MULTICOMPONENT FIBER COMPRISING A PHASE CHANGE MATERIAL

Inventors: Jeffrey S. Dugan, Erwin, TN (US); Eric Kuckhoff, Acworth, GA (US)

Assignee: Fiber Innovation Technology, Inc.

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ABSTRACT

The present invention is a multicomponent fiber comprising a temperature-regulating inner fiber component encapsulated by an outer fiber component. The invention further provides methods of preparing the inventive multicomponent fiber and methods of preparing a temperature-regulating fiber component incorporating at least one phase change material.
MULTICOMPONENT FIBER COMPRISING A PHASE CHANGE MATERIAL

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to U.S. Provisional Patent Application Ser. No. 60/717,225, filed Sep. 15, 2005, which is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention is related to multicomponent fibers. In particular, the invention is related to multicomponent fibers comprising at least one temperature-regulating inner fiber component and an outer fiber component encapsulating the temperature-regulating inner fiber component.

BACKGROUND

[0003] Fibers formed of synthetic polymers have long been recognized as useful in the production of textile articles. Such fibers can be used in diverse applications, such as apparel, disposable personal care products, filtration media, and carpet. Compositions useful in forming fibers with improved thermal capacity have also been sought.

[0004] Phase change materials have been used in a variety of applications. They have been included in wall and floor boards to store heat to provide a room with a comfortable ambient temperature. They have also been incorporated in cups, glasses, and tableware to keep foods and beverages at a desired eating temperature for extended periods of time.

[0005] Phase change materials have also been used to keep clothing at a comfortable temperature. One application requires the use of paraffin hydrocarbons mixed with silicon dry powders contained in plastic film pouches which are placed between layers of clothing. Such pouches are bulky and only provide a benefit to those areas of the article of clothing in which the pouch is used. The shape of such pouches also makes it difficult to secure them throughout a garment.

[0006] Phase change materials also have been directly incorporated into synthetic polymer fibers. This is readily accomplished, in part due to the high levels of volatile materials typically associated with the solution spinning process of forming synthetic polymer fibers. It is more problematic, though, to incorporate phase change materials into meltspun synthetic fibers, since high levels of volatile material typically are not present or desired in the melt spinning process. Furthermore, as phase change materials often exhibit a phase change at around ambient temperature, fibers directly incorporating such phase change materials have a tendency to ooze (i.e., leach out of the fibers), thereby making the fibers undesirable to the touch.

[0007] To avoid problems, such as oozing, previous attempts to incorporate phase change materials into meltspun synthetic fibers typically involved mixing microcapsules containing a phase change material with a standard fiber-grade thermoplastic polymer to form a blend, and subsequently melt spinning this blend to form monocomponent synthetic fibers. Such attempts generally led to inadequate dispersion of the microcapsules within the fibers, poor fiber properties, and poor processability unless low concentrations of the microcapsules were used. However, with low concentrations of the microcapsules, the desired enhanced reversible thermal properties normally associated with the use of phase change materials are difficult to realize. Furthermore, microcapsules do not have the structural integrity to withstand the force exerted on the microcapsule when the encapsulated phase change material is extruded to form fibers.

[0008] In light of the above, there remains a need in the art for a fiber incorporating a phase change material in such a manner to provide a fiber with desirable thermal properties while maintaining pleasant feel. The multicomponent fiber of the present invention meets such a need.

SUMMARY OF THE INVENTION

[0009] The present invention is directed to a multi-component fiber comprising a phase change material, methods of preparation of such fibers, fabrics and other materials prepared from such fibers, and methods of preparing a temperature-regulating component for use in such fibers. In particular embodiments, the invention is directed to a temperature-regulating component useful for incorporation into a multicomponent fiber, thereby providing a fiber with particularly beneficial thermal properties. The multicomponent fiber of the invention is further beneficial in that it allows for incorporation of an increased concentration of the phase change material in the overall fiber, thereby providing a fiber with increased thermal properties, without sacrificing the processability of the fiber by melt spinning.

[0010] In one aspect, the invention is directed to a multi-component fiber. In one embodiment, the multicomponent fiber comprises at least one temperature-regulating inner fiber component and an outer fiber component encapsulating the temperature-regulating inner fiber component. In one particular embodiment, the inner fiber component comprises at least about 25% by weight of a polyolefin and up to about 50% by weight of a phase change material, based on the overall weight of the inner fiber component.

[0011] The temperature-regulating inner fiber component used in the multicomponent fiber of the invention may further comprise additional components. In one embodiment, the inner fiber component further comprises a silica-containing component, such as fumed silica. In another embodiment, the inner fiber component further comprises an ethylenic material, preferentially an ethylenic copolymer, such as ethylene vinyl acetate. In one particular embodiment, the temperature-regulating inner fiber component comprises a polyolefin, a phase change material, a silica-containing material, and an ethylenic copolymer.

[0012] Various phase change materials can be used in preparing the temperature-regulating fiber component that is particularly useful as the inner fiber component of the multicomponent fiber of the present invention. In particular, the phase change material used in the invention can be varied according to the desired end use of the product incorporating the multicomponent fiber. In other words, the multicomponent fiber can incorporate a particular phase change material having a transition temperature substantially in the range for which the desired thermal properties are expected. Preferentially, the phase change material comprises at least one compound having a transition temperature of about 10° C to about 50° C. In further embodiments, the phase change material comprises at least one aliphatic
hydrocarbon having between about 8 carbon atoms and about 50 carbon atoms, such as octadecane.

[0013] The outer fiber component according to the invention can comprise any material capable of extrusion in preparing the multicomponent fiber. In one particular embodiment of the invention, the outer fiber component comprises a polymeric material having an extrusion temperature of about 150°C to about 300°C. Non-limiting examples of materials useful in preparing the outer fiber component include polyethylene terephthalate, polypropylene, polyamide, polyactic acid, and mixtures thereof.

[0014] According to another aspect, the invention is directed to a method of making a temperature-regulating fiber component. In one embodiment, the method comprises the steps of preparing a precursor material comprising a high concentration of a phase change material and combining the precursor material with a polyolefin to prepare the final temperature-regulating fiber component. In one particular embodiment, the precursor material comprises a polyolefin and greater than 50% by weight of a phase change material, based on the overall weight of the precursor material. The precursor material can be prepared by mixing the polyolefin and the phase change material in molten form, cooling the resulting mixture into a solidified mixture, and processing the solidified mixture to be in a particulate form. Further, the step of combining the precursor material with a polyolefin preferentially comprises mixing the particulate precursor material with an additional amount of a polyolefin in particular form such that the temperature-regulating fiber component comprises at least about 25% by weight of a polyolefin and up to 50% by weight of a phase change material, based on the overall weight of the temperature-regulating fiber component. In one preferred embodiment, the precursor material is prepared to further include a silica-containing material and an ethylene material.

[0015] According to another aspect, the invention is directed to a method of preparing a multicomponent fiber. In one embodiment, the method comprises the following steps: providing at least one temperature-regulating inner fiber component; providing an outer fiber component; introducing the fiber components to a fiber extrusion apparatus including a spinneret; and extruding the fiber components so as to form a multicomponent fiber wherein the outer fiber component is encapsulating the inner fiber component. Preferentially, the outer fiber component is introduced to the spinneret prior to introducing the inner fiber component to the spinneret such that the inner fiber component is prevented from contacting an ambient atmosphere.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] In order to assist the understanding of embodiments of the invention, reference will now be made to the appended drawings, which are not necessarily drawn to scale. In the drawings, which are exemplary only, and should not be construed as limiting the invention:

[0017] FIG. 1 is a cross-section illustrating a multicomponent fiber according to one embodiment of the invention, wherein the fiber is in a sheath/core configuration;

[0018] FIG. 2 is a cross-section illustrating another embodiment of a sheath/core fiber according to the invention;

[0019] FIG. 3 is a cross-section illustrating yet another embodiment of a sheath/core fiber according to the invention, wherein the core is offset within the sheath;

[0020] FIG. 4 illustrates still another embodiment of a sheath/core fiber according to the invention, wherein the sheath and the core exhibit different geometries in cross-section;

[0021] FIG. 5 also illustrates another embodiment of a sheath/core fiber according to the invention, wherein the sheath and the core exhibit different geometries in cross-section;

[0022] FIG. 6 is a cross section illustrating another embodiment of a sheath/core fiber of the invention, wherein the sheath and core are of similar rectangular geometry;

[0023] FIG. 7 is a cross-section of an islands-in-the-sea embodiment of a multicomponent fiber of the invention; and

[0024] FIG. 8 is a schematic illustration of an exemplary process for making a multicomponent fiber according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0025] The present invention will be described more fully hereinafter in connection with illustrative embodiments of the invention which are given so that the present disclosure will be thorough and complete and will fully convey the scope of the invention to those skilled in the art. However, it is to be understood that this invention may be embodied in many different forms and should not be construed as being limited to the specific embodiments described and illustrated herein. Although specific terms are used in the following description, these terms are merely for purposes of illustration and are not intended to define or limit the scope of the invention. Like numbers refer to like elements throughout. As used in this specification and the claims, the singular forms "a," "an," and the" include plural referents unless the context clearly dictates otherwise.

