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(54) **MULTIFILAMENT AND METHOD FOR PRODUCING THE SAME**

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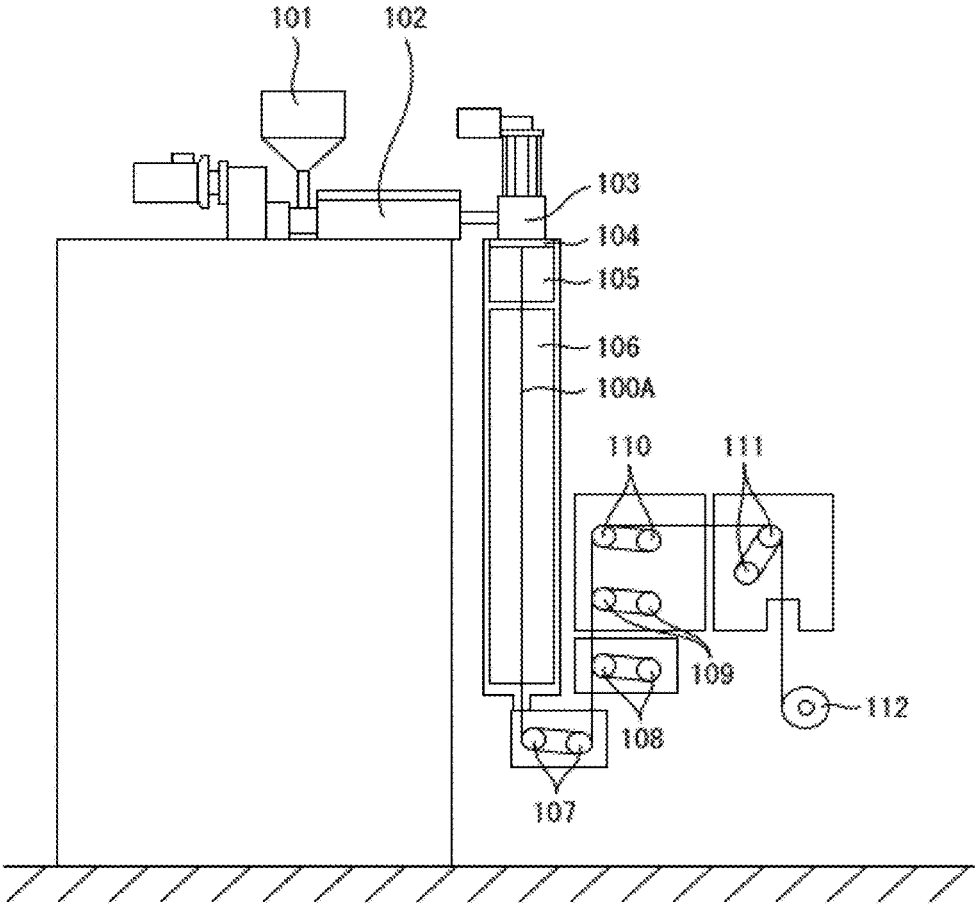
(57) **ABSTRACT**

A method for producing a multifilament, comprising (A) heat-melting a raw material composition to obtain a molten product and discharging the molten product through the discharge holes to obtain a plurality of raw filaments in a molten state; and (B) blowing gases onto the plurality of raw filaments, comprising (B1) blowing a first gas onto the plurality of raw filaments in the molten state to cool raw filaments and (B2) blowing a second gas onto the plurality of raw filaments cooled in (B1). In (B1), a temperature of the first gas is (Tc−45° C.) to (Tc−30° C.), Tc is a crystallization temperature of the poly(3-hydroxyalkanoate) resin, and in (B2), a temperature of the second gas is higher than the temperature of the first gas, and is (Tc−30° C.) to (Tc−10° C.). The raw material composition contains a poly(3-hydroxyalkanoate) resin. An average value of fineness of the single filaments is 15 dtex or less.



