(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
29 October 2015 (29.10.2015)

WIPO | PCT

(10) International Publication Number
WO 2015/164447 A2

(51) International Patent Classification:
D01F 6/62 (2006.01)

(21) International Application Number:
PCT/US2015/026984

(22) International Filing Date:
22 April 2015 (22.04.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/982,521 22 April 2014 (22.04.2014) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

WO 2015/164447 A2

(54) **Title**: FIBERS COMPRISING AN ALIPHATIC POLYESTER BLEND, AND YARNS, TOWS, AND FABRICS FORMED THEREFROM

(57) **Abstract**: The present disclosure provides thermoplastic fibers that comprise homogeneous blends of polylactic acid (PLA) polymers having different degrees of isomeric purity. The fibers exhibit reduced shrinkage and can be formed with increased productivity, specifically in relation to utilizing increased draw ratios. A homogeneous blend can comprise a first PLA polymer and a second PLA polymer, wherem the first PLA polymer has an isomeric purity for the D-isomer or the L-isomer of at least about 99% and the second PLA polymer has an isomeric purity for the D-isomer or the L-isomer of no greater than about 98.5%. The disclosure further encompasses yarns and fabrics formed from the fibers and compositions formed from the yams or fabrics, as well as methods of preparing PLA materials.

FIBERS COMPRISING AN ALIPHATIC POLYESTER BLEND, AND YARNS, TOWS, AND FABRICS FORMED THEREFROM

FIELD OF INVENTION

[0001] The present disclosure relates to thermoplastic fibers. In particular, the fibers can comprise a blend of aliphatic polyesters (e.g., polylactic acids) with different purities and can provide for reduced shrinkage at elevated temperatures as well as high productivity.

BACKGROUND

[0002] Synthetic fibers are widely used in a number of diverse applications to provide stronger, thinner, and lighter weight products. Synthetic thermoplastic fibers are typically heat adhesive (thermobondable) and thus are particularly attractive for the manufacture of nonwoven fabrics, either alone or in combination with other fibers (such as cotton, wool, and wood pulp). Nonwoven fabrics, in turn, are widely used as components of a variety of articles, including without limitation absorbent personal care products, such as diapers, incontinence pads, feminine hygiene products, and the like; medical products, such as surgical drapes, sterile wraps, and the like; filtration devices; interlinings; wipes; furniture and bedding construction; apparel; insulation; and others.

[0003] Conventional synthetic thermoplastic fibers, however, do not naturally degrade, thus creating problems associated with the disposal of products containing such fibers. In particular, recycling articles containing a blend of natural and conventional synthetic fibers is generally not cost effective, but the disposal of these articles in landfills generates significant amounts of non-degradable waste. As landfills reach their capacity, the demand has increased for the incorporation of more degradable components in disposable products, as well as the design of products that can be disposed of by means other than by incorporation into solid waste disposal facilities.

[0004] To address concern over the issue of solid waste disposal, biodegradable polymers are increasingly used as a replacement for conventional synthetic polymers. Biodegradable polymers of interest include water-soluble polymers such as polyvinyl alcohol; naturally synthesized polymers such as sodium alginate and microbial polyesters; hydrolyzable aliphatic polyester and polyurethane polymers; and the like. Synthetic biodegradable aliphatic polyesters

include polyglycolide and polylactic acid polymers. See, for example, U.S. Patent Nos. 5,166,231; 5,506,041; 5,759,569; 5,171,309; 6,177,193; 6,441,267; 6,953,622; and 7,338,877, each of which is herein incorporated by reference in its entirety.

[0005] Of particular interest is the use of lactic acid to manufacture biodegradable resin. Polylactic acid (hereinafter "PLA") was initially introduced as a biodegradable polymer for medical products. U.S. Patent Nos. 5,142,023 and 5,807,973 to Gruber et al., each of which is herein incorporated by reference in its entirety, disclose processes by which a nonmedical grade of polylactic acid may be produced and utilized in nonwoven fabrics. Examples of biodegradable fibers comprised entirely of polylactic acid polymers and/or copolymers are found in U.S. Patent Nos. 5,010,145 and 5,760,144, each of which is herein incorporated by reference in its entirety. See also U.S. Patent Nos. 5,698,322 and 5,593,778 (directed to bicomponent fibers which include polylactic acid components), each of which is herein incorporated by reference in its entirety.

[0006] Fibers made from PLA with high isomeric purity can deliver reduced shrinkage as compared to fibers made from PLA with lower isomeric purity. However, conventional PLA fibers still typically exhibit high shrinkage (e.g., 40% or more) unless the fibers are first heat-set. Even with heat-set PLA fibers, as is the case with other conventional fibers, heat-setting a fiber only reduces the shrinkage of the fiber at temperatures below the heat-set temperature. At temperatures above the heat-set temperature, the heat-set PLA fiber still has high shrinkage.

[0007] Therefore, it is desirable to provide a biodegradable fiber that is capable of exhibiting reduced shrinkage at a wide range of temperatures, particularly at temperatures above the heat-set temperature.

SUMMARY OF THE INVENTION

[0008] The present invention provides thermoplastic fibers that comprise homogeneous blends of polylactic acid (PLA) polymers having different degrees of isomeric purity. The fibers exhibit reduced shrinkage and can be formed with increased productivity, specifically in relation to utilizing increased draw ratios. In some embodiments, multicomponent thermoplastic fibers are provided wherein the fibers comprise a homopolymer high-purity PLA component and a binder component disposed on at least part of the fiber's surface.

[0009] In various embodiments of the present invention, a fiber is provided comprising a homogeneous blend of a first polylactic acid (PLA) polymer and a second polylactic acid (PLA) polymer, wherein the first PLA polymer has an isomeric purity for the D-isomer or the L-isomer, or the L-isomer, of at least about 99%, or at least about 99.5% to 100%, or about 100% (i.e., pure) by weight of the first PLA polymer and the second PLA polymer has an isomeric purity for the D-isomer or the L-isomer of no greater than 98.5% by weight of the second PLA polymer. In various embodiments of fibers described herein, the weight ratio of the first PLA polymer to the second PLA polymer in the homogeneous blend can be about 50:50 to about 99:1, or about 50:50 to about 75:25. In some embodiments, the second PLA polymer can have an isomeric purity for the D-isomer or the L-isomer, or the L-isomer, of about 40% to about 98.5%, or of about 60% to about 98.5%, or of about 98% to about 98.5% by weight of the second PLA polymer. In various embodiments, the fiber can comprise about 50% or greater by weight of the homogeneous blend. The fiber can be, for example, a continuous filament, a staple fiber, a nanofiber, or a nanofilament. The fiber may further be a multicomponent fiber.