[0026] The present invention is directed to a multicomponent fiber or filament comprising at least one temperature-regulating inner fiber component and an outer fiber component encapsulating the temperature-regulating inner fiber component. As used herein, "encapsulating" means the outer component surrounds the inner component in a radial direction when the fiber is viewed in cross-section. The inner component can be exposed at the end of a fiber (such as in the case of a staple fiber) without departing from the invention. Such encapsulation is further described below in relation to the various figures.

[0027] The multicomponent fibers according to the invention are useful for absorbing or releasing thermal energy to affect heat flow. Furthermore, such multicomponent fibers beneficially have improved containment of the phase change material within the overall fiber structure and even allow for higher loading of the phase change material within the fiber than has heretofore been possible. The multicomponent fibers are particularly beneficial for incorporation into various products, such as textiles, to provide a thermal regulating property. For example, multicomponent fibers according to the invention may be used in, clothing, protective suits, footwear, blankets, therapeutic pads, hot/cold packs, food
and drink containers, seat cushions, circuit board laminates, building insulation, wallpaper, curtain linings, pipe wraps, carpets, tiles, household appliance insulation, automotive lining material, sleeping bags, bedding, and a variety of further products. Such various uses are particularly encompassed by the multicomponent fiber of the invention as it is characterized by its incorporation of at least one phase change material in the temperature-regulating inner fiber component.

The temperature-regulating inner fiber component of the invention can be formed from a variety of component as beneficial to achieve the various uses described herein. In its most basic form, the temperature-regulating inner fiber component comprises at least one polyolefin and at least one phase change material. According to further embodiments of the invention, the temperature-regulating inner fiber component can comprise one or more further components, and such further components are described below.

A phase change material can generally comprise a compound, or mixture of compounds, that is capable of absorbing or releasing thermal energy to affect heat flow at or within a temperature stabilizing range. The temperature stabilizing range may comprise a particular transition temperature or range of transition temperatures. Preferentially, a phase change material useful according to the present invention will inhibit thermal energy flow while the phase change material is absorbing or releasing heat, which typically corresponds to a physical state transition of the phase change material (e.g., liquid and solid states, liquid and gaseous states, solid and gaseous states, or two solid states). Such thermal energy flow inhibition is typically transient, occurring until a latent heat of the phase change material is absorbed or released during a heating or cooling process. The phase change material can store or release thermal energy, and the phase change material generally can be effectively recharged via a source of heat or cold.

A wide variety of phase change materials for affecting thermal energy flow over various temperature ranges are available. Accordingly, the inventive multicomponent fiber can be customized for particular uses at different particular temperature ranges simply by selecting an appropriate phase change material for use in preparing the temperature-regulating inner fiber component of the inventive multicomponent fiber described herein.

Phase change materials particularly useful according to the invention include several organic and inorganic compounds. Non-limiting examples of phase change materials useful in preparing the temperature-regulating inner fiber component include the following: hydrocarbons (including straight chain alkanes or paraffinic hydrocarbons, branched-chain alkanes, unsaturated hydrocarbons, halogenated hydrocarbons, and alicyclic hydrocarbons); hydrated salts (including calcium chloride hydrate, calcium bromide hydrate, magnesium nitrate hydrate, lithium nitrate hydrate, potassium fluoride hydrate, ammonium nitrate, magnesium chloride hydrate, sodium carbonate hydrate, disodium phosphate dodecahydrate, sodium sulfate decahydrate, and sodium acetate trihydrate); waxes; oils; water; fatty acids; fatty acid esters; dibasic acids; dibasic esters; 1-halides; primary alcohols; aromatic compounds; clathrates; semi-clathrates, gas clathrates; anhydrides (such as steric anhydride); ethylene carbonate; polyhydric alcohols (including 2,2-dimethyl-1,3-propanediol, 2-hydroxymethyl-2-methyl-1,3-propanediol, ethylene glycol, pentaerythritol, dipentaerythritol, pentaglycerine, tetramethylethylene, neopentyl glycol, tetramethylene propane, 2-amino-2-methyl-1,3-propanediol, monoaminopentaerythritol, dianminopentaerythritol, and trihydroxymethyl acetic acyl); polymers (including polyethylene, polyethylene glycol, polyethylene oxide, polypropylene, polypropylene glycol, polytetramethylene glycol, polypropylene malonate, polypropylene glycol sebacate, polypenta- tanate glutarate, polyvinyl myristate, polyvinyl stearate, polyvinyl laurate, polyhexadecyl methacrylate, polyoctadecyl methacrylate, polyesters produced by polycrystallization of glycols (or their derivatives) with diacids (or their derivatives), and copolymers, such as polycaproate or poly(methacrylate with alkyl hydrocarbon side chain or with polyethylene glycol side chain and copolymers comprising polyethylene, polyethylene glycol, polyethylene oxide, polypropylene, polypropylene glycol, and polytetramethylene glycol); metals; and mixtures thereof.

A particular phase change material for use in the temperature-regulating inner fiber component of the invention can be selected based upon a desired transition temperature for the phase change material, which can depend upon a desired application for the inventive multicomponent fiber. For example, a phase change material having a transition temperature near room temperature may be desirable for applications in which the multicomponent fiber incorporating the phase change material is used in clothing designed to increase comfort for the wearer by regulating temperature close to room temperature.

In one embodiment of the invention, the temperature-regulating inner fiber component comprises a phase change material having a transition temperature in the range of about -20°C to about 100°C. According to further embodiments, the phase change material can have a transition temperature of about 0°C to about 75°C, about 10°C to about 50°C, or about 15°C to about 40°C. In one particular embodiment, the phase change material has a transition temperature substantially corresponding to an ambient temperature (e.g., about 20°C to about 25°C). In another embodiment, the phase change material has a transition temperature that substantially corresponds to a temperature that is in the range of about an ambient temperature and about an average human body temperature (e.g., about 20°C to about 40°C). In another particular embodiment, the phase change material has a transition temperature that substantially corresponds to an average human body temperature (e.g., about 35°C to about 40°C).

In one embodiment of the invention, the phase change material comprises one or more aliphatic hydrocarbons. Generally, aliphatic hydrocarbons are recognized as encompassing three subgroups of compounds: paraffins (alkanes), olefins (alkenes), and acetylenes (alkynes). The aliphatic hydrocarbons used in the invention may be straight chain or branched, and the phase change material can comprise a single aliphatic hydrocarbon (such as a single paraffin) or can comprise a mixture of aliphatic hydrocarbons (such as two or more paraffins of differing chain length). Still further, the phase change material can comprise a mixture of aliphatic hydrocarbons classified as being in different subgroups. For example, many paraffinic hydrocarbons are prepared by hydrogenation of an olefinic hydro-
carbon of the same chain to completely saturate the compound. Such reactions are often incomplete, and the resulting paraffinic hydrocarbon prepared by the hydrogenation reaction may contain unsaturated olefinic hydrocarbon starting material. Of course, mixtures of aliphatic hydrocarbons are not limited to such "unintentional" mixtures. Rather, the invention clearly encompasses phase change materials comprising paraffinic hydrocarbons, olefinic hydrocarbons, acetylenic hydrocarbons, and a variety of mixtures thereof. Further, the olefinic and acetylenic hydrocarbons useful in the invention can have one or more double or triple bonds, respectively, along the length of the hydrocarbon chain (i.e., can have varying levels of unsaturation).

