

POLYHYDROXYALKANOATE-BASED FIBERS**FIELD**

[0001] This disclosure relates, in general, to synthetic fibers. More particularly, this disclosure relates to synthetic fibers made from polyhydroxyalkanoates combined with a second biopolymer.

BACKGROUND

[0002] Synthetic fibers are traditionally formed from petroleum-based polymers such as polypropylene or polyethylene terephthalate. Despite the good mechanical properties of these polymers, there is a growing demand for fibers formed from more environmentally friendly materials, such as polyhydroxyalkanoates (PHAs). However, PHA fibers have been found to be challenging to work on due to poor mechanical strength and/or thermal degradability compared to petroleum-based polymers.

[0003] Thus, it would be desirable, and an object of the present disclosure, to provide synthetic fibers formed from PHA-based compositions having improved mechanical properties and resistance to thermal degradation. Preferably, the fibers formed from these PHA-based compositions would have mechanical properties comparable to those of fibers formed from petroleum-based polymers.

[0004] It would also be desirable, and an object of the present disclosure, to provide methods for forming synthetic fibers from PHA-based compositions which preserve the molecular weight and mechanical properties of the PHA-based compositions.

SUMMARY

[0006] The above and other needs are met by synthetic fibers formed from PHA-based compositions, according to the present disclosure.

[0007] In one aspect, the present disclosure provides a synthetic fiber. According to certain embodiments, the synthetic fiber is formed from a composition that is made of from about 1 to about 98 weight percent of at least one polyhydroxyalkanoate. The composition is also made of from about 1 to about 10 weight percent of at least one nucleating agent selected from the group consisting of polyester waxes, behenamide, crodamide, stearamide, erucamide, pentaerythritol, dipentaerythritol, boron nitride, and mixtures thereof and from about 0.1 to about 5 weight percent of at least one melt flow modifier selected from the group consisting of calcium stearate, zinc stearate, starch, diamide oligomers, organic peroxides and mixtures thereof and mixtures thereof.

[0008] Preferably, the composition is made of from about 30 to about 70 weight percent of the at least one polyhydroxyalkanoate, from about 1 to about 5 weight percent of the at least one nucleating agent, and from about 0.1 to about 3 weight percent of the at least one melt flow modifier. Still, more preferably, the composition is made of from about 40 to about 60 weight percent of the at least one polyhydroxyalkanoate, from about 1.5 to about 3 weight percent of the at least one nucleating agent, and from about 0.2 to about 3 weight percent of the at least one melt flow modifier.

[0009] In some embodiments, the composition may include a mixture of different polyhydroxyalkanoates. In some embodiments, for example, the composition may be made up of from about 1 to about 97 weight percent of at least one polyhydroxyalkanoate copolymer or terpolymer and from 1 to about 20 weight percent of polyhydroxybutyrate.

[0010] Preferably, the composition is made up of from about 30 to about 70 the at least one polyhydroxyalkanoate copolymer or terpolymer, and from 5 to about 15 weight percent of the polyhydroxybutyrate. Still more preferably, the composition is made up of from about 40 to about 60 the at least one polyhydroxyalkanoate copolymer or terpolymer, and from 7 to about 12 weight percent of the polyhydroxybutyrate.

[0011] In certain embodiments, other biodegradable polymer may be included, along with polyhydroxyalkanoates. For instance, the composition may include from about 30 to about 65 weight percent of at least one polyhydroxyalkanoate and from about 30 to about 60 weight percent of at least one biopolymer selected from the group consisting of polylactic acid, polybutylene succinate, polybutylene succinate adipate, polybutylene adipate terephthalate, phenylbenzimidazole sulfonic acid, and mixtures thereof.

[0012] Preferably, the composition may include from about 35 to about 60 weight percent of the at least one polyhydroxyalkanoate and from about 30 to about 50 of the at least one biopolymer. Still, more preferably, the composition may include from about 40 to about 56 weight percent of the at least one polyhydroxyalkanoate and from about 30 to about 40 weight percent of the at least one biopolymer.

[0013] In some embodiments, the at least one polyhydroxyalkanoate is made up of polyhydroxyalkanoate copolymer.

[0014] According to certain embodiments, the at least one poly(hydroxyalkanoate) is made of from about 5 to about 20 mole percent monomer repeat units selected from the group consisting of 3-hydroxyhexanoate, 3-hydroxyoctanoate, 3-hydroxydecanoate, and mixtures thereof. Still, more preferably, the at least one poly(hydroxyalkanoate) is made of from about 10 to about 15 mole percent monomer repeat units.

[0015] In some instances, the at least one polyhydroxyalkanoate is made up of poly-3-hydroxybutyrate-co-3-hydroxyhexanoate (P3HB-co-P3HHx), which includes from about 2 to about 8 mole percent monomer repeat units of 3-hydroxyhexanoate.

[0016] In certain embodiments, the at least one polyhydroxyalkanoate is made up of a polyhydroxyalkanoate terpolymer. This terpolymer is, in turn, made up of from about 75 to about 99.8 mole percent monomer repeat units of 3-hydroxybutyrate, from about 0.1 to about 24.9 mole percent monomer repeat units of 3-hydroxyhexanoate, and from about 0.1 to about 24.9 mole percent monomer repeat units of a third 3-hydroxyalkanoate selected from the group consisting of 3-hydroxyhexanoate, 3-hydroxyoctanoate, and 3-hydroxydecanoate.

[0017] Preferably, the terpolymer is made up of from about 80 to about 95 mole percent monomer repeat units of 3-hydroxybutyrate, from about 0.9 to about 19.9 mole percent monomer repeat units of 3-hydroxyhexanoate, and from about 0.1 to about 19.1 mole percent monomer repeat units of the third 3-hydroxyalkanoate.

[0018] More preferably, the terpolymer is made up of from about 85 to about 90 mole percent monomer repeat units of 3-hydroxybutyrate, from about 1.9 to about 11.1 mole percent monomer repeat units of 3-hydroxyhexanoate, and from about 3.9 to about 13.1 mole percent monomer repeat units of the third 3-hydroxyalkanoate.

[0019] In some embodiments, the composition preferably includes from about 30 to about 50 weight percent of at least one polyhydroxyalkanoate and further includes from about 5 to about 20 weight percent of at least one filler, selected from the group consisting of calcium carbonate, talc, polysaccharides, starch, clays, diatomaceous earth, kaolinite, montmorillonite, bentonite, silica, chitin, titanium dioxide, nano-clay, mica, hemp, nano-cellulose, and mixtures thereof.