[0010] In certain embodiments of the fibers described herein, the first PLA polymer can have an isomeric purity for the D-isomer or the L-isomer of at least 99% by weight of the first PLA polymer, the second PLA polymer can have an isomeric purity for the D-isomer or the L-isomer of about 98% to about 98.5% by weight of the second PLA polymer, and the weight ratio of the first PLA polymer to the second PLA polymer in the homogeneous blend can be about 50:50 to about 75:25.

[0011] In various embodiments, a fiber can exhibit a shrinkage of less than about 20%, less than about 17%, less than about 15%, less than about 12% or less than about 10% to about 0%, or about 5% at a temperature of about 110 °C to about 130 °C, or about 130 °C after the fiber has been heat-set at a temperature of about 90 °C. The fiber can exhibit a shrinkage of up to about 17%, for example.

[0012] In some embodiments of the fibers described herein, the fiber can be a multicomponent fiber. A first component of the multicomponent fiber can comprise, for example, a homogeneous blend of polylactic acid (PLA) polymers having different degrees of isomeric purity and a second component can comprise a different polymer. In certain embodiments of the present invention, a multicomponent fiber is provided wherein the fiber comprises a first component in the form of a homopolymer polylactic acid (PLA) having an

isomeric purity for the D-isomer or the L-isomer of at least about 99%, or D-isomer pure or L-isomer pure, by weight of the first component, wherein the PLA melts at a first temperature. The multicomponent fiber can further comprise a second component disposed on at least part of part of an exterior surface of the multicomponent fiber. Optionally, the second component includes a component that melts at a second temperature, and wherein when present, the second temperature is less than the first temperature. In a preferred embodiment, the second component can be a biodegradable component or blend, more preferably a PLA component or blend. In certain embodiments, the second component can be a PLA polymer having an isomeric purity for the D-isomer or the L-isomer of no greater than about 98.5%, preferably no greater than about 96%, and most preferably no greater than about 90% and preferably more than about 1.5%, or more than about 3%, or more than about 4% by weight of the second component. In a preferred embodiment, the multicomponent fiber can be in the form of a core/sheath arrangement, wherein the first component can be the core component and the second component can be the sheath component. As used herein the term "melts" indicates the commonly-understood "melting point" of a fiber, solid, and/or a crystal matrix. This term also includes situations in which an amorphous polymer softens to the point at which it is useful as a melt-binder, and is seen as a relatively viscous liquid. At such a point, the amorphous polymer flows under the forces of surface tension as it contacts adjacent fibers and flows from its original position (i.e., in the fiber's sheath or shell) to encapsulate an adjacent (touching) fiber.

[0013] In various embodiments of a multicomponent fiber, a first component of the multicomponent fiber can comprise the homogeneous blend of the present disclosure and a second component can also comprise the homogeneous blend. The homogeneous blend in the second component can be different from the homogeneous blend in the first component. For example, the homogeneous blend in the second component can differ from the homogeneous blend in the first component in relation to one or both of the isomeric purity of the second PLA polymer and the weight ratio of the first PLA polymer to the second PLA polymer.

[0014] In various embodiments of the present invention, a bundle of filaments is provided, wherein the bundle of filaments comprises a fiber comprising a homogeneous blend of a first polylactic acid (PLA) polymer and a second polylactic acid (PLA) polymer, wherein the first PLA polymer has an isomeric purity for the D-isomer or the L-isomer of at least about 99% by weight of the first PLA polymer and the second PLA polymer has an isomeric purity for the

D-isomer or the L-isomer of no greater than about 98.5% by weight of the second PLA polymer. The bundle can be in the form of a yarn or a tow, for example. In some embodiments, a portion of the filaments can be formed of fibers comprising the homogeneous blend, and a portion of the filaments can be formed of amorphous PLA. In certain embodiments, for example, a yarn or tow is provided comprising a plurality of filaments comprising polylactic acid (PLA) polymer, wherein a first set of the filaments comprise semi-crystalline PLA having an L-isomer content of at least about 99% by weight of the first set of filaments, and wherein a second set of the filaments comprise amorphous PLA having a D-isomer content of about 5% or greater, or about 15% or greater by weight of the second set of filaments.

[0015] In various embodiments, a fabric comprising fibers of the present invention can be formed. The fabric can be a nonwoven fabric, a woven fabric, or a knit fabric, for example. In some embodiments, a composition can be formed from a fabric comprising fibers described herein.

[0016] The present invention further provides a method of preparing a low shrinkage, high productivity polylactic acid (PLA) material. In various embodiments, the method can comprise: forming a fiber comprising a homogeneous blend of a first polylactic acid (PLA) polymer and a second polylactic acid (PLA) polymer, wherein the first PLA polymer has an isomeric purity for the D-isomer or the L-isomer of at least about 99% by weight of the first PLA polymer and the second PLA polymer has an isomeric purity for the D-isomer or the L-isomer of no greater than about 98.5% by weight of the second PLA polymer; drawing the formed fiber at a draw ratio of about 3:1 or greater; and heat-setting the formed fiber at a temperature of up to about 110 °C; wherein after the heat-setting step, the PLA material exhibits a shrinkage of less than about 20% at a temperature of about 115 °C to about 130 °C.

[0017] The present invention also provides a method of preparing a multicomponent binder fiber exhibiting low shrinkage. In some embodiments, the method can comprise the following steps: providing a multicomponent fiber formed of a first, high melting polymer component and a second, lower melting polymer component, wherein the first polymer component is a PLA polymer with an isomeric purity for the L-isomer of at least about 99%, wherein the second polymer component is a PLA polymer with an isomeric purity for the L-isomer of no more than about 98.5%, and wherein the second component comprises at least a portion of an outer surface of the multicomponent binder fiber; and heat-setting the

multicomponent binder fiber at a temperature that is less than the activation temperature at which the second polymer component melts. The formed, heat-set multicomponent binder fiber can exhibit a shrinkage of less than about 20% at a temperature greater than the activation temperature.