[0035] In a preferred embodiment, the phase change material used in the temperature-regulating inner fiber component comprises at least one paraffinic hydrocarbon. As generally understood in the art, the melting temperature of paraffinic hydrocarbons roughly correlates to the number of carbon atoms in the compound, the melting temperature increasing as the number of carbon atoms increases. The melting temperatures of common paraffinic hydrocarbons are well known, such being exemplified in Table 1, which lists paraffinic hydrocarbons having between 13 and 28 carbon atoms and provides the known melting temperature for each compound. As seen from the table, use of a single, pure paraffinic hydrocarbon as the phase change material is beneficial as it provides a phase change material having a sharp, well-defined transition temperature. Paraffinic hydrocarbons can be particularly useful since combinations of paraffins of different chain length (and therefore, different melting temperatures) can be combined in specific mixtures to arrive at a different, customized melting temperature for the phase change material. Such customization can also be achieved through mixture of paraffins with other aliphatic hydrocarbons.

<table>
<thead>
<tr>
<th>Paraffinic Hydrocarbon</th>
<th>Carbon Atoms</th>
<th>Melting Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tridecane</td>
<td>13</td>
<td>-5.5</td>
</tr>
<tr>
<td>Tetradecane</td>
<td>14</td>
<td>5.9</td>
</tr>
<tr>
<td>Pentadecane</td>
<td>15</td>
<td>10.5</td>
</tr>
<tr>
<td>Hexadecane</td>
<td>16</td>
<td>18.2</td>
</tr>
<tr>
<td>Heptadecane</td>
<td>17</td>
<td>22.0</td>
</tr>
<tr>
<td>Octadecane</td>
<td>18</td>
<td>28.2</td>
</tr>
<tr>
<td>Nonadecane</td>
<td>19</td>
<td>32.1</td>
</tr>
<tr>
<td>icosane</td>
<td>20</td>
<td>36.8</td>
</tr>
<tr>
<td>Dodecane</td>
<td>21</td>
<td>40.5</td>
</tr>
<tr>
<td>Tridecane</td>
<td>22</td>
<td>44.4</td>
</tr>
<tr>
<td>Tetradecane</td>
<td>23</td>
<td>47.6</td>
</tr>
<tr>
<td>Pentadecane</td>
<td>24</td>
<td>50.9</td>
</tr>
<tr>
<td>Hexadecane</td>
<td>25</td>
<td>53.7</td>
</tr>
<tr>
<td>Heptadecane</td>
<td>26</td>
<td>56.4</td>
</tr>
<tr>
<td>Octadecane</td>
<td>27</td>
<td>59.0</td>
</tr>
<tr>
<td>Nonadecane</td>
<td>28</td>
<td>61.4</td>
</tr>
</tbody>
</table>

[0036] While C_{13}-C_{28} paraffinic hydrocarbons are exemplified above, the phase change material of the invention is not so limited. Rather, as previously noted, the phase change material may comprise one or more aliphatic hydrocarbons of varying chain length. For example, in one embodiment, the phase change material comprises at least one aliphatic hydrocarbon having from about 8 carbon atoms to about 50 carbon atoms. In another embodiment, the phase change material comprises at least one aliphatic hydrocarbon having from about 10 carbon atoms to about 40 carbon atoms. In still another embodiment, the phase change material comprises at least one aliphatic hydrocarbon having from about 12 carbon atoms to about 30 carbon atoms.

[0037] The aliphatic hydrocarbons useful in the phase change material of the invention can be unsubstituted or can comprise one or more substituents. For example, the aliphatic hydrocarbons may comprise one or more halogen atoms. Chlorinated paraffins and fluorinated paraffins are particularly useful in the phase change material of the invention.

[0038] In one particular embodiment of the invention, the temperature-regulating inner fiber component comprises a phase change material that includes at least one compound selected from the group consisting of pentadecane, hexadecane, heptadecane, octadecane, nonadecane, and eicosane. In one preferred embodiment, the phase change material comprises octadecane.

[0039] Another consideration in selection of aliphatic hydrocarbons for use in the present invention is the difference between the melting and freezing points for the particular compound. For example, paraffinic hydrocarbons are self-nucleating and thus melt and freeze congruently. Accordingly, when heated or cooled at rates of 2°C/min. or less, the melting and freezing temperatures substantially coincide.

[0040] As noted above in relation to aliphatic hydrocarbons, a phase change material used in the invention can comprise a mixture of two or more substances. Combinations of two or more compounds, such as those exemplified above, are useful for providing a phase change material having a temperature stabilizing range adjustable over a wide range as desired for particular application of the inventive multicomponent fiber. For example, a mixture of two or more different phase change compounds may exhibit two or more distinct transition temperatures or a single modified transition temperature.

[0041] While aliphatic hydrocarbons, particularly paraffinic hydrocarbons, are preferred for use as the phase change material, the invention is not limited to such compounds alone. In certain embodiments, cyclic hydrocarbons may also be useful according to the invention. For example, the phase change material may comprise alicyclic compounds (including cyclopentanes, cycloolefins, and cyclosiacylenes), as well as aromatic compounds.

[0042] Other phase change materials that may be useful according to the invention include polymeric phase change materials, particularly polymeric phase change materials having transition temperatures in the range of about 20°C to about 40°C, which are particularly useful for clothing applications. A polymeric phase change material may comprise a polymer (or mixture of polymers) having a variety of chain structures that include one or more types of monomer units. In particular, polymeric phase change materials may include linear polymers, branched polymers (e.g., star branched polymers, comb branched polymers, or dendritic branched polymers), or mixtures thereof. A polymeric phase change material may comprise a homopolymer, a copolymer, a terpolymer, a statistical copolymer, a random copolymer, an alternating copolymer, a periodic copolymer, a block copolymer, a graft copolymer, or a mixture...
thereof. Such polymers may be altered by addition of a functional group such as, for example, amine, amide, carboxyl, hydroxyl, ester, ether, epoxide, anhydride, isocyanate, silane, siloxane, fluorine, ketone, or aldehyde. Further, a polymer comprising a polymeric phase change material may be capable of crosslinking, entanglement, or hydrogen bonding in order to increase its toughness or its resistance to heat, moisture, or chemicals.

As previously noted, problems such as oozing have plagued previously known materials incorporating phase change materials, and special efforts to overcome these problems, such as containment of the phase change material in microcapsules, have been made. The multicomponent fiber of the present invention, however, is particularly beneficial in that difficult measures, such as formation and incorporation of microcapsules, are unnecessary. In fact, as further described below, the multicomponent fiber of the present invention, in particular embodiments, is characterized in that the phase change material is not separated from the other fiber components through microencapsulation.

In one embodiment of the invention, the temperature-regulating inner fiber component of the invention comprises up to about 70% by weight of a phase change material (such as described above), based on the overall weight of the inner fiber component. According to further embodiments of the invention, the inner fiber component comprises up to about 60% by weight of a phase change material, up to about 50% by weight of a phase change material, up to about 40% by weight of a phase change material, up to about 35% by weight of a phase change material, or up to about 30% by weight of a phase change material. In one preferred embodiment, the inner fiber component comprises from about 5% by weight to about 50% by weight of a phase change material, preferably about 10% by weight to about 50% by weight, more preferably about 20% by weight to about 50% by weight. In another embodiment, the inner fiber component comprises from about 25% by weight to about 45% by weight of a phase change material.

The temperature-regulating fiber component of the invention further comprises a polyolefin. Various polyolefins can be used according to the invention, and the use of such is limited only in that the polyolefin and the phase change material should be compatible (i.e., capable of being prepared as molten mixture of the two components).

The polyolefins used according to the invention can be substantially pure or can be mixtures of two or more different polyolefins. Preferentially, the polyolefins used in the inner fiber component are selected from the group of polyolefins having a Melt Flow Index within a certain range.

Melt Flow Index (MFI) is generally defined as the output rate (flow) in grams that occurs in 10 minutes through a standard die of 2.0955±0.0051 mm diameter and 8.000±0.025 mm in length when a fixed pressure is applied to the melt via a piston and a load of total mass of 2.16 kg at a temperature of 190° C. While this is the typical testing quoted in relation to MFI, it is understood that some polymers are measured at a higher temperature, using a different weight, and using a different orifice. As used herein, MFI is understood to refer to a physical property measured according to the above parameters.

