatic nucleophilic displacement. The process includes reacting a di(hydroxyphenyl) benzimidazole and a monofunctional benzimidazole having the general structure

wherein EC is a radical selected from the group consisting of:

\[ \text{W is a radical selected from the group of } \]

\[ \text{V is selected from the group consisting of OH, Cl, F, NO}_2; \]

and the catenation of V is selected from meta and para. Also reacted is an activated aromatic dihalide or aromatic dinitro compound having the general structure

wherein Y is selected from the group consisting of Cl, F, and NO\textsubscript{2}. The reaction is carried out in a polar aprotic solvent selected from the group consisting of N,N-dimethylacetamide, N-methyl-2-pyrrolidinone, sulfolane, diphenylsulfone, N-cyclohexyl-2-pyrrolidinone, and dimethylsulfoxide. The reaction is also carried out in the presence of an alkali metal base selected from the group consisting of potassium carbonate, sodium carbonate, potassium hydroxide, and sodium hydroxide, and the reaction is carried out with the application of heat.

Especially advantageous results are achieved if

\[ \text{X is } \]
W is H,
V is OH,
Y is Cl or F, preferably F,
and the solvent is N,N-dimethylacetamide.

In other aspects, the present invention is a molecular
weight controlled and endcapped poly(benzimidazole): film,
fiber, molding, adhesive, and matrix resin for composites.

In yet another aspect the present invention is a molecular
weight controlled and unendcapped poly(benzimidazole)
consisting of repeat units having the general structural
formula

\[
\text{HO-} \overset{\text{Ar}}{\text{Ar}} \left( \overset{\text{O}}{\overset{\text{X}}{\text{O}}} \overset{\text{Ar}}{\text{Ar}} \right)_n \overset{\text{O}}{\overset{\text{X}}{\text{O}}} \overset{\text{Ar}}{\text{Ar}} \text{OH}
\]

or

\[
\overset{\text{Y}}{\overset{\text{X}}{\text{O}}} \left( \overset{\text{Ar}}{\text{O}} \overset{\text{O}}{\overset{\text{X}}{\text{Ar}}} \overset{\text{O}}{\overset{\text{Ar}}{\text{O}}} \right)_n \overset{\text{O}}{\overset{\text{X}}{\text{O}}} \overset{\text{Ar}}{\text{Ar}} \overset{\text{Y}}{\overset{\text{X}}{\text{O}}}
\]

wherein the catenation of oxygen is selected from the group
consisting of meta-meta, para-para, and para-meta. Y is F,
Cl, or NO₂; and Ar is a radical selected from the group of
Z is a radical selected from the group consisting of nil, CH₃,
O, S, O=C, SO₂,

etc.

X is a radical selected from the group consisting of

etc.
wherein X is a radical selected from the group consisting of

the monomer ratio (r) is $0.5 \leq r \leq 1$ and n is an integer between 4 and 1000.

In another aspect, the present invention is a process for synthesizing molecular weight controlled and unendcapped poly(benzimidazole)s by aromatic nucleophilic displacement. The process includes reacting a di(hydroxyphenyl) benzimidazole with an activated aromatic dichloride or aromatic dinitro compound having the general structure

Y selected from the group consisting of Cl, F, and NO₂.

The reaction is carried out in a polar aprotic solvent selected from the group consisting of N,N-dimethylacetamide, N-methyl-2-pyrrolidinone, sulfolane, diphenylsulfone, N-cyclohexyl-2-pyrrolidinone, and dimethylsulfoxide. The reaction is also carried out in the presence of an alkali metal base selected from the group consisting of potassium carbonate, sodium carbonate, potassium hydroxide, and
sodium hydroxide, and the reaction is carried out with the application of heat. In other aspects, the present invention is a molecular weight controlled and unendcapped poly(benzimidazole); film, fiber, molding, adhesive, and matrix resin for composites.

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.

**EXAMPLE 1**

**Endcap Synthesis**

The following example illustrates the reaction sequence in FIG. 2 for the preparation of the endcapping agent.