DETAILED DESCRIPTION

[0018] The present invention now will be described more fully hereinafter. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. As used in this specification and the claims, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise.

[0019] All measurements herein are by weight unless specifically stated.

[0020] The present disclosure provides thermoplastic fibers that comprise homogeneous blends of polylactic acid (PLA) polymers having different degrees of isomeric purity. The fibers exhibit reduced shrinkage and can be formed with increased productivity, specifically in relation to utilizing increased draw ratios.

[0021] The term "fiber" as used herein means both fibers of finite length, such as conventional staple fibers, as well as substantially continuous structures, such as continuous filaments, unless otherwise indicated. The fibers of the invention can be hollow or non-hollow fibers, and further can have a substantially round or circular cross section or non-circular cross sections (for example, oval, rectangular, multi-lobed, and the like).

[0022] As used herein, the term "multicomponent fibers" includes staple fibers and continuous filaments prepared from two or more polymers present in discrete structured domains in the fiber, as opposed to blends where the domains tend to be dispersed in a melt prior to or during extrusion. For purposes of illustration only, multicomponent embodiments may be described in terms of an exemplary bicomponent fiber comprising two polymer components. However, it should be understood that the scope of the present invention is meant to include multicomponent fibers with two or more structured components and is not limited to the exemplary bicomponent fibers described below. Although the invention is not limited to two

components, the terms first component and second component are used herein for the ease of describing the invention.

[0023] As used herein, the term "polymer blend" includes two or more different polymers blended together. The blend can be a homogeneous polymer blend and can specifically be a polymer blend wherein the polymers are sufficiently intermixed such that the blend is substantially a single-phase structure. A homogeneous polymer blend can comprise two or more homopolymers.

[0024] The fibers according to the present invention can vary, and include fibers having any type of cross-section, including, but not limited to, circular, rectangular, square, oval, triangular, and multilobal. In certain embodiments, the fibers can have one or more void spaces, wherein the void spaces can have, for example, circular, rectangular, square, oval, triangular, or multilobal cross-sections. The fibers may be selected from single-component (*i.e.*, substantially uniform in composition throughout the fiber) or multicomponent fiber types including, but not limited to, fibers having a sheath/core structure and fibers having an islands-in-the-sea structure, as well as fibers having a side-by-side, segmented pie, segmented cross, segmented ribbon, or tipped multilobal cross-sections.

[0025] In various embodiments of the present invention, a fiber is provided comprising a blend of thermoplastic polymers. Preferably, the fiber comprises a homogeneous blend of polymers. In various embodiments of the fibers described herein, polymer components of the homogeneous blend can be formed of the same or different polymers. As used herein, the "same" polymer refers to polymer components having an identical or similar chemical formula; however, each polymer component can differ with respect to their isomeric form, for example.

[0026] The polymer components of a homogeneous blend can each be an aliphatic polyester. Examples of aliphatic polyesters which may be useful in the present invention include, without limitation, fiber forming polymers formed from (1) a combination of glycol (*e.g.*, ethylene, glycol, propylene glycol, butylene glycol, hexanediol, octanediol or decanediol) or an oligomer of ethylene glycol (*e.g.*, diethylene glycol or triethylene glycol) with an aliphatic dicarboxylic acid (*e.g.*, succinic acid, adipic acid, hexanedicarboxylic acid or decaneolicarboxylic acid) or (2) the self condensation of hydroxy carboxylic acids other than polylactic acid, such as polyhydroxy butyrate, polyethylene adipate, polybutylene adipate, polyhexane adipate, and copolymers containing them. Examples of aliphatic polyesters include,

but are not limited to, polyglycolide or polyglycolic acid (PGA), polylactide or polylactic acid (PLA), polycaprolactone (PCL), polyethylene adipate (PEA), polyhydroxyalkonoate (PHA), polyhydroxybutyrate (PHB), poly (3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV), and polylactide-co-glycolide.

[0027] Aliphatic polyesters can be particularly useful because of the biodegradable nature thereof. In addition to biodegradability, aliphatic polyesters, particularly polylactic acid, can impart other desirable properties to the fibers of the invention. For example, the fibers of the invention which include polylactic acid (or a further aliphatic polyester) as a component can exhibit improved hydrophilic properties, improved flame retardant capabilities, or can be dyed to deeper and brighter shades as compared to fibers including polyethylene terephthalate or polyamides.

[0028] In various embodiments of the thermoplastic fibers described herein, the fibers can comprise homogeneous blends of polylactic acid (PLA) polymers having different degrees of isomeric purity. Polylactic acid polymers useful according to the present disclosure can be prepared by either the polymerization of lactic acid or lactide. PLA and methods of making thereof are disclosed in U.S. Patent Nos. 5,698,322; 5,142,023; 5,760,144; 5,593,778; 5,807,973; and 5,010,145, and the entire disclosure of each is hereby incorporated by reference.

[0029] Lactic acid and lactide are known to be asymmetrical molecules, having two optical isomers referred to, respectively as the levorotatory (hereinafter referred to as "L") enantiomer and the dextrorotatory (hereinafter referred to as "D") enantiomer. As a result, by polymerizing a particular enantiomer or by using a mixture of the two enantiomers, it is possible to prepare polymers that are chemically similar yet which have significantly differing properties.

[0030] The degree of crystallinity of a PLA polymer, for example, is based on the regularity of the polymer backbone and its ability to line up with similarly shaped sections of itself or other chains. If even a relatively small amount of D-enantiomer (of either lactic acid or lactide), such as about 3 to about 4 weight percent, is copolymerized with L-enantiomer (of either lactic acid or lactide), the polymer backbone generally becomes irregularly shaped enough that it cannot line up and orient itself with other backbone segments of pure L-enantiomer polymer, thus reducing the crystallinity of the polymer.

[0031] PLA fibers can suffer from heat shrinkage, which mainly occurs due to the thermally-induced chain relaxation of the polymer segments. This is a particular problem with

PLA because its shrinkage force is known in the art to be relatively high. Thus, when such fiber is utilized in forming a heat bonded fabric, for example, the shrinking PLA fiber is more likely to cause holes or non-uniformities in the fabric as it shrinks. According to the present invention, however, using a first PLA component with a relatively high L-isomer purity in the homogeneous blend can significantly lower shrinkage of the fiber.