MFI is an assessment of average molecular mass and is an inverse measure of the melt viscosity. In other words, the higher the MFI, the more polymer flows under test conditions. Knowing the MFI of a polymer is vital to anticipating and controlling its processing. Generally, higher MFI polymers are used in injection molding, and lower MFI polymers are used with blow molding or extrusion processes. Among various polymers, MFI may be affected by molecular weight distribution, the presence of co-monomers, the degree of chain branching, crystallinity, and heat transfer in polymer processing.

In one embodiment, the polyolefin used in the temperature-regulating inner fiber component of the invention is selected from the group of polyolefins, or mixtures thereof, having a Melt Flow Index of about 3 to about 1200. Preferentially, the polyolefins have a Melt Flow Index of about 5 to about 500, more preferably about 7 to about 200, still more preferably about 10 to about 100, and most preferably about 12 to about 50.

Non-limiting examples of polyolefins useful in the temperature-regulating inner fiber component include polyethylene, propylene, polybutylene, polybutene, polyoctene, polymethylpentene, and the like. In one particular embodiment, the temperature-regulating inner fiber component comprises polypropylene.

The temperature-regulating inner fiber component generally comprises at least about 25% by weight of a polyolefin. Preferably, the inner fiber component comprises at least about 30% by weight of a polyolefin, more preferably at least about 35% by weight, still more preferably at least about 40% by weight, and most preferably at least about 45% by weight of a polyolefin. In particular embodiments, the inner fiber component comprises from about 20% by weight to about 60% by weight of a polyolefin, about 25% by weight to about 55% by weight, or about 30% by weight to about 50% by weight.

The temperature-regulating inner fiber component of the multicomponent fiber of the invention can generally comprise, in addition to the polyolefin and the phase change material, one or more further components. Particularly, in one embodiment, the inner fiber component further comprises a micro-porous material.

The micro-porous material is generally useful as a stabilizing component for the lower-melting phase change material. Specifically, while not wishing to be bound by theory, it is believed that the micro-porous material ties up the phase change material in a stable gel, and is particularly useful for minimizing or eliminating oozing of the phase change material, as described previously. Accordingly, in one embodiment, the amount of micro-porous material included in the temperature-regulating inner fiber component is related to the amount of the phase change material.

Any material recognizable by one of skill in the art as being generally particulate and having a micro-porous structure could be used as the micro-porous material in the temperature-regulating inner fiber component of the invention. Particularly useful according to the invention are silica-containing materials. Non-limiting examples of micro-porous silica-containing materials useful in the temperature-regulating inner fiber component include fumed silica, aluminosilicates (e.g., clays, zeolites, and pumice), talc (magnesium silicate hydroxide), and crystalline micro-porous silicas. Other micro-porous materials not including silica, such as carbonates, could also be used in the invention.
While any silica-containing material is envisioned as being generally useful according to the invention, in one embodiment, hydrophobic silicas are used. Particularly preferred are hydrophobic fumed silicas. For example, CAB-O-SIL® TS-530, available from Cabot Corporation, can be used. Hydrophilic silicas can also be used according to the invention. For example, ORISIL 200, available from Orisil, can be used and has a surface area of 200 m²/g. Other silicas having similar properties would also be particularly useful in the invention. Furthermore, combinations of silicas, such as combinations of hydrophilic and hydrophobic silicas could also be used. Still further, different silicas could be used in different portions of the methods of the invention.

In one embodiment, the temperature-regulating inner fiber component comprises about 1% by weight to about 15% by weight of the silica-containing material, based upon the overall weight of the inner fiber component. According to further embodiments, the inner fiber component comprises about 2% by weight to about 12% by weight of the inner fiber component, about 3% by weight to about 10% by weight, or about 4% by weight to about 8% by weight of the inner fiber component. While the above concentrations are provided specifically in relation to a silica-containing component, similar concentrations would be expected in relation to other micro-porous materials used in the invention.

According to another embodiment of the invention, the temperature-regulating inner fiber component of the invention can further comprise one or more medium-melting polymers. As used herein, “medium-melting polymers” refers to polymeric materials having a melting temperature between the melting temperature of the phase change material and the melting temperature of the polyolefin used in the temperature-regulating inner fiber component of the invention. Preferably, an ethylene material is used as the medium-melting polymer. In one particular embodiment, the ethylene material comprises an ethylene copolymer. Again, while not wishing to be bound by theory, it is believed that such medium melting polymers serve as a compatibilizing bridge between the lower molecular weight phase change material and the higher molecular weight, higher melting polyolefin. In one specific embodiment, the temperature-regulating inner fiber component comprises an ethylene material, preferably an ethylene-vinyl acetate (EVA) copolymer. EVA copolymers used in the invention can contain about 10% by weight to about 20% by weight of vinyl acetate, more preferably about 15% by weight to about 17% by weight vinyl acetate. Further, non-limiting examples of ethylenes useful in the invention include ethylene/methyl acrylate (EMA) and ethylene/ethyl acrylate (EEA).

In one embodiment, the temperature-regulating inner fiber component comprises about 4% by weight to about 20% by weight of an ethylene material, based upon the overall weight of the inner fiber component. In further embodiments, the ethylene material comprises about 6% by weight to about 18% by weight of the inner fiber component, about 8% by weight to about 16% by weight, or about 10% by weight to about 14% by weight of the inner fiber component. While the above concentrations are provided specifically in relation to an ethylene material, similar concentrations would be expected in relation to other medium melting polymers used in the invention.

As previously noted, the present invention, in one aspect, comprises a multicomponent fiber comprising at least one temperature-regulating inner fiber component and an outer fiber component encapsulating the temperature-regulating inner fiber component. Particular attention is drawn to the formation of the multicomponent fiber, in that the inner fiber component (which includes the phase change material) is encapsulated by the outer fiber component. This formation is particularly beneficial in that it greatly reduces, and preferably eliminates, the problems associated with known fibers including phase change materials, that being oozing of the phase change material. Such is not a problem in the present invention, however, particularly in light of the inventive temperature-regulating fiber component incorporating a phase change material and the presence of the outer fiber component encapsulating the temperature-regulating inner fiber component comprising the phase change material. Furthermore, as previously noted, the phase change material according to certain embodiments of the present invention is specifically not encapsulated by a component layer separate from the outer fiber component. In other words, there is no need to use microencapsulation of the phase change material.

A great variety of conformations for the multicomponent fiber of the invention are envisioned wherein a temperature-regulating inner fiber component is encapsulated by an outer fiber component, and some of the preferred embodiments are described below with reference to the various Figures. Of course, the skilled artisan, with the benefit of the present disclosure, may envision further conformations that are in accordance with the present invention, and such further conformations are fully encompassed herein.

In one particular embodiment of the invention, the multicomponent fiber is in the form of a sheath/core fiber. FIG. 1 generally illustrates such an embodiment by showing a cross-section of a sheath/core fiber 5 having a core 10 encapsulated by a sheath 15. Preferably, the core 10 extends through substantially the length of the fiber 5 and comprises a temperature-regulating inner fiber component according to the invention.

The invention encompasses multiple different embodiments of a sheath/core fiber. As shown in FIG. 1, the core 10 is concentrically positioned within, and encapsulated by, the sheath 15, and the core 10 comprises approximately 75% by weight of the fiber 5. Of course, the core can comprise a greater or lesser amount of the overall fiber weight. Further, while the core is shown substantially centered within the sheath, such is not required.

A sheath/core fiber, according to the invention, can also take on a variety of cross-sectional geometries. For example, the sheath/core fiber could have a cross-section that is a circle, oval, triangle, rectangle, octagon, pentagon, trapezoid, or the like. Furthermore, in cross-section, the sheath could have one geometry while the core has a different geometry. In further embodiments, the sheath/core fiber could also be multi-lobal.

Non-limiting examples of various sheath/core fiber embodiments encompassed by the invention are provided in FIG. 2 through FIG. 6. FIG. 2 illustrates a sheath/core fiber 5 wherein the core 10 is concentric to the sheath 15 encapsulating the core 10, but wherein the core 10 comprises...
a smaller percentage of the overall fiber as compared to the 
fiber illustrated in FIG. 1. FIG. 3 illustrates a sheath/core 
fiber 5, wherein the core 10 is off-center within the sheath 
15. FIG. 4 illustrates a sheath/core fiber 5, wherein the core 
10 has a triangular geometry while the sheath 15 encapsu-
lating the core 10 has a circular geometry. FIG. 5 illustrates 
a sheath/core fiber 5, wherein the core 10 has a rectangular 
geometry while the sheath 15 encapsulating the core 10 has 
a circular geometry. FIG. 6 illustrates a sheath/core fiber 5, 
wherein the core 10 and the sheath 15 encapsulating the core 
10 both have a rectangular geometry.