**2-(4-Hydroxyphenyl)benzimidazole**

A mixture of 1,2-diaminobenzene (25.17 g, 0.233 mol), phenyl-4-hydroxyphenylbenzoate (50.17 g, 0.234 mol), diphenylsulfone (121.15 g), and toluene (100 ml) were heated under a nitrogen atmosphere for 16 hours at 150°C. The toluene was removed and the temperature increased to 260°C and maintained for two and one-half hours. A vacuum was subsequently applied and the temperature increased to 290°C, and maintained for one and one-half hours. The warm reaction mixture was precipitated in toluene, washed in hot toluene, and subsequently dried at 110°C to afford 45.00 g (92% crude yield) of a red-brown powder, m.p. (DTA) 279°C (broad). The product was recrystallized from 40% aqueous ethanol using charcoal to afford 31.46 g (64% yield). The compound exhibited a sharp melt by DTA with an endothermic minimum at 280°C. Anal. caled for C19H19N2O: C, 74.27%; H, 4.79%; Found: C, 74.21%; H, 4.75%; N, 13.21%.

**EXAMPLE 2**

**Molecular Weight Controlled and Endcapped Poly(arylene ether benzimidazole) Synthesis**

0% Stoichiometric Offset, 0% Endcapped PBI

The following example illustrates the reaction sequence for the preparation of high molecular weight polymer where X is equal to an isophthaloyl group, Y is F, and Z is S,5'-nil, the catenation of the hydroxy groups is para-para, and the stoichiometric imbalance is 0% (r=1). Into a 100 ml three necked round bottom flask equipped with nitrogen inlet, thermometer, mechanical stirrer, and Dean Stark trap was placed 5.5'-bis(2-(4-hydroxyphenyl)benzimidazole) (20.7397 g, 72.3 mmol), 1,3-bis(4-fluorobenzoyl)benzene (23.6544 g, 73.4 mmol), 2-(4-hydroxyphenyl)benzimidazole (0.4629 g, 2.2 mmol), pulverized anhydrous potassium carbonate (25.8851 g, 187.3 mmol), dry DMAC (250 ml, 18.8% solids w/w) and toluene (225 ml). The mixture was heated at 140°-150°C for five hours and then heated to 155°-160°C. The viscous reaction mixture was diluted with 250 ml of DMAC (7.2% solids w/w) after an additional one hour. Stirring was continued for one and one-quarter hours at 155°-160°C. After about one hour the viscous reaction mixture was diluted with 250 ml DMAC (10.4% solids w/w) and stirring continued at 155°-160°C. The reaction mixture was cooled. The viscous solution was precipitated in a water/acetic acid (10/1) mixture, washed successively in hot water and methanol and dried at 110°C to provide a light tan crystalline product (31.46 g, 64% yield). The mixture was heated at 140°-150°C for two and one-half hours and then heated to 155°-160°C. After about two hours the viscous reaction mixture was diluted again with 25 ml DMAC (9.0% solids w/w) and stirring continued at 155°-160°C. The viscous reaction mixture was diluted again with 25 ml DMAC (5.7% solids w/w) after an additional three-quarters hour. The viscous solution was precipitated in a water/acetic acid (10/1) mixture, washed successively in hot water and methanol and dried at 110°C to provide a light brown polymer (2.48 g, 73% yield) with a Tg of 276°C. The inherent viscosity of a 0.5% solution in DMAC at 25°C was 2.00 dL/g. Unoriented thin films cast from a DMAC solution gave tensile strength, tensile modulus, and elongation at 23°C of 18.2 ksi, 602 ksi, and 14%, respectively; at 177°C of 14.0 ksi, 447 ksi, and 7%, respectively; and at 232°C of 12.4 ksi, 409 ksi, and 7%, respectively.

**EXAMPLE 3**

1.5% Stoichiometric Offset, 3% Endcapped PBI

The following example illustrates the reaction sequence in FIG. 3 for the preparation of the molecular weight controlled and endcapped polymer where X is equal to an isophthaloyl group, Y is F, and Z is 5,5'-nil, the catenation of the hydroxy groups is para-para and the stoichiometric imbalance is 1.5% (r=0.985). The endcapping reagent [3%, 2x(1-r)] is 2-(4-hydroxyphenyl)benzimidazole.