[0032] In various embodiments of present invention, a fiber is provided comprising a homogeneous blend of a first polylactic acid (PLA) polymer and a second polylactic acid (PLA) polymer, wherein the first PLA polymer has an isomeric purity for the D-isomer or the L-isomer of at least about 99% and the second PLA polymer has an isomeric purity for the D-isomer or the L-isomer of no greater than about 98.5%. In various embodiments of fibers described herein, the weight ratio of the first PLA polymer to the second PLA polymer in the homogeneous blend can be about 50:50 to about 99:1, about 75:25 to about 99:1, or about 50:50 to about 75:25. In various embodiments, the fiber can comprise about 20% or greater to about 100%, or about 35% or greater to about 100%, or about 50% or greater to about 100% by weight of the homogeneous blend.

[0033] The first PLA polymer can have an isomeric purity for the D-isomer or the L-isomer of at least 99%; or from at least about 99% to about 100%. In specific embodiments, the first PLA polymer particularly can have an isomeric purity for the L-isomer of at least about 99%; or from at least about 99% to about 100%. In various embodiments of the present invention, the homogeneous blend can comprise at least about 50% by weight, at least about 60% by weight, at least about 70% by weight, or at least about 80% by weight to about 100% by weight of the first PLA polymer that exhibits high isomeric purity. Of course, if the fiber is 100% isomerically pure, then it would not be a blend; however, such a fiber is still useful herein.

[0034] It is known that PLA fibers can exhibit high shrinkage (e.g., about 40% or more). It has been found that heat-setting a fiber comprising at least about 50% of a PLA with high L-isomer purity (e.g., an L-isomer of at least about 99%) can provide surprisingly low shrinkage (e.g., about 5% to about 17%) in comparison to conventional PLA fibers, even at temperatures above the heat-set temperature. Fibers formed from blends including at least about 50% by weight of a first PLA polymer with such high L-isomer content can exhibit a heat shrinkage value of less than about 20%, less than about 17%, less than about 15%, less than about 12% or less than about 10% to about 0%, or about 5%at temperatures above the heat-set temperature.

For example, heat-setting such a fiber at 90 °C can produce a fiber with shrinkage of only about 10% at 130 °C. It is noted that the heat-set temperature (e.g., 90 °C), can be picked such that the heat-set temperature is below the temperature at which any low-purity PLA component (i.e., the second PLA polymer having an isomeric purity of no greater than about 98.5%) starts to melt or soften enough to become sticky and degrade fiber properties or impede processing.

[0035] The second polylactic acid (PLA) polymer can have an isomeric purity for the D-isomer or the L-isomer of no greater than about 98.5%. In specific embodiments, the second PLA polymer particularly can have an isomeric purity for the L-isomer of no greater than about 98.5%. In some embodiments, the second PLA polymer can have an isomeric purity for the D-isomer or the L-isomer of about 40% to about 98.5%, or of about 60% to about 98.5%.

[0036] Despite the beneficial reduced shrinkage properties provided by a fiber comprising PLA having an isomeric purity for the L-isomer of at least 99%, a fiber comprising 100% by weight of such a PLA polymer component can produce a fiber only capable of a relatively low draw ratio (e.g., only capable of a draw ratio of about 2.5:1 or less). For example, for a given process that imparts suitable fiber strength, denier, and other properties, the maximum draw ratio achievable is less for fibers using a pure high-purity component than it is for fibers using a blend of high-purity and lower-purity PLA. For a typical production process of fibers comprising a homogeneous blend of high-purity and lower-purity PLA, it has been found that these fibers can exhibit increased draw ratios, such as about 3:1 or higher, and still maintain a low (i.e., reduced) shrinkage, particularly at temperatures above a heat-setting temperature. The ability of fibers of a homogeneous blend to extend the draw ratio without sacrificing the low shrinkage performance can be important because higher productivity (and thus lower cost) can be achieved with higher draw ratios.

[0037] A homogeneous blend described herein can optionally include other components not adversely affecting the desired properties thereof. Exemplary materials which can be used as additional components would include, without limitation, pigments, antioxidants, stabilizers, surfactants, waxes, flow promoters, solid solvents, particulates, and other materials added to enhance processability of the first and the second components. For example, a stabilizing agent may be added to the biodegradable polymer to reduce thermal degradation which might otherwise occur during the polylactic acid spinning process. The use of such stabilizing agents is disclosed in U.S. Patent No. 5,807,973, hereby incorporated in its entirety by reference. Further,

additives which enhance the biodegradability of the polylactic acid may optionally be included, as disclosed in U.S. Patent No. 5,760,144, previously incorporated by reference. These and other additives can be used in conventional amounts. In an embodiment herein the stabilizing agent is a photostabilizing agent.

[0038] In some embodiments of the fibers described herein, the fiber can be a multicomponent fiber. A first polymer component of the multicomponent fiber can comprise, for example, a homogeneous blend of polylactic acid (PLA) polymers having different degrees of isomeric purity, and a second polymer component can comprise a different polymer. For example, the first polymer component can comprise a homogeneous blend of a first polylactic acid (PLA) polymer and a second polylactic acid (PLA) polymer, wherein the first PLA polymer has an isomeric purity for the D-isomer or the L-isomer of at least about 99% and the second PLA polymer has an isomeric purity for the D-isomer or the L-isomer of no greater than about 98.5%. The second polymer component of the multicomponent fiber can comprise one or more further polymers selected from any of the types of polymers known in the art that are capable of being formed into fibers, including polyolefins, polyesters, polyamides and the like. Examples of suitable polymers for use as the second component of a multicomponent fiber include, without limitation, polyolefins including polypropylene, polyethylene, polybutene, and polymethyl pentene (PMP), polyamides including nylon, such as nylon 6 and nylon 6,6, polyacrylates, polystyrenes, polyurethanes, acetal resins, polyethylene vinyl alcohol, polyesters including aromatic polyesters, such as polyethylene terephthalate, polyethylene naphthalate, polytrimethylene terephthalate, poly (1,4-cyclohexylene dimethylene terephthalate) (PCT), polyphenylene sulfide, thermoplastic elastomers, polyacrylonitrile, cellulose and cellulose derivatives, polyaramids, acetals, fluoropolymers, copolymers and terpolymers thereof and mixtures or blends thereof.