[0020] Preferably, the composition includes from about 32 to about 45 weight percent of the at least one polyhydroxyalkanoate and from about 7 to about 18 weight percent of the at least one filler. More preferably, the composition includes from about 37 to about 43 weight percent of the at least one polyhydroxyalkanoate and from about 10 to about 15 weight percent of the at least one filler.

[0021] In certain instances, the at least one biopolymer preferably includes polylactic acid.

[0022] In certain embodiments, the at least one polyhydroxyalkanoate preferably has a weight average molecular weight from about 50,000 to about 1,500,000 Daltons, as determined by ASTM D5296-05. Preferably, the weight average molecular weight is from about 200,000 to about 1,000,000 Daltons, and more preferably from about 300,000 to about 600,000 Daltons.

[0023] According to some embodiments, the at least one polyhydroxyalkanoate preferably has a bimodal molecular weight distribution, having a first molecular weight peak centered at about 100,000 to about 175,000 Daltons and a second molecular weight peak centered at about 200,000 to about 300,000 Daltons, as determined by ASTM D5296-05.

[0024] In some instances, the at least one polyhydroxyalkanoate preferably has a polydispersity index from about 1.5 to about 5, as determined by ASTM D5296-05. Preferably the polydispersity index is from about 1.75 to about 4 and more preferably from about 2 to 3.

[0025] In certain embodiments, the at least one polyhydroxyalkanoate has a weight average molecular weight from about 100,000 to about 400,000 Daltons, as determined by ASTM D5296-05, and a polydispersity index from about 2 to about 3, as determined by ASTM D5296-05.

[0026] According to certain embodiments, the composition preferably has a melting temperature from about 110 °C to about 165 °C, more preferably from about 135 °C to about 155 °C, and even more preferably from about 140 °C to about 150 °C as determined by ASTM D3418.

[0027] Moreover, in some embodiments, the composition preferably has a melt flow index from about 5 to about 1500 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[0028] In accordance with certain embodiments, the composition also preferably includes from about 0.1 to about 4.0 weight percent of at least one melt strength enhancer selected from the group consisting of carbodiimides, epoxides, and mixtures thereof. Preferably, the composition includes from about 0.5 to about 3 of the at least one melt strength enhancer. More preferably, the composition includes from about 0.75 to about 1.5 of the at least one melt strength enhancer.

[0029] More specifically, the melt flow index of the composition is preferably selected to allow the spinning of the fibers at a temperature which does not lead to degradation of the polyhydroxyalkanoate polymer and loss of weight average molecular weight.

[0030] Thus, in accordance with some embodiments, the fiber is filament spun, and the composition has a melt flow index from about 5 to about 30 grams/10 minutes, preferably from about 10 to about 25 grams/10 minutes, and more preferably from about 12 to about 18 grams/10 minutes, when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[0031] According to other embodiments, a nonwoven fabric is formed from the synthetic fiber, and the composition has a melt flow index from about 50 to about 100 grams/10 minutes, preferably from about 65 to about 90 grams/10 minutes and more preferably from about 75 to about 85 grams / 10 minutes, when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[0032] In still other embodiments, a nonwoven fabric is formed from the synthetic fiber, and the composition has a melt flow index from about 500 to about 1500 grams/10 minutes, preferably from about 750 to about 1300 grams/ 10 minutes, and more preferably from about 900 to about 1100 grams/ 10 minutes, when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[0033] In some instances, the fiber is preferably oriented.

[0034] Further, in certain embodiments, the fiber is preferably post-treated with a fiber lubricant composition, which includes at least one lubricant selected from the group consisting of hydrophobic esters, mineral oils, silicon compositions, and mixtures thereof.

[0035] In another aspect, the present disclosure also provides a nonwoven fabric that is made up of a plurality of the aforementioned synthetic fibers. In certain embodiments, the present disclosure also provides articles formed from this nonwoven fabric, which are selected from the group consisting of medical protective equipment, personal hygienic wipes, cleaning wipes, filtration systems, diapers, feminine hygiene products, coffee/tea bags, and laundry fabric sheets.

[0036] In a further aspect, the present disclosure provides a method for forming a plurality of synthetic fibers. According to one embodiment, the method includes a step of blending at least one polyhydroxyalkanoate, at least one nucleating agent, and at least one melt flow modifier in a first extruder to form a resin composition. This resin composition is made up of from about 1 to about 98 weight percent of at least one polyhydroxyalkanoate; from about 1 to about 10 weight percent of at least one nucleating agent selected from the group consisting of polyester waxes, behenamide, crodamide, stearamide, erucamide, pentaerythritol, dipentaerythritol, boron nitride, and mixtures thereof; and from about 0.1 to about 5 weight percent of at least one melt flow modifier selected from the group

consisting of calcium stearate, zinc stearate, starch, diamide oligomers, organic peroxides, and mixtures thereof.

[0037] The method also includes a step of melt processing the resin composition at a temperature from about 165 to about 185 °C and extruding the composition through a plurality of spinnerets to produce a plurality of fibers.

[0038] Advantageously, it has been found that extruding and spinning the fibers within this temperature range minimizes the degradation of the polymer and loss of weight average molecular weight of the polymer. In order to extrude and spin the fibers at this relatively low-temperature range, melt flow modifiers are selected to provide an appropriate composition viscosity for the spinning of the fibers.

[0039] According to certain embodiments of the method, the plurality of fibers is made up of fiber filaments having a length of at least 300 mm. In such embodiments, the resin composition preferably has a melt flow index from about 5 to about 30 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[0040] In some embodiments, the method includes a further step of collecting the plurality of fibers on a flat conveyer belt and bonding the fibers together to form a spunbond nonwoven web. In such embodiments, the resin composition preferably has a melt flow index from about 50 to about 100 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[0041] In other embodiments, the method includes a further step of collecting the plurality of fibers on a rotating circular conveyer and bonding the fibers together to form a melt-blown nonwoven web. In such embodiments, the resin composition preferably has a melt flow index from about 500 to about 1500 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

DETAILED DESCRIPTION

[0043] The present disclosure first provides synthetic fibers formed from PHA-based compositions having improved mechanical properties and resistance to thermal degradation.

[0044] In general, the present disclosure provides synthetic fibers which are formed from a composition comprising at least one polyhydroxyalkanoate and optionally at least one additional biopolymer.