[0065] In another particular embodiment of the invention, 
the multicomponent fiber is in the form of an islands-in-the- 
sea fiber. According to such an embodiment, a plurality 
of island members is positioned within and extending through 
substantially the length of the fiber, wherein each of the 
island members is separated from one another. The island 
members comprise a temperature-regulating inner fiber 
component according to the invention and are each encap-
sulated by an outer fiber component according to the 
 invention. The island members, being formed of a temperature-
regulating fiber component of the invention, include a phase 
change material, as described herein.

[0066] FIG. 7, illustrates a multicomponent fiber of the 
invention according to an islands-in-the-sea embodiment. 
The cross-sectional view shows a plurality of islands (10, 11, 
12, 13, and 14) encapsulated by an outer fiber component 15. 
The islands can each comprise the same temperature-regu-
lating inner core fiber or can comprise different temperature-
regulating inner core fibers.

[0067] Regardless of the various embodiments which the 
multicomponent fiber can take on (i.e., sheath/core, islands-
in-the-sea, etc.), the multicomponent fiber still comprises a 
temperature-regulating inner fiber component encapsulated 
by an outer fiber component. Preferably, the multicomponent 
fiber is formed such that the ratio of the inner fiber 
component to the outer fiber component (based on an overall 
weight percentage of the multicomponent fiber) is greater 
than about 50:50. In one embodiment, the ratio of inner fiber 
component to outer fiber component is greater than about 
55:45. In further embodiments, the ratio of the inner fiber 
component to the outer fiber component is greater than about 
60:40, greater than about 65:35, or greater than about 70:30.

[0068] The overall composition of the multicomponent 
fiber can vary depending upon the application of the fiber. 
For example, in applications wherein properties particularly 
exhibited by the outer fiber component are valued (such as 
tensile strength or bending ability), it may be beneficial for 
the outer fiber component to comprise up to about 50% by 
weight of the overall weight of the multicomponent fiber. 
As noted above, however, particular benefit of the multicomponent 
fiber of the invention arises from the thermal prop-
erties derived from the temperature-regulating inner fiber 
component. Accordingly, it is generally beneficial to maxi-
mize the weight content of the temperature-regulating inner 
fiber component.

[0069] The temperature-regulating inner fiber component, 
in particular embodiments, comprises between about 50% by 
weight and about 95% by weight of the multicomponent 
fiber. In further embodiments, the temperature-regulating 
inner fiber component comprises about 55% by weight to 
about 95% by weight of the multicomponent fiber, about 
55% by weight to about 90% by weight, about 60% by 
weight to about 90% by weight, and about 65% by weight 
to about 85% by weight of the multicomponent fiber.

[0070] As would be recognized by one of skill in the art, 
the thermal properties of the multicomponent fiber of the 
invention can vary depending upon the overall concentra-
tion of the phase change material incorporated into the multi-
component fiber. The present invention is particularly char-
acterized by its ability to incorporate an overall greater 
centration of a phase change material than heretofore 
known. For example, in known fibers incorporating a phase 
change material, the concentration of the phase change 
material in the fiber is generally in the range of less than 
about 10% by weight, based on the overall weight of the 
fiber. According to the present invention, it is possible to 
prepare a multicomponent fiber comprising only relatively 
small amounts of phase change material (e.g., 0.1% by 
weight to about 15% by weight, based on the overall weight of 
the multicomponent fiber). The invention is particularly 
useful, however, in that it enables preparation of a multi-
component fiber comprising a much greater concentration of 
phase change material.

[0071] In one embodiment of the invention, the multicom-
ponent fiber comprises a phase change material in a con-
centration of at least about 15% by weight, based on the 
overall weight of the multicomponent fiber. Preferably, 
the phase change material comprises at least about 20% by 
weight of the overall multicomponent fiber. In further 
embodiments, the phase change material comprises at least 
about 25% by weight, at least about 30% by weight, or at 
least about 35% by weight of the overall multicomponent 
fiber of the invention. In one particular embodiment, the 
multicomponent fiber of the invention comprises about 10% 
by weight to about 55% by weight of the phase change 
material, based on the overall weight of the multicomponent 
fiber. According to further embodiments, the phase change 
material comprises about 15% by weight to about 50% by 
weight of the multicomponent fiber, about 20% by weight 
to about 50% by weight, and about 20% by weight to about 
40% by weight of the multicomponent fiber.

[0072] The outer fiber component used in the multicom-
ponent fiber of the invention can comprise any polymeric 
material (or mixture thereof) that is capable of being formed 
into an elongated fiber. The polymeric material used in 
forming the outer fiber component can vary depending upon 
the process used in preparing the multicomponent fiber. For 
example, when a melt spinning process is used to form the 
multicomponent fiber, the polymeric material is beneficially 
a melt-processable thermoplastic polymer, or mixture of 
polymers. According to other embodiments of the invention, 
the polymeric material can include an elastomeric polymer, 
or mixture of polymers. The polymeric material used in 
forming the outer fiber component according to the inven-
tion can also vary depending upon the desired end-use of the 
multicomponent fiber, and the multicomponent fiber of the 
invention can therefore be customized to fit a variety of 
end-uses.

[0073] The polymeric material used in preparing the outer 
fiber component of the invention can comprise a polymer (or 
mixture of polymers) having a variety of chain structures 
that include one or more types of monomer units. In par-
cular, a polymeric material may comprise a linear polymer,
a branched polymer (such as a star branched polymer, a comb branched polymer, or a dendritic branched polymer), or a mixture thereof. A polymeric material may also comprise a homopolymer, copolymer, terpolymer, statistical copolymer, random copolymer, alternating copolymer, periodic copolymer, block copolymer, radial copolymer, or graft copolymer, or a mixture thereof.

[0074] In certain embodiments, a polymeric material useful as an outer fiber component according to the invention can be determined based upon the extrusion temperature of the polymeric material. In one particular embodiment, the outer fiber component comprises a polymeric material having an extrusion temperature of about 80°C to about 340°C. In other embodiments, the outer fiber component comprises a polymeric material having an extrusion temperature of about 120°C to about 320°C, about 140°C to about 300°C, or about 160°C to about 290°C. By way of non-limiting example, various classes of polymers that may be used to form an outer fiber component according to the invention can include the following: polyamides, polyanines, polyimides, polyacrylates, polycarbonate, polydienes, polyepoxides, polyesters, polyethers, polyfluorocarbons, polyolefins, polyphenylenes, silicon-containing polymers, polystyrenes, polyvinyls, polyacetals, polyarylates, and combinations thereof, and mixtures thereof. Non-limiting examples of specific polymeric materials useful as the outer fiber component according to the present invention include the following: Nylon 6, Nylon 6/6, Nylon 12, polysaccharide, polyesters, polyacrylamide, polyacrylonitrile, esters of methacrylic acid and acrylamide, polystyrene, polyethylene, polypropylene, polybutadiene, polyisobutene, polynorbornene, polyethylene terephthalate, polybutylene terephthalate, polyvinyl chloride, polyethylene oxide, polystyrene, polyethylene oxide, polyvinylidene fluoride, polyethylene terephthalate, and polytetrafluoroethylene.

[0075] The specific polymer (or mixture of polymers) used in the outer fiber component of the inventive multicomponent fiber can vary depending upon the desired chemical and physical properties desired for the multicomponent fiber. For example, in certain embodiments, it may be desirable to choose a polymer providing specific tensile or bending properties. In other embodiments, it may be desirable to choose a polymer providing resistance to chemical degradation. In yet further embodiments, it may be desirable to choose a polymer exhibiting stability at relatively high temperatures. Other factors, such as dyeability, can also impact the choice of polymer used in the outer fiber component. The present invention, therefore, is particularly useful in that all of the above considerations can be taken into account, and a specific polymer (or mixture of polymers) can be used in the outer fiber component to meet a large array of needs.