[0039] Further examples of aromatic polyesters include (1) polyesters of alkylene glycols having 2-10 carbon atoms and aromatic diacids; (2) polyalkylene naphthalates, which are polyesters of 2,6-naphthalenedicarboxylic acid and alkylene glycols, as for example polyethylene naphthalate; and (3) polyesters derived from 1,4-cyclohexanedimethanol and terephthalic acid, as for example polycyclohexane terephthalate. Exemplary polyalkylene terephthalates include without limitation, polyethylene terephthalate (PET) and polybutylene terephthalate.

[0040] In certain embodiments of the present invention, a multicomponent fiber is provided wherein the fiber comprises a first component in the form of a polylactic acid (PLA) homopolymer having an isomeric purity for the D-isomer or the L-isomer of at least about 99%, wherein the PLA melts at a first temperature. The multicomponent fiber can further comprise a second polymer component disposed on at least part of the fiber's surface, wherein the second polymer component includes a component that melts at a second temperature, and wherein the second temperature is less than the first temperature. In a preferred embodiment, the second polymer component can be a biodegradable component or blend, more preferably a PLA component or blend. In certain embodiments of a multicomponent fiber, the second polymer component can be about 100% PLA. The second polymer component of the multicomponent fiber can have an isomeric purity for the D-isomer or the L-isomer of about 98.5% or less. The high purity first PLA polymer (i.e., the core component) can permit heat-setting at a lower temperature (e.g., about 90 °C), but the fiber can still maintain low shrinkage at a higher bonding temperature (e.g., about 130 °C).

[0041] In various embodiments of a multicomponent fiber disclosed herein, the multicomponent fiber can have a sheath/core configuration. The core of the multicomponent fiber can comprise a first component in the form of a polylactic acid (PLA) homopolymer having an isomeric purity of at least 99%. In a preferred embodiment, the first component can be a first PLA polymer having an L-isomer purity of at least about 99%. The sheath of the multicomponent fiber can comprise a second component wherein the second component has a melting point lower than the melting point of the core component. In some embodiments, the second component can be in the form of a second PLA polymer being a polylactic acid (PLA) homopolymer having an isomeric purity of about 98.5% or less. In some embodiments, the second component can be in the form of a homogenous blend as described herein. A sheath/core arrangement wherein the core comprises a first PLA polymer (i.e., a high purity PLA component) as described herein can allow for fibers to be heat set at a lower temperature (e.g., about 90 °C) and still exhibit low shrinkage at higher temperatures (e.g., about 130 °C). Conventional binder fibers do not possess this feature and must be heat-set at a lower temperature than the bonding temperature to prevent sticking of the fibers and typically demonstrate higher levels of shrinkage at the higher binding temperatures. According to the present disclosure, although a binder fiber is preferably heat-set below tacking/bonding

temperatures, the present binder fibers are unexpectedly able to achieve low shrinkage compared to convention binder fibers. Traditionally, low shrinkage has been pursued by heat-setting at a temperature above the fiber's use temperature. For binder fibers, this has been historically impossible because the binder activates at its use temperature and premature activation of the binder in heat-setting disrupts the process. The presently disclosed binder fibers, however, surprisingly can be heat-set to achieve low shrinkage where the heat-setting temperature is below the activation temperature of the binder component.

[0042] In various embodiments of a multicomponent fiber, a first polymer component of the multicomponent fiber can comprise a homogeneous blend of a first polylactic acid (PLA) polymer and a second polylactic acid (PLA) polymer, wherein the first PLA polymer has an isomeric purity for the D-isomer or the L-isomer of at least about 99%, and the second PLA polymer has an isomeric purity for the D-isomer or the L-isomer of no greater than about 98.5%. Additionally, a second component of the multicomponent fiber can also comprise the homogeneous blend of a first polylactic acid (PLA) polymer and a second polylactic acid (PLA) polymer, wherein the first PLA polymer has an isomeric purity for the D-isomer or the L-isomer of at least about 99% and the second PLA polymer has an isomeric purity for the D-isomer or the L-isomer of no greater than about 98.5%.

[0043] In various embodiments of a multicomponent fiber comprising a first homogeneous blend and a second homogeneous blend, the second homogeneous blend can be different from the first homogeneous blend. In some embodiments, the homogeneous blend in the second polymer component can comprise a different isomeric purity of the second PLA polymer in relation to the second PLA polymer of the first polymer component. In certain embodiments, the weight ratio of the first PLA polymer to the second PLA polymer in the first homogeneous blend can differ from the weight ratio of the first PLA polymer to the second PLA polymer in the second homogeneous blend. For example, the first homogeneous blend can have a blend ratio of the first PLA polymer to the second PLA polymer of about 50:50 and the second homogeneous blend can have a blend ratio of the first PLA polymer to the second PLA polymer of about 75:25. Other relative ratios also are encompassed according to various embodiment of this disclosure.

[0044] In various embodiments of the present invention, a bundle of filaments is provided. The bundle of filaments can be in the form of a yarn or a tow, for example. In various

embodiments, the bundle of filaments comprises a fiber comprising a homogeneous blend of a first polylactic acid (PLA) polymer and a second polylactic acid (PLA) polymer, wherein the first PLA polymer has an isomeric purity for the D-isomer or the L-isomer of at least about 99% and the second PLA polymer has an isomeric purity for the D-isomer or the L-isomer of no greater than about 98.5%. In some embodiments, a first portion of the filaments can be formed of fibers comprising the homogeneous blend, and a second portion of the filaments can include fibers comprising one or more polymers or blends other than the homogeneous blend. For example, the second portion of filaments can comprise amorphous PLA or semi-crystalline PLA.

[0045] In various embodiments of the present invention, a yarn or tow is provided comprising a plurality of filaments comprising polylactic acid (PLA), wherein a first set of the filaments comprise a first PLA polymer having an isomeric purity for the D-isomer or the L-isomer of at least about 99% and a second PLA polymer having an isomeric purity for the D-isomer or the L-isomer of no greater than about 98.5% (e.g., about 40% to about 98.5%, or of about 60% to about 98.5%). The ratio of the first set of filaments to the second set of filaments can be about 50:50 to about 99:1, or about 50:50 to about 75:25. In certain embodiments, for example, a yarn or tow is provided comprising a plurality of filaments comprising polylactic acid (PLA) polymer, wherein a first set of the filaments comprise semi-crystalline PLA having an L-isomer content of at least about 99%, and wherein a second set of the filaments comprise amorphous PLA having a D-isomer content of about 5% or greater

[0046] In various embodiments, a fabric comprising fibers of the present invention can be formed. The fabric can be a nonwoven fabric, a woven fabric, or a knit fabric, for example. In some embodiments, a composition can be formed from a fabric comprising fibers described herein. Nonwoven fabrics which include the fibers of the invention as a component are particularly suited for use in disposable products. Specific examples include without limitation disposable diapers, adult incontinent products, sanitary napkins, tampons, wipes, bibs, wound dressings, and surgical capes or drapes. Nonwoven fabrics formed from the fibers described herein are also suited for articles such as ropes and cords comprising the fibers and filaments.