Into a 2000 ml three necked round bottom flask equipped with nitrogen inlet, thermometer, mechanical stirrer, and Dean Stark trap was placed 5.5'-bis(2-(4-hydroxyphenyl)benzimidazole) (68.7930 g, 164.4 mmol), 1,3-bis(4-fluorobenzoyl)benzene (23.6544 g, 73.4 mmol), 2-(4-hydroxyphenyl)benzimidazole (0.4629 g, 2.2 mmol), pulverized anhydrous potassium carbonate (25.8851 g, 187.3 mmol), dry DMAC (250 ml, 18.8% solids w/w) and toluene (225 ml). The mixture was heated at 140°-150°C for five hours and then heated to 155°-160°C. The viscous reaction mixture was diluted again with 250 ml of DMAC (7.2% solids w/w) after an additional one hour. Stirring was continued for one and one-quarter hours at 155°-160°C. After about one hour the viscous reaction mixture was diluted with 250 ml DMAC (10.4% solids w/w) and stirring continued at 155°-160°C. The reaction mixture was cooled. The viscous solution was precipitated in a water/acetic acid (10/1) mixture, washed successively in hot water and methanol and dried at 110°C to provide a light tan polymer (47.3 g, 92% yield) with a Tg of 274°C. The inherent viscosity of 0.5% solution in DMAC at 25°C was 1.65 dL/g. Unoriented thin films cast from a DMAC solution gave tensile strength, tensile modulus, and elongation at 23°C of 18.1 ksi, 524 ksi, and 12%, respectively, at 177°C of 14.0 ksi, 432 ksi, and 6%, respectively; and at 232°C of 11.7 ksi, 364 ksi, and 5%, respectively. G<sub>R</sub>=4.9 (in lb/in²). (Fracture toughness, critical strain energy release rate).

**EXAMPLE 4**

3.0% Stoichiometric Offset, 6% Endcapped PBI

The following example illustrates the reaction sequence in FIG. 3 for the preparation of the molecular weight controlled and endcapped polymer where X is equal to an isophthaloyl group, Y is F, and Z is 5,5'-nil, the catenation of the hydroxy groups is para-para and the stoichiometric imbalance is 3.0% (r=0.97). The endcapping reagent [6%, 2x(1-r)] is 2-(4-hydroxyphenyl)benzimidazole.

Into a 2000 ml three necked round bottom flask equipped with nitrogen inlet, thermometer, mechanical stirrer, and Dean Stark trap was placed 5.5'-bis(2-(4-hydroxyphenyl)benzimidazole) (68.7930 g, 164.4 mmol), 1,3-bis(4-fluorobenzoyl)benzene (54.6260 g, 169.5 mmol), 2-(4-hydroxyphenyl)benzimidazole (2.1379 g, 10.2 mmol), pulverized anhydrous potassium carbonate (59.83 g, 432.9 mmol), dry DMAC (600 ml, 18.3% solids w/w) and toluene (250 ml). The mixture was heated at 140°-150°C for seven and one-half hours and then heated to 155°-160°C. After about one and one-half hours the viscous reaction mixture was diluted with 600 ml DMAC (10.0% solids w/w) and...
stirring continued for an additional one-half hour at 155°-160° C. and the reaction mixture was cooled. The viscous solution was precipitated in a water/acetic acid (10/1) mixture, washed successively in hot water and methanol and dried at 110° C. to provide a light tan polymer (115.2 g, 97% yield) with a Tg of 274° C. The inherent viscosity of 0.5% solution in DMAc at 25° C. was 1.42 dl/g. Unoriented thin films cast from a DMAc solution gave tensile strength, tensile modulus, and elongation at 23° C. of 18.7 ksi, 582 ksi, and 30%, respectively, at 177° C. of 13.6 ksi, 429 ksi, and 11%, respectively; and at 232° C. of 12.0 ksi, 406 ksi, and 12%, respectively. Gc=5.7 (in lb)/in². (Fracture toughness, critical strain energy release rate.)

EXAMPLE 5

7.0% Stoichiometric Offset, 14% Endcapped PBI

The following example illustrates the reaction sequence in FIG. 3 for the preparation of the molecular weight controlled and endcapped polymer where X is equal to an isophthaloyl group, Y is F, and Z is 5,5'-nil, the catenation of the hydroxy groups is para-para and the stoichiometric imbalance is 7.0% (=0.93). The endcapping reagent is [14%, 2x(1-r)] is 2-(4-hydroxyphenyl)benzimidazole.