[0076] In one particular embodiment, the invention provides a multicomponent fiber in the form of a sheath/core fiber. According to this embodiment, the sheath can comprise about 15% by weight to about 40% by weight, based on the overall weight of the fiber. The sheath can particularly comprise a polymer selected from the group consisting of polyethylene teraphthalate, polyacrylate, polypropylene, polyethylene oxide, polystyrene, polyethylene sulfide, and polyethylene terephthalate. The core in such an embodiment comprises a temperature regulating inner fiber component, and particularly comprises one or more phase change materials as described herein.

[0077] According to another aspect, the invention is directed to a method of making a temperature-regulating fiber component that includes a phase change material and is useful for incorporation into a multicomponent fiber. While other temperature-regulating fibers have previously been made, such previously known fibers are limited in their ability to be used on a large-scale manufacturing basis because such previously known temperature-regulating materials are difficult to extrude into a fiber.

[0078] Previously known temperature-regulating materials have been prepared in a single batch mix process wherein all components of the temperature-regulating material are combined, melted, mixed, and cooled. As stated above, the resulting material has been found to be difficult to extrude for use in large-scale manufacturing. According to the present invention, however, such problems are solved. The present invention provides a method for preparing a temperature-regulating fiber component that comprises two steps and that provides a temperature-regulating fiber component that is easily extruded in large-scale manufacturing processes to prepare fibers therewith.

[0079] In one embodiment according to this aspect of the invention, the two-step method comprises preparing a particular precursor material that is highly loaded with a phase change material, and then mixing the particular precursor with a polyolefin to make the final temperature-regulating fiber component. This allows for preparation of a temperature-regulating fiber component having improved properties. By use of the phrase "highly loaded", it is intended to mean that the precursor material comprises a phase change material in an amount of greater than about 50% by weight, based on the total weight of the precursor material. Preferably, the precursor material comprises greater than about 55% by weight of a phase change material, more preferably greater than about 60% by weight, and most preferably greater than about 65% by weight of a phase change material.

[0080] In one embodiment, the temperature-regulating fiber component prepared according the method of the invention comprises a phase change material, a polyolefin, a silica-containing component, and an ethylene material. Accordingly, in the first step of the method of preparing the temperature-regulating component, the precursor material is prepared by mixing at least the phase change material and
the polyolefin in molten form, cooling the resulting mixture into a solidified mixture, and processing the solidified mixture to be in a particulate form. As previously noted, this precursor material is highly loaded with the phase change material and can then be used in the second process step to prepare the final temperature-regulating fiber component.

[0081] One or both of the silica-containing component and the ethylenic material can be included in the temperature-regulating fiber component during the first or second step of the method of the invention. In one embodiment, the silica-containing component and the ethylenic material are both added in the first step noted above. In another embodiment, one or both of the silica-containing component and the ethylenic material are added in the first step and an additional amount of one or both of the silica-containing component and the ethylenic material is also added in the second step.

[0082] In the second step of the process for preparing a temperature-regulating fiber component, the particulate precursor material is mixed with an additional amount of a polyolefin that is also in particulate form. Accordingly, the final temperature-regulating fiber component comprises the materials used in the first step and any materials used in the second step. For example, the polyolefin used in the second step can be the same polyolefin as used in the first step or can be a different polyolefin. Further, additional components can be added in the second step as desirable for imparting useful properties to the final temperature-regulating fiber component. For example, in one embodiment, an additional amount of a silica-containing component can also be added in the second process step, as previously noted. As with the polyolefin, the silica-containing component used in the second step can be the same silica-containing component used in the first process step or can be a different silica-containing component.

[0083] Regardless of the further components used in the second step, the final temperature-regulating fiber component will comprise a phase change material in a concentration that is less than the concentration of the phase change material in the precursor material. In one preferred embodiment, the final temperature-regulating fiber component comprises at least about 25% by weight of a polyolefin and up to 50% by weight of a phase change material, based on the overall weight of the temperature-regulating fiber component.

[0084] The second step in the above process further comprises processing the temperature-regulating fiber component to be in a form for direct use in an extrusion process for preparing a multicomponent fiber according to the present invention. In one embodiment, such further processing comprises extruding and pelletizing the temperature-regulating fiber component. Of course, other, similar processing steps that could be envisioned by one of skill in the art are also encompassed by the present invention.

[0085] The temperature-regulating fiber component of the invention is particularly useful as an inner component of a multicomponent fiber, as disclosed herein. Accordingly, in another aspect of the invention, there is provided a method for preparing a multicomponent fiber.

[0086] A multicomponent fiber according to the invention can be prepared using any of the fiber formation techniques as known in the art. An exemplary method for producing the fibers of the invention is illustrated in FIG. 8, which illustrates a melt spinning line 20 for producing bicomponent fibers, and which includes a pair of extruders 22 and 24. As will be appreciated by the skilled artisan, additional extruders may be added to increase the number of components (for example, wherein a plurality of temperature-regulating inner fiber components are encapsulated by an outer fiber component in a sheath/core embodiment). Extruders 22 and 24 separately extrude a temperature-regulating inner fiber component and an outer fiber component. The temperature-regulating inner fiber component is fed into extruder 22 from a hopper 26 and the outer fiber component is fed into extruder 24 from a separate hopper 28. The temperature-regulating inner fiber component and the outer fiber component are fed from extruders 22 and 24 through respective conduits 30 and 32 by a melt pump (not shown) to a spinneret 34.

[0087] The temperature-regulating inner fiber component and the outer fiber component are preferably matched to allow spinning of the components through a common capillary at substantially the same temperature without degrading one of the components. The invention, however, should not be viewed as limited to combinations of inner fiber components and outer fiber components with substantially similar extrusion temperatures. Rather, the inner fiber component may have a relatively low extrusion temperature, and the outer fiber component may have a relatively high extrusion temperature. Temperature disparity is only limited in that the extrusion temperature of the outer fiber component should be sufficiently low so as to not cause thermal degradation of the inner fiber component.

[0088] In one advantageous embodiment, polypropylene or polyethylene is used as the outer fiber component. In another useful embodiment, polyamide is used as the outer fiber component. In yet another embodiment, polyurethane is used as the outer fiber component. Some thermoplastic polyurethanes can be extruded at a temperature ranging from about 160° C. to about 220° C. Nylon, a particularly useful polyamide according to the invention, is typically extruded at a temperature ranging from about 250° C. to about 280° C. Polyethylene and polypropylene are typically extruded at a temperature ranging from about 200° C. to about 230° C.

[0089] Extrusion processes and equipment, including spinnerets, for making multicomponent continuous filament fibers are well known and need not be described here in detail. Generally, a spinneret includes a housing containing a spin pack which includes a plurality of plates stacked one on top of the other with a pattern of openings arranged to create flow paths for directing fiber-forming components separately through the spinneret. The spinneret has openings or holes arranged in one or more rows. The polymers are combined in a spinneret hole. The spinneret is configured so that the extrudant has the desired overall fiber cross section (e.g., round, trilobal, etc.). The spinneret openings form a downwardly extending curtain of filaments. Such a process and apparatus is described, for example, in U.S. Pat. No. 5,162,074, to Hills, which is incorporated herein by reference.

[0090] Following extrusion through the die, the resulting thin fluid strands, or filaments, remain molten for some distance before they are solidified by cooling in a surround-
ing fluid medium, which may be chilled air blown through the strands (not shown). Once solidified, the filaments are taken up on a godet or other take-up surfac. For example, in a continuous filament process as illustrated in FIG. 8, the strands are taken up on godet rolls 36 that draw down the thin fluid streams in proportion to the speed of the take-up godet.

[0091] In light of the above general description, according to one specific embodiment, the present invention provides a method for preparing a multicomponent fiber comprising: providing at least one temperature-regulating inner fiber component; providing an outer fiber component; introducing the fiber components to a fiber extrusion apparatus including a spinneret; and extruding the fiber components so as to form a multicomponent fiber wherein the outer fiber component is encapsulating the temperature-regulating inner fiber component. The above-described method is particularly beneficial in that the temperature-regulating inner fiber component is encapsulated by the outer fiber component. This is a distinct advantage over known methods for preparing fibers incorporating phase change materials, which generally allow for release of at least a portion of the phase change material to the surface of the extruded fiber.