[0047] In an embodiment herein the fibers of the present invention may be formed into a filtration device, such as an air filter, a water filter, an oil filter, a smoke filter, etc. In an embodiment herein the filter is an air filter or a smoke filter; or an air conditioning filter, a cigarette filter, a humidifier filter, a respirator filter, an automotive filter, an aircraft filter; or a

cigarette filter. Embodiments of products and machines incorporating such filtration devices, such as air conditioners, filtered cigarettes, engines, liquid and water treatment facilities, milk and beverage processing facilities, air purification systems, drains, etc. are also contemplated herein and are within the scope of this invention. In an embodiment of the present invention, the fibers, monocomponent fibers, multicomponent fibers, yarn and/or tow herein are formed or manufactured into a cigarette filter. The cigarette filter is then combined with other cigarette components to form or manufacture a cigarette.

[0048] Cigarette filters and methods for making such are well-known in the art. It is believed that the present fibers, monocomponent fibers, multicomponent fibers, yarns and/or tows may be compatible with the manufacturing processes, components, and machinery for such cigarette filters and other air filters. Filters for electronic cigarettes and the like are explicitly included herein as a potential use for these fibers described herein. Representative examples of cigarette manufacturing methods and filters themselves are seen in, for example, US Pat. Pub. No. 2015/0090283 A1 to Zhang, et al., published on April 2, 2015; US Pat. Pub. No. 2014/0352708 A1 to Tan, et al., published on December 4, 2014; US Pat. No. 8,997,755 B2 to Ingebrethsen, et al published on April 7, 2015 and US Pat. No. 6,761, 174 B2 to Dwyer, et al., published on June 14, 2004, all of which are specifically incorporated herein by reference in their entireties.

[0049] Methods for making monocomponent and multicomponent fibers are well known and need not be described here in detail. Generally, to form a monocomponent fiber, a polymer or a polymer blend is extruded. Generally, to form a multicomponent fiber, at least two polymers are extruded separately and fed into a polymer distribution system wherein the polymers are introduced into a segmented spinneret plate. The polymers follow separate paths to the fiber spinneret and are combined in a spinneret hole. The spinneret is configured so that the extrudant has the desired shape.

[0050] Following extrusion through the die, the resulting thin fluid strands, or filaments, remain in the molten state for some distance before they are solidified by cooling in a surrounding fluid medium, which may be chilled air blown through the strands. Once solidified, the filaments are taken up on a godet or another take-up surface. In a continuous filament process, the strands are taken up on a godet which draws down the thin fluid streams in proportion to the speed of the take-up godet. In the jet process, the strands are collected in a jet,

such as for example, an air gun, and blown onto a take-up surface such as a roller or a moving belt to form a spunbond web. In the meltblown process, air is ejected at the surface of the spinneret which serves to simultaneously draw down and cool the thin fluid streams as they are deposited on a take-up surface in the path of cooling air, thereby forming a fiber web. Regardless of the type of melt spinning procedure which is used, it is important that the thin fluid streams be melt drawn down in a molten state, i.e. before solidification occurs, to reduce the diameter of the fibers. Typical melt draw down ratios known in the art may be utilized. Where a continuous filament or staple process is employed, it may be desirable to draw the strands in the solid state with conventional drawing equipment, such as, for example, sequential godets operating at differential speeds. See, for example, U.S. Pat. No. 5,082,899, incorporated herein by reference in its entirety.

[0051] Following drawing in the solid state, the continuous filaments may be crimped or texturized and cut into a desirable fiber length, thereby producing staple fiber. The length of the staple fibers generally ranges from about 25 to about 50 millimeters, although the fibers can be longer or shorter as desired. See, for example, U.S. Pat. No. 4,789,592 to Taniguchi et al. and U.S. Pat. No. 5,336,552 to Strack et al., each of which is herein incorporated by reference in its entirety.

[0052] The fibers of the invention can be staple fibers, tows, spunbond filaments, continuous filaments, or meltblown fibers. In general, staple, multi-filament, and spunbond fibers formed in accordance with the present invention can have a fineness of about 0.5 to about 100 denier. Meltblown filaments can have a fineness of about 0.001 to about 10.0 denier. Monofilament fibers can have a fineness of about 50 to about 10,000 denier.

[0053] As noted above, the fibers can be incorporated into a nonwoven fabric. The fibers of the present invention may be formed into nonwoven webs by any means suitable in the art, particularly wherein heat bonding is used. In addition, continuous filament may be spun directly into nonwoven webs by a spunbonding process. Fibers other than the fibers of the invention may be present as well, including any of the various synthetic and/or natural fibers known in the art. Exemplary synthetic fibers include polyolefin, polyester, polyamide, acrylic, rayon, cellulose acetate, thermoplastic multicomponent fibers (such as conventional sheath/core fibers, for example polyethylene sheath/polyester core fibers) and the like and mixtures thereof. Exemplary natural fibers include wool, cotton, wood pulp fibers and the like and mixtures thereof.

[0054] The fibers of the invention particularly may be incorporated, alone or in conjunction with other fibers, into a meltblown nonwoven fabric. The technique of meltblowing is known in the art and is discussed in various patents, e.g., Buntin et al., U.S. Patent No. 3,987,185; Buntin, U.S. Patent No. 3,972,759; and McAmish et al., U.S. Patent No. 4,622,259, each of which is herein incorporated by reference in its entirety. Other thermal bonding means known in the art can be used as well.