[0045] The synthetic fibers, according to the present disclosure, may include staple fibers, nonwoven fibers, yarn fibers, and filaments.

[0046] For instance, fibers may be melt spun by melting the composition of the present disclosure and spinning the molten composition from a spinneret to form filaments. In some instances, a monofilament may be collected, while in other instances, multiple filaments may be collected together as a single strand.

[0047] The filaments so produced may be quite long, or they may be cut into relatively short staple fibers. For staple fibers the length of the staple fibers is typically from about 10 mm to about 150 mm. Filaments which are not cut into staple fibers will typically have a length from about 300 mm to about 5 meters.

[0048] In various embodiments, the fibers of the present disclosure may have a solid cross-section or a hollow cross-sectional structure. In some embodiments, the fibers of the present disclosure may have a bicomponent structure, such as a side-by-side structure, a core and sheath structure, and so forth.

[0049] The average cross-sectional diameter of the fibers will typically be from about 2 to about 50 microns.

[0050] In accordance with certain embodiments of the present disclosure, the fibers are preferably oriented by drawing the fibers.

[0051] In some embodiments, the fibers are also preferably post-treated with a fiber lubricant composition, which includes at least one lubricant selected from the group consisting of hydrophobic esters, mineral oils, silicon compositions, and mixtures thereof.

A suitable example of such a fiber lubricant is Lurol PL, available from Goulston Technologies, Inc.

[0052] In some embodiments, the fibers made from the composition of the present disclosure may be used to form a nonwoven fabric. For instance, the nonwoven fabric may be formed by a spun bond process, in which multiple fibers are simultaneously extruded onto a flat conveyor belt and then bonded together (such as by thermal bonding or hydroentanglement) to form a nonwoven material. Alternatively, the nonwoven fabric may be formed by a melt-blown process, in which the melted composition is shot from small capillaries to form small fibers, which are collected on a rotating circular conveyor and bonded together to form a nonwoven material.

[0053] Various articles may be formed from the nonwoven fabric according to the present disclosure, such as medical protective equipment, personal hygienic wipes, cleaning wipes, filtration systems, diapers, feminine hygiene products, coffee/tea bags, and laundry fabric sheets.

[0054] As noted above, the fibers are prepared from a composition comprising at least one polyhydroxyalkanoate. In some embodiments, the composition also comprises at least one additional biopolymer, which is selected from the group consisting of polylactic acid, polybutylene succinate, polybutylene succinate adipate, polybutylene adipate terephthalate, phenylbenzimidazole sulfonic acid, and mixtures thereof.

[0055] In general, the composition comprises from about 1 to about 98 weight percent of the at least one polyhydroxyalkanoate and, more preferably, from about 30 to about 70, and even more preferably 40 to about 60 weight percent of the at least one polyhydroxyalkanoate.

[0056] In various embodiments, the at least one polyhydroxyalkanoate may comprise a homopolymer, a copolymer, a terpolymer, or a mixture thereof. In some instances, the composition may comprise a polyhydroxyalkanoate homopolymer, such as polyhydroxybutyrate. In other instances, the composition may comprise a polyhydroxyalkanoate copolymer.

[0057] In some embodiments, the at least one poly(hydroxyalkanoate) is made up of from about 1 to about 25 mole percent monomer repeat units selected from the group consisting of 3-hydroxyhexanoate, 3-hydroxyoctanoate, 3-hydroxydecanoate, and mixtures thereof, preferably from about 5 to about 20 mole percent, and more preferably from about 10 to about 15 mole percent.

[0058] In other embodiments, the at least one polyhydroxyalkanoate, preferably is poly-3-hydroxybutyrate-co-3-hydroxyhexanoate (P3HB-co-P3HHx), comprising from about 2 to about 8 weight percent of the 3-hydroxyhexanoate monomer.

[0059] In some embodiments, the at least one polyhydroxyalkanoate preferably includes a polyhydroxyalkanoate terpolymer, wherein the terpolymer is made up from about 75 to about 99.8 mole percent monomer repeat units of 3-hydroxybutyrate, from about 0.1 to about 24.9 mole percent monomer repeat units of 3-hydroxyhexanoate, and from about 0.1 to about 24.9 mole percent monomer repeat units of a third 3-hydroxyalkanoate selected from the group consisting of 3-hydroxyhexanoate, 3-hydroxyoctanoate, and 3-hydroxydecanoate.

[0060] More preferably, the terpolymer is made up of from about 80 to about 95 mole percent monomer repeat units of 3-hydroxybutyrate, from about 0.9 to about 19.9 mole percent monomer repeat units of 3-hydroxyhexanoate, and from about 0.1 to about 19.1 mole percent monomer repeat units of the third 3-hydroxyalkanoate.

[0061] Even more preferably, the terpolymer is made up of from about 85 to about 90 mole percent monomer repeat units of 3-hydroxybutyrate, from about 1.9 to about 11.1 mole percent monomer repeat units of 3-hydroxyhexanoate, and from about 3.9 to about 13.1 mole percent monomer repeat units of the third 3-hydroxyalkanoate.

[0062] The composition may also comprise a mixture of polyhydroxyalkanoate homopolymers, copolymers, and/or terpolymers.

[0063] In some instances, the composition comprises from about 1 to about 97 weight percent of at least one polyhydroxyalkanoate copolymer or terpolymer and from 1 to about 20 weight percent of polyhydroxybutyrate.

[0064] More preferably, the composition comprises from about 30 to about 70 weight percent of at least one polyhydroxyalkanoate copolymer or terpolymer and from about 6 to 15 weight percent of polyhydroxybutyrate. Even more preferably, the composition comprises from about 40 to about 60 weight percent of at least one polyhydroxyalkanoate copolymer or terpolymer and from about 7 to 12 weight percent of polyhydroxybutyrate

[0065] In certain embodiments, the at least one polyhydroxyalkanoate preferably has a weight average molecular weight from about 50,000 to about 1,500,000 Daltons, as determined by ASTM D5296-05. Preferably, the weight average molecular weight is from about 200,000 to about 1,000,000 Daltons, and more preferably from about 300,000 to about 600,000 Daltons.

[0066] In other embodiments, the at least one polyhydroxyalkanoate more preferably has a weight average molecular weight from about 100,000 to about 400,000 Daltons, as determined by ASTM D5296-05.