Into a 2000 ml three necked round bottom flask equipped with nitrogen inlet, thermometer, mechanical stirrer, and Dean Stark trap was placed 5,5'-bis[2-(4-hydroxyphenyl) benzimidazole] (56.0292 g, 133.9 mmol), 1,3-bis(4-fluorobenzoyl)benzene (46.4043 g, 144.0 mmol), 2-(4-hydroxyphenyl)benzimidazole (4.2376 g, 20.02 mmol), pulverized anhydrous potassium carbonate (51.8656 g, 3.75 mmol), dry DMAc (500 ml, 18.5% solids w/w) and toluene (200 ml). The mixture was heated to 140°-150° C. for five hours and then heated to 155°-160° C. After about one and three-quarters hours the viscous reaction mixture was diluted with 400 ml DMAc (11.2% solids w/w) and stirring continued for an additional one-half hour at 155°-160° C.

The viscous reaction mixture was diluted again with 370 ml hot DMAc (8.5% solids w/w) after and additional four hours. The viscous solution was precipitated in a water/acetic acid (10/1) mixture, washed successively in hot water and methanol and dried at 110° C. to provide a light tan polymer (96.85 g, 96% yield) with a Tg of 266° C. The inherent viscosity of 0.5% solution in DMAc at 25° C. was 0.55 dl/g. Unoriented thin films cast from a DMAc solution gave tensile strength, tensile modulus, and elongation at 23° C. of 16.5 ksi, 530 ksi, and 22%, respectively, at 177° C. of 13.1 ksi, 426 ksi, and 33%, respectively; and at 232° C. of 10.3 ksi, 384 ksi, and 10%, respectively. Gc=2.2 (in lb)/in². (Fracture toughness, critical strain energy release rate.)

Polymer characterization and unoriented thin film properties are presented in Table 1. Adhesive properties of the 3% stoichiometric imbalance and endcapped polymer are presented in Table 2. Adhesive properties of the 7% stoichiometric imbalance and endcapped polymer are presented in Table 3, and composite properties of the 7% stoichiometric imbalance and endcapped polymer are presented in Table 4.

### TABLE 1

CHARACTERIZATION OF MOLECULAR WEIGHT CONTROLLED PAEBI

<table>
<thead>
<tr>
<th>PROPERTIES</th>
<th>0%</th>
<th>1.5%</th>
<th>3%</th>
<th>7%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tg, °C (powder)</td>
<td>256</td>
<td>274</td>
<td>274</td>
<td>266</td>
</tr>
<tr>
<td>Tg, °C (film)</td>
<td>284</td>
<td>287</td>
<td>284</td>
<td>273</td>
</tr>
<tr>
<td>Temp. of 5% wt. loss in N2</td>
<td>447/515</td>
<td>467/511</td>
<td>467/507</td>
<td>470/472</td>
</tr>
<tr>
<td>Tensile Strength, ksi</td>
<td>18.2/14.0/12.4</td>
<td>18.1/14.0/11.7</td>
<td>18.3/13.6/12.0</td>
<td>16.3/13.1/10.3</td>
</tr>
<tr>
<td>Tensile Modulus, ksi</td>
<td>602/447/409</td>
<td>526432894</td>
<td>582453406</td>
<td>530429584</td>
</tr>
<tr>
<td>% Elong. at break</td>
<td>14/77</td>
<td>12/65</td>
<td>30/11/12</td>
<td>22/23/10</td>
</tr>
<tr>
<td>Gc, (in lb)/in²</td>
<td>4.9</td>
<td>5.7</td>
<td>2.2</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 2

PRELIMINARY Ti-to-Ti TENSILE SHEAR PROPERTIES

<table>
<thead>
<tr>
<th>TEST TEMPERATURE, °C</th>
<th>SHEAR STRENGTH, psi</th>
<th>FAILURE MODE, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>2524</td>
<td>~60 Adh.¹</td>
</tr>
<tr>
<td>177</td>
<td>2276</td>
<td>~55 Adh.</td>
</tr>
<tr>
<td>200</td>
<td>2024</td>
<td>~70 Adh.</td>
</tr>
<tr>
<td>232</td>
<td>2567</td>
<td>~100 Coh. °</td>
</tr>
</tbody>
</table>

1 Mole % molecular weight controlled endcapped PAEBI, Tg = 276 °C.
2 Shear samples bonded at 250 psi/330 °C/15 minutes.
3 Adh.: Adhesive, Coh.: Cohesive.
TABLE 3

PRELIMINARY Ti-to-Ti TENSILE SHEAR PROPERTIES1,2:

<table>
<thead>
<tr>
<th>Test Temp., °C.</th>
<th>Shear Strength, psi</th>
<th>Failure Mode, %</th>
<th>Shear Strength, psi</th>
<th>Failure Mode, %</th>
<th>Shear Strength, psi</th>
<th>Failure Mode, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>3236</td>
<td>–90 Adh</td>
<td>3537</td>
<td>–100 Adh</td>
<td>3076</td>
<td>–100 Adh</td>
</tr>
<tr>
<td>177</td>
<td>2235</td>
<td>–90 Adh</td>
<td>2439</td>
<td>–90 Adh</td>
<td>2562</td>
<td>–90 Adh</td>
</tr>
<tr>
<td>200</td>
<td>2019</td>
<td>–90 Adh</td>
<td>2491</td>
<td>–75 Adh</td>
<td>2403</td>
<td>–80 Adh</td>
</tr>
<tr>
<td>232</td>
<td>1649</td>
<td>–50 Adh</td>
<td>1929</td>
<td>–70 Coh</td>
<td>2336</td>
<td>–70 Coh</td>
</tr>
</tbody>
</table>

1. Mol % molecular weight controlled endcapped PAEBI, \( \eta_{inh} = 0.22 \text{ dl/g}, T_g = 265^\circ \text{C}.
2. Specimens bonded at 250 psi/330° C/15 minutes
3. Adh.: Adhesive, Coh.: Cohesive

TABLE 4

PRELIMINARY PROPERTIES OF CARBON FIBER (AS-4) UNIDIRECTIONAL COMPOSITES1

<table>
<thead>
<tr>
<th>TEST TEMP., °C.</th>
<th>FLEXURAL STREN., ksi</th>
<th>FLEXURAL MOD., msi</th>
<th>RESIN CONTENT(^3), %</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>277</td>
<td>19.7</td>
<td>31</td>
</tr>
<tr>
<td>23</td>
<td>233(^a)</td>
<td>14.9(^3)</td>
<td>35(^a)</td>
</tr>
<tr>
<td>23</td>
<td>209(^a)</td>
<td>15.9(^3)</td>
<td>35(^3)</td>
</tr>
<tr>
<td>200</td>
<td>187(^3)</td>
<td>15.6(^3)</td>
<td>35(^3)</td>
</tr>
<tr>
<td>232</td>
<td>163(^3)</td>
<td>14.5(^3)</td>
<td>35(^3)</td>
</tr>
</tbody>
</table>

1. Stoichiometric imbalance fabricated at 360° C/200 psi/1 h
2. Resin content determined by acid digestion using concentrated sulfuric acid and 30% hydrogen peroxide.
3. Properties determined using specimens cut from the same panel.

We claim:

1. A molecular weight controlled and unendcapped poly (benzimidazole) consisting of repeat units having a general structural formula selected from the group consisting of:

\[
\text{HO-}\overset{\text{Ar}}{\bigg(}\overset{\text{O-}}{\bigg(}\overset{\text{OH}}{\bigg)}_{n}\bigg)_{x}\overset{\text{Ar}}{-X} \quad \text{and} \quad \overset{\text{O-}}{\bigg)_{x}\overset{-X}{\bigg(}\overset{\text{OH}}{\bigg)}_{n}\overset{-X}{\bigg(}\overset{\text{Ar}}{\bigg)\overset{\text{Ar}}{-Y}}
\]

wherein the catenation of oxygen is selected from the group consisting of meta-meta, para-para, and para-meta; wherein \( Y \) is selected from the group consisting of F, Cl, and NO\(_2\); and

\[
\overset{\text{Ar}}{-Y}
\]

wherein \( \text{Ar} \) is a radical selected from the group consisting of...
wherein $n$ is an integer between 4 and 1000; and wherein monomer ratio ($r$) is $0.5 \leq r \leq 1$.

2. A film prepared from the molecular weight controlled and unendcapped poly(benzimidazole) of claim 1.

3. A film prepared from the molecular weight controlled and unendcapped poly(benzimidazole) of claim 1.

4. A molding prepared from the molecular weight controlled and unendcapped poly(benzimidazole) of claim 1.

5. An adhesive prepared from the molecular weight controlled and unendcapped poly(benzimidazole) of claim 1.

6. A matrix resin for composites prepared from the molecular weight controlled and unendcapped poly(benzimidazole) of claim 1.

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