[0055] Thus, in various embodiments, the method can comprise forming a fiber comprising a homogeneous blend of a first polylactic acid (PLA) polymer and a second polylactic acid (PLA) polymer, wherein the first PLA polymer has an isomeric purity for the D-isomer or the L-isomer of at least about 99% and the second PLA polymer has an isomeric purity for the D-isomer or the L-isomer of no greater than about 98.5%; drawing the formed fiber at a draw ratio of about 2.8:1 or greater, or of about 3:1 or greater to about 3.5:1; and heat-setting the formed fiber. The fiber can be heat set, for example, at a temperature of up to about 130 °C. After the heat-setting step, the PLA material can exhibit a shrinkage of less than about 20%, less than about 17%, less than about 15%, less than about 12% or less than about 10% to about 0%, or about 5% at a temperature greater than the heat-set temperature. For example, the reduced shrinkage can be displayed at a temperature exceeding the heat-set temperature by at least about 20 °C, by at least about 30 °C, or by at least about 40 °C. In some embodiments, the fibers can exhibit reduced shrinkage at temperatures of about 95 °C to about 150 °C, about 100 °C to about 145 °C, or about 110 °C to about 130 °C. "Shrinkage" as described herein relates to a reduction of the length of the fiber, in the longest direction as described in ASTM test method D5104-2 run at a temperature of 130 °C.

[0056] In further embodiments, the present disclosure can provides methods of forming a low shrinkage, multicomponent binder fiber. The binder fiber can be a multicomponent fiber as described herein, such as a fiber comprising a component formed of a high isomeric purity PLA (e.g., isomeric purity of at 99%) and comprising a binder component formed of a lower melting material, such as a PLA (i.e., the second PLA polymer) having an isomeric purity of no more than about 98.5%, no more than about 96%, or no more than about 90%. Such purities particularly can be in relation to the L-isomer. The methods can comprise providing a multicomponent fiber having the noted composition, particularly in a core/sheath configuration, and heat-setting the multicomponent fiber at a temperature below the melting temperature and/or

below the softening temperature of the binder component. Such temperature may be defined as the activation temperature of the binder component. Heat-setting likewise can be carried out at a temperature below the use temperature of the multicomponent binder fiber. The use temperature is understood to be the temperature to which the binder fiber is subjected to provide its intended binding function. The multicomponent binder fiber formed by the noted method exhibits a shrinkage of less than 20%, less than 17%, less than 15%, less than 12% or less than 10% at a temperature greater than the activation temperature of the binder component. Multicomponent binder fibers formed by such methods can exhibit further properties for multicomponent fibers as otherwise described herein.

EXPERIMENTAL

[0057] The following example is provided to illustrate further aspects associated with the present disclosure, but should not be construed as limiting the scope thereof.

Example 1

[0058] Drawn sheath/core PLA/PLA bicomponent staple fibers were produced according to a standard sheath/core bicomponent fiber extrusion process. The extruded sheath/core fibers were drawn and then cut to form the staple. The fibers were not crimped, and the fibers were of a size of 3.7 denier per filament. Drawing was carried out via a two-stage process utilizing a heated water bath in the first draw stage and a steam chest in the second draw stage.

[0059] Five sample fibers were prepared. For all samples, the sheath of the sheath/core fibers was formed of a low-melting PLA grade polymer, Natureworks 6302D, with a D-isomer content of about 10%. In the drawing and cutting process, all samples were heat-set in a dryer, under no tension, at a temperature of 90 °C. Heat setting was carried out between the drawing and cutting steps. The table below shows the nature of the polymer used as the core component, shrinkage in air at the test temperature of 130°C for about 5 minutes, and draw ratio.

Sample	Core Polymer	% Shrinkage	Draw Ratio
1	Commercial PLA: 98.5% pure for L-isomer	40.0%	3.0
2	Commercial PLA: > 99% pure for L-isomer	8.6%	2.5
3	PLA polymer blend of present disclosure: 1st PLA (> 99% pure for L-isomer) and 2nd PLA (approx. 98.5% L-isomer) at wt. ratio of 75:25	18.0%	3.0
4	PLA polymer blend of present disclosure: 1st PLA (> 99% pure for L-isomer) and 2nd PLA (approx. 98.5% L-isomer) at wt. ratio of 50:50	25.1%	3.0
5	Commercial PLA: > 99% pure for L-isomer (NOTE: sample was heat-set at 65 °C rather than 90 °C)	21.8%	2.5

[0060] Regarding draw ratio, Sample 2 and Sample 5 were only able to achieve a draw ratio of 2.5 before breaking occurred. Samples 1, 3, and 4 were able to surpass the 2.5 draw ratio threshold without breakage, and draw was not increased above a ratio of 3.0.

[0061] Regarding shrinkage, Sample 1 did not have a sufficiently high L-isomer purity to achieve reduced shrinkage. At an L-isomer purity of 98.5%, shrinkage was 40.0%. Sample 1, however, was able to achieve a draw ratio of 3.0 without breakage. Sample 2 utilized the same type of polymer but had the higher L-isomer purity (i.e., greater than 99%). The increased L-isomer purity, however, reduced the draw ratio that could be achieved without breakage. Nevertheless, it has not previously been recognized that a multicomponent fiber comprising a first component that is a high-purity PLA can be heat set at 90 °C and maintain low shrinkage at 130 °C. Thus, a multicomponent fiber utilizing the Sample 2, high purity PLA as a first component and utilizing a lower melting material (e.g., a lower purity PLA) as a second, binder component, can be useful as a binder fiber. Thus, it is possible according to the present disclosure to provide a multicomponent binder fiber that can be heat set at a temperature below the softening or melting point of the binder component (e.g., about 90 °C) and then can be utilized at the binding temperature (e.g., about 130 °C) with low shrinkage. This is a significant advancement over known binder fibers where heat setting at 130 °C (the traditional way to attain low shrinkage at 130 °C) prematurely activates the binder component, gluing all the fibers together and preventing further processing. Sample 5 performed similarly to Sample 2 in relation to exhibiting reduced shrinkage; however, the lower heat-setting temperature also increased the amount of shrinkage at the test temperature.

[0062] Regarding Sample 3 and Sample 4 prepared according to the present disclosure, it can be seen that the blend of the high purity PLA (L-isomer greater than 99%) with the lower purity PLA (L-isomer 98.5% or less) was able to provide reduced shrinkage in combination with increased draw ratio without breakage. Shrinkage reduction appeared to increase when the ratio of the first PLA to the second PLA increased. This showed that the improvement in shrinkage associated with the use of high purity PLA (greater than 99% pure for the L-isomer) can be retained while draw ratio without breakage can be simultaneously increased when the high purity PLA is blended with a content of lower purity PLA (98.5% or less pure for the L-isomer).