[0067] In some embodiments, the at least one polyhydroxyalkanoate may have an unimodal molecular weight distribution with one clear peak in the molecular weight distribution.

[0068] In other embodiments, however, it is preferred that the at least one polyhydroxyalkanoate has a bimodal molecular weight distribution, typically having a first molecular weight peak centered at about 100,000 to about 175,000 Daltons and a second molecular weight peak centered at about 200,000 to about 300,000 Daltons, as determined by ASTM D5296-05.

[0069] In some instances, the at least one polyhydroxyalkanoate preferably has a polydispersity index from about 1.5 to about 5, as determined by ASTM D5296-05. Preferably the polydispersity index is from about 1.75 to about 4 and more preferably from about 2 to 3. More preferably, the at least one polyhydroxyalkanoate has a weight average molecular weight from about 100,000 to about 400,000 Daltons, as determined by ASTM D5296-05, and a polydispersity index from about 2 to about 3, as determined by ASTM D5296-05.

[0070] In addition to the polyhydroxyalkanoate, the composition may also comprise at least one additional biopolymer. This biopolymer is typically selected from the group consisting of polylactic acid, polybutylene succinate, polybutylene succinate adipate, polybutylene adipate terephthalate, phenylbenzimidazole sulfonic acid, and mixtures thereof. In some embodiments, the biopolymer is more preferably polylactic acid. The additional biopolymer is present in the composition in an amount from about 30 to about 60 weight percent, preferably from about 30 to about 50 weight percent, and more preferably from about 30 to about 40 weight percent.

[0071] The composition also comprises at least one nucleating agent to improve the crystallization speed of the polymer. Typically, the nucleating agent is selected from the group consisting of polyester waxes, behenamide, crodamide, stearamide, erucamide, pentaerythritol, dipentaerythritol, boron nitride, and mixtures thereof. More preferably, the nucleating agent is pentaerythritol. The amount of the nucleating agent in the composition is typically from about 1 to about 10 weight percent, preferably from about 1 to about 5 weight percent, and more preferably from about 1.5 to about 3 weight percent.

[0072] The composition further includes at least one melt flow modifier to improve the melt flow index of the composition. Typically, the at least one melt flow modifier is selected from the group consisting of calcium stearate, zinc stearate, starch, diamide oligomers, organic peroxides, and mixtures thereof. The amount of the melt flow modifier is generally from about 0.1 to about 5 weight percent, preferably from about 0.1 to about 3 weight percent, and more preferably from about 0.2 to about 3 weight percent,

[0073] With the melt flow modifiers, the composition, in general terms, typically has a melt flow index from about 5 to about 1500 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[0074] More particularly, the melt flow index of the composition may be more narrowly optimized depending upon the nature of the fibers being formed from it. For instance, if the fibers are filament spun from the composition, then the composition generally has a melt flow index from about 5 to about 30 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238, preferably

from about 10 to about 25 grams/10 minutes, and more preferably from about 12 to about 18 grams/10 minutes.

[0075] In embodiments in which the fibers are formed from spunbond, the composition generally has a melt flow index from about 50 to about 100 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238, preferably from about 65 to about 90 grams/10 minutes and more preferably from about 75 to about 85 grams / 10 minutes.

[0076] In still other embodiments, the fiber is preferably formed from melt-blown, and the composition has a melt flow index from about 500 to about 1500 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238., preferably from about 750 to about 1300 grams/ 10 minutes, and more preferably from about 900 to about 1100 grams/ 10 minutes.

[0077] In some instances, the composition also comprises at least one filler material. For example, the filler may be selected from the group consisting of calcium carbonate, talc, polysaccharides, starch, clays, diatomaceous earth, kaolinite, montmorillonite, bentonite, silica, chitin, titanium dioxide, nano-clay, mica, hemp, nano-cellulose, and mixtures thereof. When a filler is present, the composition preferably includes from about 5 to about 20 weight percent of at least one filler and includes from about 30 to about 50 weight percent of at least one polyhydroxyalkanoate.

[0078] In accordance with certain embodiments, the composition also preferably includes from about 0.1 to about 4.0 weight percent of at least one melt strength enhancer selected from the group consisting of carbodiimides, epoxides, and mixtures thereof. More preferably, the composition includes from about 0.5 to about 3 of the at least one melt strength enhancer. Still, more preferably, the composition includes from about 0.75 to about 1.5 of the at least one melt strength enhancer.

[0079] Without being bound by theory, it is believed that adding a melt strength enhancer allows the fibers to be stretched in certain embodiments while still maintaining a desired melt flow index for processing. Moreover, these melt strength enhancers are also believed

to prevent degradation of the fibers during processing due to hydrolysis of the polymers and/or exposure to shear and heat.

[0080] Moreover, in certain embodiments, the composition may also comprise one or more further additives selected from the group consisting of dodecenylsuccinic anhydride, succinic anhydride, and mixtures thereof.

[0081] In some instances, the composition preferably has a melting temperature from about 140 °C to about 150 °C as determined by ASTM D3418.

[0082] In a further aspect, the present disclosure also provides a nonwoven fabric that is made up of a plurality of the aforementioned synthetic fibers. The nonwoven fabric may be formed using methods such as spunbond and melt blown.

[0083] In addition to nonwoven fabrics, the fibers of the present disclosure may also be used for staple, air-laid, and spunlaid processes.

[0084] The present disclosure also provides a method for forming a plurality of the synthetic fibers described above. According to this method, the components for the fiber composition are first blended together in a first extruder to form a resin composition. This includes the at least one polyhydroxyalkanoate, at least one nucleating agent, and at least one melt flow modifier, as well as any other biopolymers or other additives.

[0085] The resultant resin composition is then melt-processed, typically in a second extruder. The melt processing is typically carried out at a temperature from about 165 to about 185 °C, and the composition is extruded through a plurality of spinnerets to produce a plurality of fibers.

[0086] These melt processing temperatures are significantly lower than conventional processing temperatures for the spinning of PHA-based synthetic fibers, particularly fibers intended for use in nonwoven fabrics. Synthetic fibers for spunbond nonwovens typically have a diameter on the order of about 10 microns (μm), and fibers for melt-blown nonwovens typically have an even smaller diameter on the order of about 1 – 2 microns (μm).

[0087] In order to spin fibers of such a small diameter, the viscosity of the polymer composition must be quite low. Typically, this is achieved by heating the polymer composition to highly elevated temperatures of at least about 190 – 210 °C prior to spinning. However, heating PHA-based compositions to such temperatures leads to the degradation of the PHA molecules, leading to a significant loss of weight average molecular weight for the PHA molecules.