[0092] As noted above, the presence of phase change material at the surface of the fiber gives a disagreeable, greasy feel to the fiber, provides the potential for staining adjacent fabrics and other surfaces, and can result in the loss of at least part of the phase change material. Beyond this, however, the extrusion process actually can become hazardous by allowing the phase change material to be exposed to ambient conditions. As described herein, the extrusion process is generally performed at temperatures well in excess of ambient temperature. Since many phase change materials, such as aliphatic hydrocarbons, can have relatively low flash points, a fire hazard can result if a phase change material at an extrusion temperature is immediately exposed to oxygen (as noted above, extruded fibers leaving the spinneret can be immediately exposed to ambient conditions). According to the present invention, however, this hazard is eliminated.

[0093] In one particularly preferred embodiment according to this aspect of the invention, the outer fiber component is introduced to the spinneret prior to introducing the temperature-regulating inner fiber component to the spinneret. Accordingly, the free end of the extruded fiber leaving the spinneret and being exposed to ambient conditions comprises the outer fiber component, and the temperature-regulating inner fiber component, being encapsulated by the outer fiber component, is prevented from contacting an ambient atmosphere.

[0094] The use of the outer fiber component, according to the invention, is further particularly beneficial in that fibers made entirely from a blended phase change material exhibit several known limitations. However, multicomponent fibers prepared according to the present invention, wherein temperature-regulating inner fiber component is encapsulated by an outer fiber component, exhibit improved properties, such as improved dyeability.

[0095] Continuous filament fiber prepared according to the invention may further be processed into staple fiber. In processing staple fibers, large numbers, e.g., 10,000 to 1,000,000 strands, of continuous filament are gathered together following extrusion to form a tow for use in further processing, as is known in that art.

[0096] In relation to preparation of staple fibers, the present invention is further advantageous over other known methods. Again, as noted above, it is disadvantageous for the phase change material used in the multicomponent fibers to be exposed at a surface of the fiber as staining, loss of material, and other undesirable effects are known to occur. Processing continuous filament fiber prepared according to the invention into staple fibers includes cutting of the fibers, therefore providing a cross-section at either end of the staple fibers wherein the temperature-regulating inner fiber component may be exposed to the environment. The present invention, however, provides a solution to this problem. According to one embodiment of the invention, when the multicomponent fiber is formed into staple fibers having free ends, the staple fibers are further processed to seal the free ends thereof. For example, the cutting apparatus used in preparing the staple fibers can incorporate a heated component that melts the ends of the fibers as they are cut. This deforms the outer fiber components at the ends of the staple fibers, allowing the outer fiber component to “flow” around the cut ends, thereby sealing the cut ends. In another embodiment, the free ends of the staple fibers are sealed after the staple fibers are incorporated into a fabric or web capable of undergoing further processing. For example, the staple fibers can be formed into a fabric or web, and the fabric or web can then be immersed in a bath comprising a film-forming material that coats the staple fibers (including the free ends of the fibers), thereby sealing the free ends of the staple fibers upon solidification of the film-forming material (such as by drying, cooling, curing, coagulation, or the like). To reduce loss of phase change material from the staple fiber free ends in the interim between cutting and sealing, the fabric-forming or web-forming steps can advantageously be performed at temperatures below the transition temperature of the phase change material.

[0097] A continuous multicomponent fiber, rather than being taken up on a godet, may also be meltspun as a direct laid nonwoven web. In a spunbond process, for example, the strands are collected in an air attenuator following extrusion through the die and then directed onto a take-up surface, such as a roller or a moving belt, to form a spunbond web. As an alternative, direct laid composite fiber webs may be prepared by a meltblown process, in which air is ejected at the surface of a spinneret to simultaneously draw down and cool the thin fluid polymer streams which are subsequently deposited on a take-up surface in the path of cooling air to form a fiber web. Meltblown webs made of short fibers may benefit from a subsequent wet treatment to seal the free ends of the fibers, such as described above.

[0098] As noted above, the multicomponent fibers of the present invention can be used in their filament form, or they could be chopped into staple fibers, spunbond, or meltblown to form fabrics, or the like. Accordingly, in another aspect, the present invention provides a fabric at least partially comprising a multicomponent fiber as described herein. Fabrics encompassed by the present invention include, without limitation, nonwoven fabrics, woven fabrics, and knit fabrics. Fibers that are not cut (filament yarns) may be formed into fabrics by knitting or weaving, optionally in combination with other yarns. Staple fibers may be spun, optionally in combination with other staple fibers, into spun yarns. These yarns can be formed into fabrics by knitting or weaving. Staple fibers, optionally in combination with other staple fibers, also may be formed into nonwoven
fabrics by wet-laid processes, such as paper-forming, by air-laid processes, or by carding to form a card web that can be subsequently strengthened by thermal bonding, chemical bonding, needlepunching, stitchbonding or hydroentangling.

[0099] The multicomponent fiber of the invention can be incorporated into various fabrics, as described above, in varying amounts, depending upon the end-use of the fabric and the desired thermal properties thereof. In certain embodiments, fabrics according to the invention can comprise from about 5% by weight to 100% by weight of the multicomponent fiber disclosed therein. In further embodiments, the inventive fabric can comprise about 20% by weight to 100% by weight of the multicomponent fiber, about 30% by weight to 100% by weight, or about 50% by weight to 100% by weight.

[0100] In yet further aspects, the present invention provides a composite material comprising a multicomponent fiber as described herein. Composite materials are generally understood to be a single material made by the combination of two or more materials, each exhibiting different properties, wherein the composite material formed by the combination of the two or more materials exhibits the different properties of the materials used in the formation of the composite material. The individual materials used in preparing the composite material do not necessarily blend together. Beneficially, the thermal properties provided by the multicomponent fiber of the present invention can be combined with a variety of other materials having different desirable properties to prepare a composite material.

[0101] One example of a composite material possible according to the present invention comprises multicomponent fibers as described herein applied to a substrate by an encapsulating material that is solidified on the substrate and encapsulates the multicomponent fibers. In one specific embodiment a resilient substrate, such as a synthetic, leather-like material, can be used as the substrate. Of course, other substrate materials could also be used. Multicomponent fibers according to the invention could then be combined with a resinous material (or other material having similar properties), such as a polyurethane, and applied to the substrate. The multicomponent fibers could be applied to the substrate prior to addition of the resinous material, or they could be combined prior to application to the substrate. The resinous material could then be solidified to encapsulate the multicomponent fibers. Alternatively, the resinous material could be applied as a matrix or a matrix phase comprising discrete particles encapsulating the multicomponent fibers. Such a composite material could particularly find application in the clothing industry.

[0102] The composite material according to the embodiment described above can exist in multiple variants according to the scope of the present invention. In particular, a number of different materials could be used as the substrate material. For example, the substrate can comprise any textile material capable of accommodating the resinous material applied thereto at least partially encapsulate the multicomponent fiber.

[0103] Composite materials according to the present invention may also find particular use in structural applications. Accordingly, the invention provides structural materials that provide not only structural properties but also thermal regulation properties. For example, in one embodiment, a multicomponent fiber according to the invention can be encapsulated in a resinous material, particularly a thermoset resin, such as an epoxy resin or the like, to form the structural composite. Such a structural composite could be shaped or molded to desired dimensions. In particular embodiments, the multicomponent fiber used in such a structural composite could particularly comprise an outer fiber component comprising a high-tensile strength polymer. In further embodiments, the outer fiber component could comprise a high-modulus polymer. Structural composites as described herein could particularly find use as components with strength, weight, and thermal regulation are to be optimized, such as an aircraft fuselage member.

[0104] Still further composite materials could be prepared incorporating the multicomponent fibers of the present invention, and the foregoing discussion of such should not be construed as limiting the scope thereof. Rather, the present invention encompasses a variety of composite materials wherein the multicomponent fiber of the invention could be used to impart thermal regulation to the resulting composite material.

[0105] The present invention will be further illustrated by the following non-limiting examples.

EXAMPLE 1

Preparation of Temperature-Regulating Fiber Component

[0106] A precursor material highly loaded with a phase change material was prepared according to the following steps. First, a phase change material was prepared in a molten state. Polypropylene was added, and the combination was mixed until the polypropylene was molten. The same was then done with EVA and fumed silica. While the components are described above in a sequential addition, the method is not limited to such a sequence. For example, all components could be added at once and heated to a molten state. Further, the above components could be combined according to a different order than described above.

[0107] Once all components of the precursor material were in a molten state, the mixture was cooled and then ground into a powder. The powdered precursor material comprised 67.3% by weight of the phase change material.