Example 2

[0063] A cigarette filter is formed from the tow fibers herein is produced using typical production processes and machinery in the art. The cigarette filter is naturally compostable and therefore is significantly more biodegradable than traditional cigarette fibers made with traditional tow fibers, cellulose acetate, and/or polypropylene. These cigarette filter therefore reduce that amount of space needed by degrading when discarded in land fills, and other locations. These cigarette filters also prove less unsightly when discarded in other locations as they disappear more quickly and pose less of an environmental hazard. These cigarette filters also find a good balance the need for durability and improved processability during manufacturing and storage better than other biodegradable fibers present in the industry.

[0064] Many modifications and other embodiments of the invention will come to mind to one skilled in the art to which this invention pertains having the benefit of the teachings presented in the foregoing description. Therefore, it is to be understood that the invention is 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.

CLAIMS

1. A fiber comprising a homogeneous blend of:

a first polylactic acid (PLA) polymer and a second polylactic acid (PLA) polymer, wherein the first PLA polymer has an isomeric purity for the D-isomer or the L-isomer of at least about 99%, and

a second PLA polymer has an isomeric purity for the D-isomer or the L-isomer of no greater than about 98.5%; or of about 40% to about 98.5%; or of about 60% to about 98.5%; or of about 98% to about 98.5%, and

optionally where the weight ratio of the first PLA polymer to the second PLA polymer in the homogeneous blend is about 50:50 to about 99:1, or about 50:50 to about 75:25,

optionally wherein the fiber is a multicomponent fiber,

optionally wherein the fiber comprises about 50% or greater by weight of the homogeneous blend, and

optionally wherein the fiber is a continuous filament, a staple fiber, a nanofiber, or a nanofilament.

2. The fiber of claim 1, wherein the first PLA polymer has an isomeric purity for the D-isomer or the L-isomer of at least about 99%, the second PLA polymer has an isomeric purity for the D-isomer or the L-isomer of about about98% to about 98.5%, and the weight ratio of the first PLA polymer to the second PLA polymer in the homogeneous blend is about 50:50 to about 75:25.

3. The fiber of claim 1, wherein a fiber exhibits a shrinkage of less than about 20%, or up to about 17%, or up to about 13%, or up to about 10%, at a temperature of about 110 °C to about 130 °C, or about 130 °C after the fiber has been heat-set at a temperature of about 90 °C.

4. A multicomponent fiber comprising:

a first component in the form of a polylactic acid (PLA) homopolymer having an isomeric purity for the D-isomer or the L-isomer of at least about 99%, or L-isomer or D-isomer pure, wherein the PLA melts at a first temperature; and

a second component disposed on at least part of an exterior surface of the multicomponent fiber, wherein the second component has an isomeric purity for the D-isomer or the L-isomer of no greater than about 98.5%, optionally wherein the second component comprises a component that melts at a second temperature;

wherein when present the second temperature is less than the first temperature, and

optionally wherein the multicomponent fiber is in the form of a core/sheath arrangement, wherein the first component is a core component and the second component is a sheath component.

5. The multicomponent fiber of claim 4, wherein the second component is in the form of a homopolymer.

6. The multicomponent fiber of claim 4, wherein the second component is in the form of a blend.

7. The multicomponent fiber of claim 6, wherein the blend is a homogeneous blend of a first polylactic acid (PLA) polymer and a second polylactic acid (PLA) polymer, wherein the first PLA polymer has an isomeric purity for the D-isomer or the L-isomer of at least about 99% and the second PLA polymer has an isomeric purity for the D-isomer or the L-isomer of no greater than about 98.5%.

8. A bundle of filaments comprising a fiber according to claim 1, wherein the bundle is in the form of a yarn or a tow, and

optionally wherein a portion of the filaments are formed of fibers comprising the homogeneous blend, and wherein a portion of the filaments are formed of amorphous PLA.

9. A fabric comprising a fiber according to claim 1 or a multicomponent fiber according to Claim 4, and

optionally wherein the fabric is a nonwoven fabric, a woven fabric, or a knit fabric.

10. A composition formed from a fabric according to claim 9.

11. A yarn or tow comprising a plurality of filaments comprising polylactic acid (PLA) polymer, wherein a first set of the filaments comprise semi-crystalline PLA having an L-isomer content of at least about 99%, and wherein a second set of the filaments comprise amorphous PLA having a D-isomer content of about 5% or greater.

12. A filtration device comprising a fiber according to claim 1, a multicomponent fiber according to Claim 4, or the yarn or tow according to Claim 11.

13. The filtration device according to Claim 12, wherein the filtration device is a cigarette filter.

14. A cigarette comprising the filtration device according to Claim 13.

15. A method of preparing a low shrinkage, high productivity polylactic acid (PLA) material, the method comprising:

forming a fiber comprising a homogeneous blend of a first polylactic acid (PLA) polymer and a second polylactic acid (PLA) polymer, wherein the first PLA polymer has an isomeric purity for the D-isomer or the L-isomer of at least about 99% and the second PLA polymer has an isomeric purity for the D-isomer or the L-isomer of no greater than about 98.5%;

drawing the formed fiber at a draw ratio of about 3:1 or greater; and

heat-setting the formed fiber at a temperature of up to about 110 °C;

wherein after the heat-setting step, the PLA material exhibits a shrinkage of less than about 20% at a temperature of about 115 °C to about 130 °C.

16. A method of preparing a multicomponent binder fiber exhibiting low shrinkage, the method comprising:

providing a multicomponent fiber formed of a first, high melting polymer component and a second, lower melting polymer component, wherein the first polymer component is a PLA polymer with an isomeric purity for the L-isomer of at least about 99%, wherein the second polymer component is a PLA polymer with an isomeric purity for the L-isomer of no more

than about 98.5%, and wherein the second component comprises at least a portion of an outer surface of the multicomponent binder fiber; and

heat-setting the multicomponent binder fiber at a temperature that is less than the activation temperature at which the second polymer component melts;

wherein the formed, heat-set multicomponent binder fiber exhibits a shrinkage of less than about 20% at a temperature greater than the activation temperature.