[0088] According to the present disclosure, however, the viscosity of the polymer composition is lowered by the addition of melt flow modifiers rather than by excessive heating of the polymer composition prior to spinning.

[0089] Thus, depending upon the intended use of the fibers, the fiber composition may have significantly different melt flow characteristics when the fibers are initially formed.

[0090] In some embodiments, the plurality of fibers is made up of fiber filaments having a length of at least 300 mm. In such embodiments, the resin composition preferably has a melt flow index from about 5 to about 30 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[0091] In other embodiments, the fibers may be used to form a spunbond nonwoven web, which is formed by collecting the plurality of fibers on a flat conveyer belt and bonding the fibers together to form the nonwoven web. In such embodiments, the resin composition preferably has a melt flow index from about 50 to about 100 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[0092] In other embodiments, the fibers may be used to form a meltblown nonwoven web, which is formed by collecting the plurality of fibers on a rotating circular conveyer and bonding the fibers together to form a melt-blown nonwoven web. In such embodiments, the resin composition preferably has a melt flow index from about 500 to about 1500 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[0093] EMBODIMENTS

[0094] The present disclosure is also further illustrated by the following embodiments:

[0095] Embodiment 1. A synthetic fiber formed from a composition comprising:

[0096] from about 1 to about 98 weight percent, preferably from about 30 to about 70 weight percent, and more preferably from about 40 to about 60 weight percent, of at least one polyhydroxyalkanoate;

[0097] from about 1 to about 10 weight percent, preferably from about 1 to about 5 weight percent, and more preferably from about 1.5 to about 3 weight percent, of at least one nucleating agent selected from the group consisting of polyester waxes, behenamide, crodamide, stearamide, erucamide, pentaerythritol, dipentaerythritol, boron nitride, and mixtures thereof; and

[0098] from about 0.1 to about 5 weight percent, preferably from about 0.1 to about 3 weight percent, and more preferably from about 0.2 to about 3 weight percent, of at least one melt flow modifier selected from the group consisting of calcium stearate, zinc stearate, starch, diamide oligomers, organic peroxides and mixtures thereof.

[0099] Embodiment 2. The synthetic fiber of Embodiment 1, wherein the composition comprises from about 1 to about 97 weight percent, preferably from about 30 to about 70 weight percent, and more preferably from about 40 to about 60 weight percent, of at least one polyhydroxyalkanoate copolymer or terpolymer and from about 1 to about 20 weight percent, preferably from about 5 to about 15 weight percent, and more preferably from about 7 to about 12 weight percent, of polyhydroxybutyrate.

[00100] Embodiment 3. The synthetic fiber of Embodiment 1 or 2, wherein the composition comprises:

[00101] from about 30 to about 65 weight percent, preferably from about 35 to about 60 weight percent, and more preferably from about 40 to about 56 weight percent, of at least one polyhydroxyalkanoate;

[00102] from about 30 to about 60 weight percent, preferably from about 30 to about 50 weight percent, and more preferably from about 30 to about 40 weight percent, of at least one biopolymer selected from the group consisting of polylactic acid, polybutylene succinate, polybutylene succinate adipate, polybutylene adipate terephthalate,

phenylbenzimidazole sulfonic acid, and mixtures thereof. Preferably the at least one biopolymer comprises polylactic acid.

[00103] Embodiment 4. The synthetic fiber of any of the preceding Embodiments, wherein the at least one polyhydroxyalkanoate comprises a polyhydroxyalkanoate copolymer.

[00104] Embodiment 5. The synthetic fiber of any of the preceding Embodiments, wherein the at least one poly(hydroxyalkanoate) comprises from about 1 to about 25 mole percent, preferably from about 5 to about 20 mole percent, or from about 10 to about 15 mole percent, monomer repeat units selected from the group consisting of 3-hydroxyhexanoate, 3-hydroxyoctanoate, 3-hydroxydecanoate, and mixtures thereof.

[00105] Embodiment 6. The synthetic fiber of any of the preceding Embodiments, wherein the at least one polyhydroxyalkanoate comprises poly-3-hydroxybutyrate-co-3-hydroxyhexanoate (P3HB-co-P3HHx), comprising from about 2 to about 8 mole percent monomer repeat units of 3-hydroxyhexanoate.

[00106] Embodiment 7. The synthetic fiber of any of the preceding Embodiments, wherein the at least one polyhydroxyalkanoate comprises a polyhydroxyalkanoate terpolymer, wherein the terpolymer comprises

[00107] from about 75 to about 99.8 mole percent, preferably from about 80 to about 95 mole percent and more preferably from about 85 to about 90 mole percent, monomer repeat units of 3-hydroxybutyrate,

[00108] from about 0.1 to about 24.9 mole percent, preferably from about 0.9 to about 19.9 mole percent and more preferably from about 1.9 to about 11.1 mole percent, monomer repeat units of 3-hydroxyhexanoate, and

[00109] from about 0.1 to about 24.9 mole percent monomer, preferably from about 0.1 to about 19.1 mole percent and more preferably from about 3.9 to about 13.1 mole percent repeat units of a third 3-hydroxyalkanoate selected from the group consisting of 3-hydroxyhexanoate, 3-hydroxyoctanoate, and 3-hydroxydecanoate.

[00110] Embodiment 8. The synthetic fiber of any of the preceding Embodiments, wherein the composition comprises from about 30 to about 50 weight percent, preferably from about 32 to about 45 weight percent, and more preferably from about 37 to about 43 weight percent, of at least one polyhydroxyalkanoate, and further comprises from about 5 to about 20 weight percent, preferably from about 7 to about 18 weight percent, and more preferably from about 10 to about 15 weight percent, of at least one filler, selected from the group consisting of calcium carbonate, talc, polysaccharides, starch, clays, diatomaceous earth, kaolinite, montmorillonite, bentonite, silica, chitin, titanium dioxide, nano-clay, mica, hemp, nano-cellulose, and mixtures thereof.

[00111] Embodiment 9. The synthetic fiber of any of the preceding Embodiments, wherein the at least one polyhydroxyalkanoate has a weight average molecular weight from about 50,000 to about 1,500,000 Daltons, preferably from about 200,000 to about 1,000,000 Daltons and more preferably from about 300,000 to about 600,000 Daltons, as determined by ASTM D5296-05.