[0108] The powdered precursor material was then combined with an additional amount of fumed silica, followed by an additional amount of a polypropylene powder. The three components were processed to a substantially homogeneous mixture, which was then extruded and pelletized to make the final temperature-regulating fiber component of the invention in a form ready for use in an extrusion process for preparing a multicomponent fiber. The overall composition of the precursor material and the final temperature-regulating component is provided below in Table 2, with percentages provided as weight percent based on the overall weight of the precursor material and the temperature-regulating fiber component, respectively.
TABLE 2

<table>
<thead>
<tr>
<th>Material</th>
<th>Phase Change Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precursor</td>
<td>13.3%</td>
</tr>
<tr>
<td>Temperature-Regulating Fiber</td>
<td>47%</td>
</tr>
</tbody>
</table>

EXAMPLE 2

Preparation of Bicomponent Fiber

[0109] A bicomponent fiber, in a sheath/core embodiment, was prepared using a temperature-regulating fiber component as described in Example 1 as the inner fiber component (i.e., the core). The outer fiber component comprised polylactic acid (PLA).

[0110] The bicomponent fiber was prepared using a standard extruding apparatus, such as illustrated in FIG. 8, with a granular PLA loaded into one hopper and the granular temperature-regulating component loaded into a second hopper. The bicomponent fiber was extruded at a temperature of 220°C, with the temperature-regulating inner fiber component comprising 75% of the bicomponent fiber's cross-section and the PLA outer fiber component comprising 25% of the bicomponent fiber's cross-section. The bicomponent fibers were spun at a rate of 1,500 meters/minute and subsequently drawn to a linear density of 6 denier per filament.

[0111] The bicomponent fibers can be used in the form of the plain filament described above or can undergo further processing. In a further example, filaments were prepared as described above, and the filaments were crimped along the length of the filament at 10-12 crimps per inch. In still a further embodiment, filaments were prepared as described above, and the filaments were cut into staple fibers having a length of about 1.5 inches per fiber.

[0112] Many modifications and other embodiments of the inventions set forth herein will come to mind to one skilled in the art to which these inventions pertain. The teaching presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the inventions are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

That which is claimed:

1. A multicomponent fiber comprising:

(a) at least one temperature-regulating inner fiber component comprising:

(i) at least about 25% by weight of a polyolefin; and

(ii) up to about 50% by weight of a phase change material, based on the overall weight of the at least one inner fiber component; and

(b) an outer fiber component encapsulating the at least one temperature-regulating inner fiber component.

2. The multicomponent fiber of claim 1, wherein the at least one temperature-regulating inner fiber component further comprises a micro-porous material.

3. The multicomponent fiber of claim 2, wherein the micro-porous material comprises a fumed silica.

4. The multicomponent fiber of claim 1, wherein the at least one temperature-regulating inner fiber component further comprises an ethylene material.

5. The multicomponent fiber of claim 4, wherein the ethylene material comprises ethylene vinyl acetate.

6. The multicomponent fiber of claim 1, wherein the phase change material comprises at least one compound having a transition temperature of about 10°C to about 50°C.

7. The multicomponent fiber of claim 1, wherein the phase change material comprises at least one aliphatic hydrocarbon having at least 8 carbon atoms and at least 50 carbon atoms.

8. The multicomponent fiber of claim 7, wherein the phase change material comprises octadecane.

9. The multicomponent fiber of claim 1, wherein the inner fiber component comprises about 5% to about 50% by weight of the phase change material, based on the overall weight of the inner fiber component.

10. The multicomponent fiber of claim 1, wherein the inner fiber component comprises about 10% to about 50% by weight of the phase change material, based on the overall weight of the inner fiber component.

11. The multicomponent fiber of claim 1, wherein the inner fiber component comprises about 20% to about 50% by weight of the phase change material, based on the overall weight of the inner fiber component.

12. The multicomponent fiber of claim 1, wherein the phase change material comprises at least about 10% by weight of the overall weight of the multicomponent fiber.

13. The multicomponent fiber of claim 1, wherein the phase change material comprises at least about 15% by weight of the overall weight of the multicomponent fiber.

14. The multicomponent fiber of claim 1, wherein the phase change material comprises at least about 10% by weight to about 55% by weight of the overall weight of the multicomponent fiber.

15. The multicomponent fiber of claim 1, wherein the polyolefin comprises at least one polyolefin having a melt flow index of about 3 to about 1200.

16. The multicomponent fiber of claim 1, wherein the polyolefin comprises propylene.

17. The multicomponent fiber of claim 1, wherein the outer fiber component comprises a polymeric material having an extrusion temperature of about 120°C to about 320°C.

18. The multicomponent fiber of claim 1, wherein the outer fiber component comprises a polymer selected from the group consisting of polyamides, polyamines, polyanhydrides, polyacrylates, polycarbonates, polydiene, polycarbonates, polyesters, polyethers, polyfluorocarbons, polyfluorocarbon, polyolefins, polyphenylene, silicon containing polymers, polyurethanes, polyvinyls, polycetals, polyelectrolytes, and co- and ter-polymers thereof, and mixtures thereof.

19. The multicomponent fiber of claim 1, wherein the outer fiber component comprises a polymer selected from...
the group consisting of polyethylene terephthalate, polypropylene, polyamide, polylactic acid, and mixtures thereof.

20. The multicomponent fiber of claim 1, wherein the outer fiber component is the only component layer encapsulating the at least one temperature-regulating inner fiber component.

21. The multicomponent fiber of claim 1, wherein the phase change material is not microencapsulated.

22. The multicomponent fiber of claim 1, wherein the multicomponent fiber is selected from the group consisting of islands-in-the-sea fibers and sheath/core fibers.

23. The multicomponent fiber of claim 1, wherein the multicomponent fiber is selected from the group consisting of continuous filament fibers, staple fibers, spunbond fibers, and meltblown fibers.


25. The fabric of claim 24, wherein the fabric is selected from the group consisting of nonwoven fabrics, woven fabrics, and knit fabrics.

26. A composite material, wherein the composite material comprises the multicomponent fiber of claim 1.

27. The composite material of claim 26, wherein said composite comprises the multicomponent fiber at least partially encapsulated by a resinous material and applied to a substrate.

28. The composite material of claim 26, wherein said composite comprises the multicomponent fiber encapsulated in a thermoset resin.

29. A yarn, wherein the yarn comprises the multicomponent fiber of claim 1.

30. A method of making a temperature-regulating fiber component, wherein the method comprises:

(a) preparing a precursor material comprising a polyolefin and greater than 50% by weight of a phase change material, said preparing comprising mixing the polyolefin and the phase change material in molten form, cooling the resulting mixture into a solidified mixture, and processing the solidified mixture to be in a particulate form; and

(b) mixing the particulate precursor material with an additional amount of a polyolefin in particulate form such that the temperature-regulating fiber component comprises at least about 25% by weight of a polyolefin and up to 50% by weight of a phase change material, based on the overall weight of the temperature-regulating fiber component.

31. The method of claim 30, said step of preparing a precursor material further comprises adding one or more additional components selected from the group consisting of micro-porous materials and ethylenic materials.

32. The method of claim 30, wherein, in step (a), said processing comprises grinding the solidified mixture.

33. The method of claim 30, wherein step (b) further comprises mixing the precursor material with one or more additional components selected from the group consisting of micro-porous materials and ethylenic materials.

34. The method of claim 33, further comprising extruding and pelletizing the temperature-regulating fiber component.

35. A method for preparing a multicomponent fiber comprising:

(a) providing at least one temperature-regulating inner fiber component;

(b) providing an outer fiber component;

(c) introducing the fiber components to a fiber extrusion apparatus including a spinneret; and

(d) extruding the fiber components so as to form a multicomponent fiber wherein the outer fiber component is encapsulating the at least one temperature-regulating inner fiber component,

wherein the outer fiber component is introduced to the spinneret prior to introducing the at least one temperature-regulating inner fiber component to the spinneret such that the at least one temperature-regulating inner fiber component is prevented from contacting an ambient atmosphere.

36. The method of claim 35, wherein the multicomponent fiber is formed into staple fibers having free ends.

37. The method of claim 36, wherein the method further comprises processing the staple fibers to seal the free ends.

38. A fabric comprising fibers to seal the free ends.