[00112] Embodiment 10. The synthetic fiber of any of the preceding Embodiments, wherein the at least one polyhydroxyalkanoate has a bimodal molecular weight distribution, having a first molecular weight peak centered at about 100,000 to about 175,000 Daltons and a second molecular weight peak centered at about 200,000 to about 300,000 Daltons, as determined by ASTM D5296-05.

[00113] Embodiment 11. The synthetic fiber of any of the preceding Embodiments, wherein the at least one polyhydroxyalkanoate has a polydispersity index from about 1.5 to about 5, preferably from about 1.75 to about 4, and more preferably from about 2 to about 3, as determined by ASTM D5296-05.

[00114] Embodiment 12. The synthetic fiber of any of the preceding Embodiments, wherein the at least one polyhydroxyalkanoate has a weight average molecular weight from about 100,000 to about 400,000 Daltons, as determined by ASTM D5296-05 and a polydispersity index from about 2 to about 3, as determined by ASTM D5296-05.

[00115] Embodiment 13. The synthetic fiber of any of the preceding Embodiments, wherein the composition has a melting temperature from about 140 °C to about 150 °C as determined by ASTM D3418.

[00116] Embodiment 14. The synthetic fiber of any of the preceding Embodiments, wherein the composition has a melt flow index from about 5 to about 1500 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[00117] Embodiment 15. The synthetic fiber of any of the preceding Embodiments, wherein the composition further comprises from about 0.1 to about 4.0 weight percent, preferably from about 0.5 to about 3 weight percent, and more preferably from about 0.75 to about 1.5 weight percent, of at least one melt strength enhancer selected from the group consisting of carbodiimides, epoxides, and mixtures thereof.

[00118] Embodiment 16. The synthetic fiber of any of the preceding Embodiments, wherein the fiber is filament spun, and the composition has a melt flow index from about 5 to about 30 grams/10 minutes, preferably from about 10 to about 25 grams/10 minutes, and more preferably from about 12 to about 18 grams/10 minutes, when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[00119] Embodiment 17. The synthetic fiber of any of the preceding Embodiments, wherein the fiber is oriented.

[00120] Embodiment 18. The synthetic fiber of any of the preceding Embodiments, wherein the fiber is post-treated with a fiber lubricant composition which includes at least one lubricant selected from the group consisting of hydrophobic esters, mineral oils, silicon compositions, and mixtures thereof.

[00121] Embodiment 19. A nonwoven fabric comprising a plurality of synthetic fibers according to any of the preceding Embodiments.

[00122] Embodiment 20. A spunbond nonwoven fabric formed from the synthetic fiber of any of Embodiments 1 – 18, wherein the composition has a melt flow index from about 50 to about 100 grams/10 minutes, preferably from about 65 to about 90 grams/10

minutes and more preferably from about 75 to about 85 grams / 10 minutes, when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[00123] Embodiment 21. A melt-blown nonwoven fabric formed from the synthetic fiber of any of Embodiments 1 – 18, wherein the composition has a melt flow index from about 500 to about 1500 grams/10 minutes, preferably from about 750 to about 1300 grams/ 10 minutes, and more preferably from about 900 to about 1100 grams/ 10 minutes, when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[00124] Embodiment 22. An article comprising the nonwoven fabric of any of Embodiments 19 – 22, wherein the article is selected from the group consisting of medical protective equipment, personal hygienic wipes, cleaning wipes, filtration systems, diapers, feminine hygiene products, coffee/tea bags, and laundry fabric sheets.

[00125] Embodiment 23. A method for forming a plurality of synthetic fibers, comprising the steps of:

[00126] blending at least one polyhydroxyalkanoate, at least one nucleating agent, and at least one melt flow modifier in a first extruder to form a resin composition, wherein the resin composition comprises

[00127] from about 1 to about 98 weight percent of at least one polyhydroxyalkanoate;

[00128] from about 1 to about 10 weight percent of at least one nucleating agent selected from the group consisting of polyester waxes, behenamide, crodamide, stearamide, erucamide, pentaerythritol, dipentaerythritol, boron nitride, and mixtures thereof; and

[00129] from about 0.1 to about 5 weight percent of at least one melt flow modifier selected from the group consisting of calcium stearate, zinc stearate, starch, diamide oligomers, organic peroxides, and mixtures thereof; and

[00130] melt processing the resin composition at a temperature from about 165 to about 185 °C and extruding the composition through a plurality of spinnerets to produce a plurality of fibers.

[00131] Embodiment 24. The method of Embodiment 23, wherein the plurality of fibers comprise fiber filaments having a length of at least 300 mm.

[00132] Embodiment 25. The method of Embodiment 24, wherein the resin composition has a melt flow index from about 5 to about 30 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[00133] Embodiment 26. The method of Embodiment 23, further comprising collecting the plurality of fibers on a flat conveyer belt and bonding the fibers together to form a spunbond nonwoven web.

[00134] Embodiment 27. The method of Embodiment 26, wherein the resin composition has a melt flow index from about 50 to about 100 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[00135] Embodiment 28. The method of Embodiment 23, further comprising collecting the plurality of fibers on a rotating circular conveyer and bonding the fibers together to form a melt-blown nonwoven web.

[00136] Embodiment 29. The method of Embodiment 28, wherein the composition has a melt flow index from about 500 to about 1500 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

[00137] EXAMPLES

[00138] The following non-limiting examples illustrate various additional aspects of the invention. Unless otherwise indicated, temperatures are in degrees Celsius, and percentages are by weight based on the dry weight of the formulation.

[00139] Example 1. A fiber composition consisting of 65.25% of a 6 mol% hexanoate and 94% butyrate polyhydroxyalkanoate copolymer, 31.25% of PLA, 1.50% pentaerythritol, and 2.00% of calcium stearate were compounded on a twin-screw extruder with a melt flow index of 15 grams/10 minutes at a compounding temperature of 175-180 °C. The compounded material was converted to a filament at a process temperature of 170 – 175 °C, with the pump set to 20 RPM and a post-conversion finish treatment of 30%. The filament was collected with a feed roll speed of 300 meters per minute (mpm) at a

temperature of 50 °C, a draw roll at 400 mpm and a temperature of 50 °C, and a relaxation roll of 500 mpm and a temperature of 30 °C.

[00140] Example 2. A fiber composition consisting of 45.25% of a 6 mol% hexanoate and 94% butyrate polyhydroxyalkanoate copolymer, 51.25% of PLA, 1.5% pentaerythritol, and 2.00% of N, N'-Ethylene bis-12-hydroxystearamide were compounded on a twin-screw extruder with a melt flow index of 13 grams/10 minutes at a compounding temperature of 175-180 °C. The compounded material was converted to a filament at a process temperature of 170 – 175 °C, with the pump set to 20 RPM and a post-conversion finish treatment of 30%. The filament was collected with a feed roll speed of 300 mpm at a temperature of 50 °C, a draw roll at 400 mpm and a temperature of 50 °C, and a relaxation roll of 500 mpm and a temperature of 50 °C.

[00141] Example 3. A fiber composition consisting of 56.75% of a 6 mol% hexanoate and 94% butyrate polyhydroxyalkanoate copolymer, 41.25% of PLA, 1.5% pentaerythritol, and 0.5% of calcium stearate were compounded on a twin-screw extruder with a melt flow index of 91 grams/10 minutes. The compounded material was converted to a filament at a process temperature of 165 – 172 °C, with a die temperature of 165 °C, a feeder speed of 20-30 rpm, and an air pressure of 20-40 PSI. Then, the filaments were turned into a spunbond material using thermal bonding at a calendar temperature of 100 °C.

[00142] Example 4. A fiber composition consisting of 46.75% of a 6 mol% hexanoate and 94% butyrate polyhydroxyalkanoate copolymer, 36.25% of PLA, 1.50% pentaerythritol, 10.00% of calcium carbonate, 5.00% talc, and 0.50% of calcium stearate were compounded on a twin-screw extruder with a melt flow index of 111 grams/10 minutes at a compounding temperature of 175-180 °C. The compounded material was converted to a filament at a process temperature of 165 – 172 °C, with a die temperature of 165 °C, a feeder speed of 20-30 rpm, and an air pressure of 20-40 PSI. Then, the filaments were turned into a spunbond material using thermal bonding at a calendar temperature of 100 °C.

[00143] Example 5. A fiber composition consisting of 56.75% of a 6 mol% hexanoate and 94% butyrate polyhydroxyalkanoate copolymer, 31.25% of PLA, 1.50% pentaerythritol, 10.00% of calcium carbonate, and 0.50% of calcium stearate were

compounded on a twin-screw extruder with a melt flow index of 149 grams/10 minutes at a compounding temperature of 175-180 °C. The compounded material was converted to a filament at a process temperature of 165 – 172 °C, with a die temperature of 165 °C, a feeder speed of 20-30 rpm, and an air pressure of 20-40 PSI. Then, the filaments were turned into a spunbond material using thermal bonding at a calendar temperature of 100 °C.

[00144] Example 6. A fiber composition consisting of 46.75% of a 6 mol% hexanoate and 94% butyrate polyhydroxyalkanoate copolymer, 36.25% of PLA, 1.5% pentaerythritol, 0.5% of calcium stearate, and 15% of calcium carbonate were compounded on a twin-screw extruder with a melt flow index of 241 grams/10 minutes at a compounding temperature of 175-180 °C. The compounded material was converted to a filament at a process temperature of 165 – 172 °C, with a die temperature of 165 °C, a feeder speed of 20-30 rpm, and an air pressure of 20-40 PSI. Then, the filaments were cut into smaller pieces and converted into staple fibers.

[00145] Example 7. A fiber composition consisting of 54.25% of a polyhydroxyalkanoate copolymer, 30.75% of PLA, 1.5% pentaerythritol, 2% of N, N'-Ethylene bis-12-hydroxystearamide, 1.5% of calcium stearate, 5% of calcium carbonate, and 5% of talc were compounded on a twin-screw extruder with a melt flow index of 580 grams/10 minutes at a compounding temperature of 175-180 °C. The compounded material was converted to a melt-blown material at a process temperature of 175 – 185 °C, utilizing a line with 368 capillaries at 0.009" diameter. The die temperature was 185 °C, the feeder speed was 20-25 rpm, and the blowing air temperature was 185 °C. Samples were collected at 20, 50, and 100 grams per square meter (gsm) thickness.

Example 8. A fiber composition consisting of 64.25% of a 6 mol% hexanoate and 94% butyrate polyhydroxyalkanoate copolymer, 30.75% of PLA, 1.5% pentaerythritol, 2% of N, N'-Ethylene bis-12-hydroxystearamide, and 1.5% of calcium stearate were compounded on a twin-screw extruder with a melt flow index of 487 grams/10 minutes at a compounding temperature of 175-180 °C. The compounded material was converted to a meltblown material at a process temperature of 175 – 185 °C, utilizing a line with 368 capillaries at 0.009" diameter. The die temperature was 185 °C, the feeder speed was 20-25 rpm, and

the blowing air temperature was 185 °C. Samples were collected at 20, 50, and 100 gsm thickness.

[00146] Example 9. A fiber composition consisting of 54.25% of a 6 mol% hexanoate and 94% butyrate polyhydroxyalkanoate copolymer, 40.25% of PLA, 1.50% pentaerythritol, 2.00% of N, N'-Ethylene bis-12-hydroxystearamide, and 2.00% of calcium stearate were compounded on a twin-screw extruder with a melt flow index of 455 grams/10 minutes at a compounding temperature of 175-180 °C. The compounded material was converted to a meltblown material at a process temperature of 175 – 185 °C, utilizing a line with 368 capillaries at 0.009" diameter. The die temperature was 185 °C, the feeder speed was 20-25 rpm, and the blowing air temperature was 185 °C. Samples were collected at 20, 50, and 100 gsm thickness.

[00147] Example 10. A fiber composition consisting of 64.25% of a 6 mol% hexanoate and 94% butyrate polyhydroxyalkanoate copolymer, 30.25% of PLA, 1.50% pentaerythritol, 2.00% of N, N'-Ethylene bis-12-hydroxystearamide, and 2.00% of calcium stearate were compounded on a twin-screw extruder with a melt flow index of 455 grams/10 minutes at a compounding temperature of 175-180 °C. The compounded material was converted to a meltblown material at a process temperature of 175 – 185 °C, utilizing a line with 368 capillaries at 0.009" diameter. The die temperature was 185 °C, the feeder speed was 20-25 rpm, and the blowing air temperature was 185 °C. Samples were collected at 20, 50, and 100 gsm thickness.

[00148] The foregoing description of preferred embodiments for this disclosure has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure to the precise form disclosed. Obvious modifications or variations are possible in light of the above teachings. The embodiments are chosen and described in an effort to provide the best illustrations of the principles of the disclosure and its practical application and to thereby enable one of ordinary skill in the art to utilize the disclosure in various embodiments and with various modifications as are suited to the particular use contemplated.

CLAIMS

Claim 1. A synthetic fiber formed from a composition comprising:

from 1 to 98 weight percent of at least one polyhydroxyalkanoate;

from 1 to 10 weight percent of at least one nucleating agent selected from the group consisting of polyester waxes, behenamide, crodamide, stearamide, erucamide, pentaerythritol, dipentaerythritol, boron nitride, and mixtures thereof; and

from 0.1 to 5 weight percent of at least one melt flow modifier selected from the group consisting of calcium stearate, zinc stearate, starch, diamide oligomers, organic peroxides, and mixtures thereof.

Claim 2. The synthetic fiber of Claim 1, wherein the composition comprises from 1 to 97 weight percent of at least one polyhydroxyalkanoate copolymer or terpolymer and from 1 to 20 weight percent of polyhydroxybutyrate.

Claim 3. The synthetic fiber of Claim 1, wherein the composition comprises:

from 30 to 65 weight percent of at least one polyhydroxyalkanoate; and further comprises from 30 to 60 weight percent of at least one biopolymer selected from the group consisting of polylactic acid, polybutylene succinate, polybutylene succinate adipate, polybutylene adipate terephthalate, phenylbenzimidazole sulfonic acid, and mixtures thereof.

Claim 4. The synthetic fiber of Claim 1, wherein the at least one polyhydroxyalkanoate comprises a polyhydroxyalkanoate copolymer.

Claim 5. The synthetic fiber of Claim 1, wherein the at least one poly(hydroxyalkanoate) comprises from 1 to 25 mole percent monomer repeat units selected from the group consisting of 3-hydroxyhexanoate, 3-hydroxyoctanoate, 3-hydroxydecanoate, and mixtures thereof.

Claim 6. The synthetic fiber of Claim 1, wherein the at least one polyhydroxyalkanoate comprises poly-3-hydroxybutyrate-co-3-hydroxyhexanoate (P3HB-co-P3HHx), comprising from 2 to 8 mole percent monomer repeat units of 3-hydroxyhexanoate.

Claim 7. The synthetic fiber of Claim 1, wherein the at least one polyhydroxyalkanoate comprises a polyhydroxyalkanoate terpolymer, wherein the terpolymer comprises from 75 to 99.8 mole percent monomer repeat units of 3-

hydroxybutyrate, from 0.1 to 24.9 mole percent monomer repeat units of 3-hydroxyhexanoate, and from 0.1 to 24.9 mole percent monomer repeat units of a third 3-hydroxyalkanoate selected from the group consisting of 3-hydroxyhexanoate, 3-hydroxyoctanoate, and 3-hydroxydecanoate.

Claim 8. The synthetic fiber of Claim 1, wherein the at least one polyhydroxyalkanoate has a weight average molecular weight from 50,000 to 1,500,000 Daltons, as determined by ASTM D5296-05.

Claim 9. The synthetic fiber of Claim 1, wherein the at least one polyhydroxyalkanoate has a bimodal molecular weight distribution, having a first molecular weight peak centered at 100,000 to 175,000 Daltons and a second molecular weight peak centered at 200,000 to 300,000 Daltons, as determined by ASTM D5296-05.

Claim 10. The synthetic fiber of Claim 1, wherein the at least one polyhydroxyalkanoate has a polydispersity index from 1.5 to 5, as determined by ASTM D5296-05.

Claim 11. The synthetic fiber of Claim 1, wherein the composition has a melting temperature from 140 °C to 150 °C as determined by ASTM D3418.

Claim 12. The synthetic fiber of Claim 1, wherein the composition further comprises from 0.1 to 4.0 weight percent of at least one melt strength enhancer selected from the group consisting of carbodiimides, epoxides, and mixtures thereof.

Claim 13. The synthetic fiber of Claim 1, wherein the fiber is filament spun, and the composition has a melt flow index from 5 to 30 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

Claim 14. The synthetic fiber of Claim 1, wherein the fiber is post-treated with a fiber lubricant composition, which includes at least one lubricant selected from the group consisting of hydrophobic esters, mineral oils, silicon compositions, and mixtures thereof.

Claim 15. A spunbond nonwoven fabric formed from the synthetic fiber of Claim 1, wherein the composition has a melt flow index from 50 to 100 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

Claim 16. A melt-blown nonwoven fabric formed from the synthetic fiber of Claim 1, wherein the composition has a melt flow index from 500 to 1500 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

Claim 17. A method for forming a plurality of synthetic fibers, comprising the steps of:

blending at least one polyhydroxyalkanoate, at least one nucleating agent, and at least one melt flow modifier in a first extruder to form a resin composition, wherein the resin composition comprises

from 1 to 98 weight percent of at least one polyhydroxyalkanoate;

from 1 to 10 weight percent of at least one nucleating agent selected from the group consisting of polyester waxes, behenamide, crodamide, stearamide, erucamide, pentaerythritol, dipentaerythritol, boron nitride, and mixtures thereof; and

from 0.1 to 5 weight percent of at least one melt flow modifier selected from the group consisting of calcium stearate, zinc stearate, starch, diamide oligomers, organic peroxides, and mixtures thereof; and

melt processing the resin composition at a temperature from 165 to 185 °C and extruding the composition through a plurality of spinnerets to produce a plurality of fibers.

Claim 18. The method of Claim 17, wherein the plurality of fibers comprise fiber filaments having a length of at least 300 mm.

Claim 19. The method of Claim 18, wherein the resin composition has a melt flow index from 5 to 30 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

Claim 20. The method of Claim 17, further comprising collecting the plurality of fibers on a flat conveyer belt and bonding the fibers together to form a spunbond nonwoven web.

Claim 21. The method of Claim 20, wherein the resin composition has a melt flow index from 50 to 100 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.

Claim 22. The method of Claim 17, further comprising collecting the plurality of fibers on a rotating circular conveyer and bonding the fibers together to form a melt-blown nonwoven web.

Claim 23. The method of Claim 22, wherein the composition has a melt flow index from 500 to 1500 grams/10 minutes when measured at a temperature of 175 °C with a 2.16 kg load in accordance with ASTM D1238.