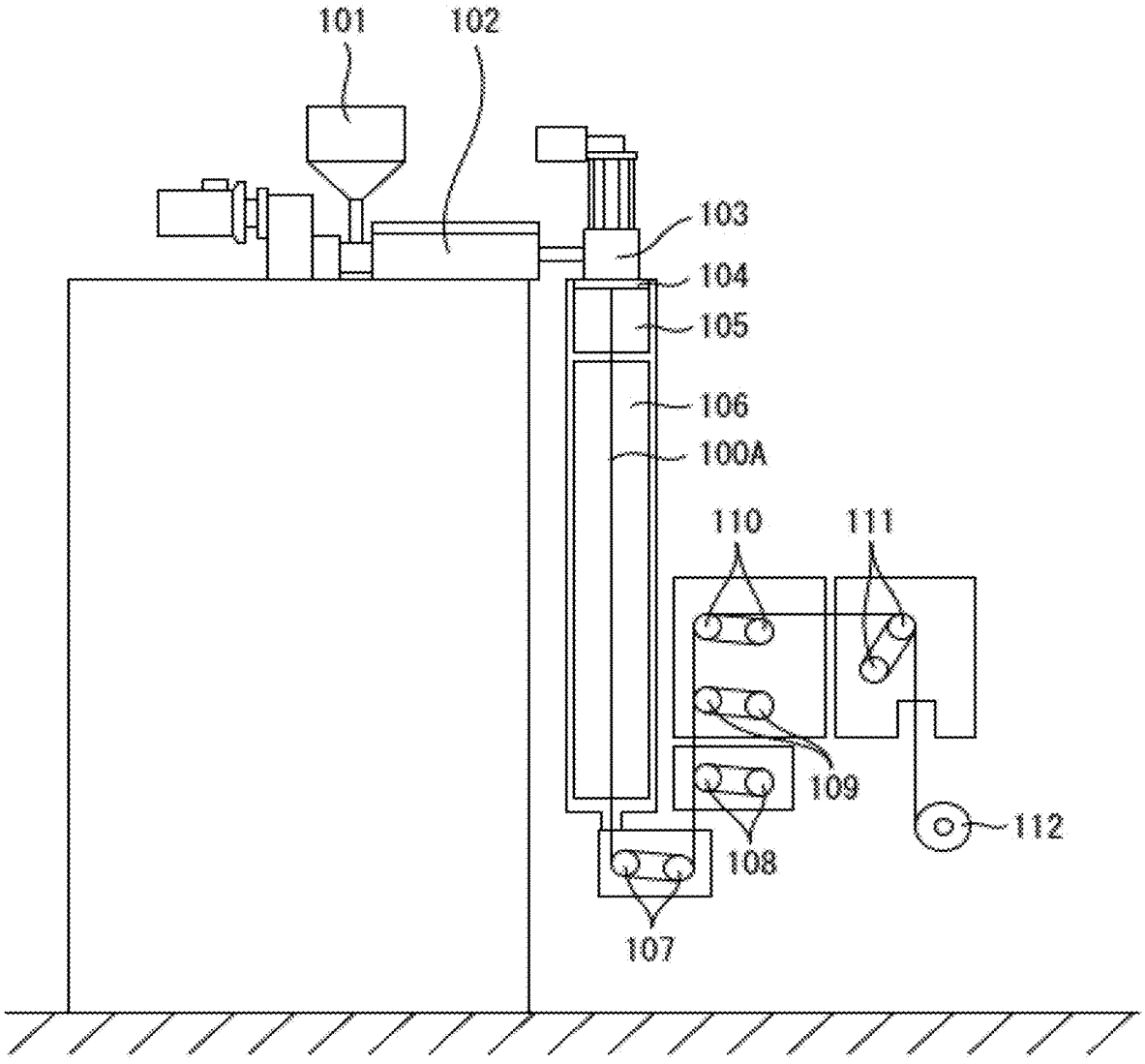


FIG. 1

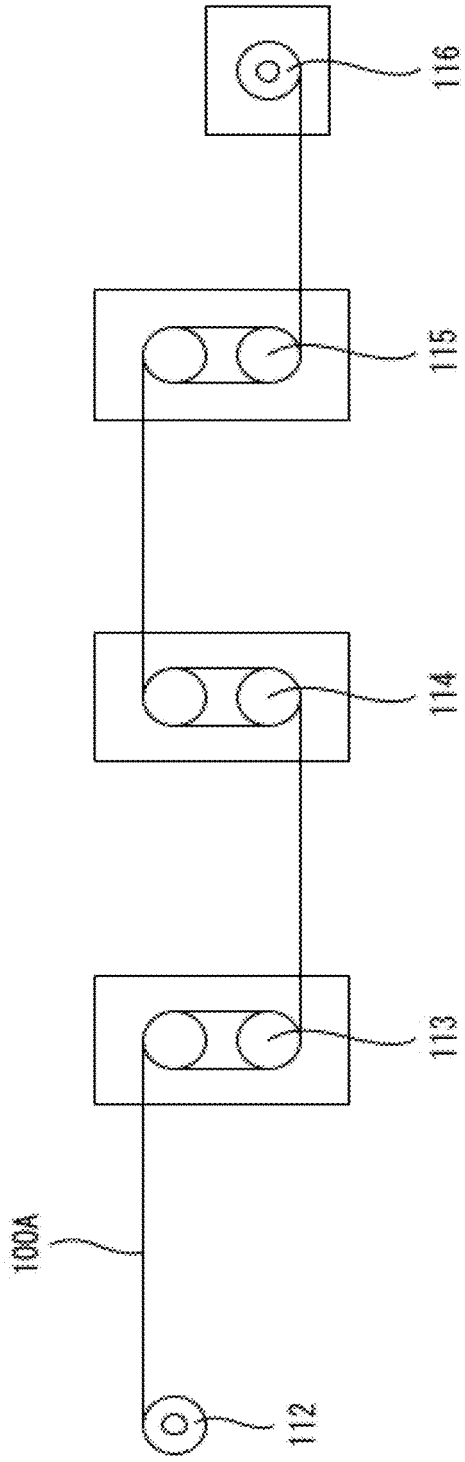


FIG. 2

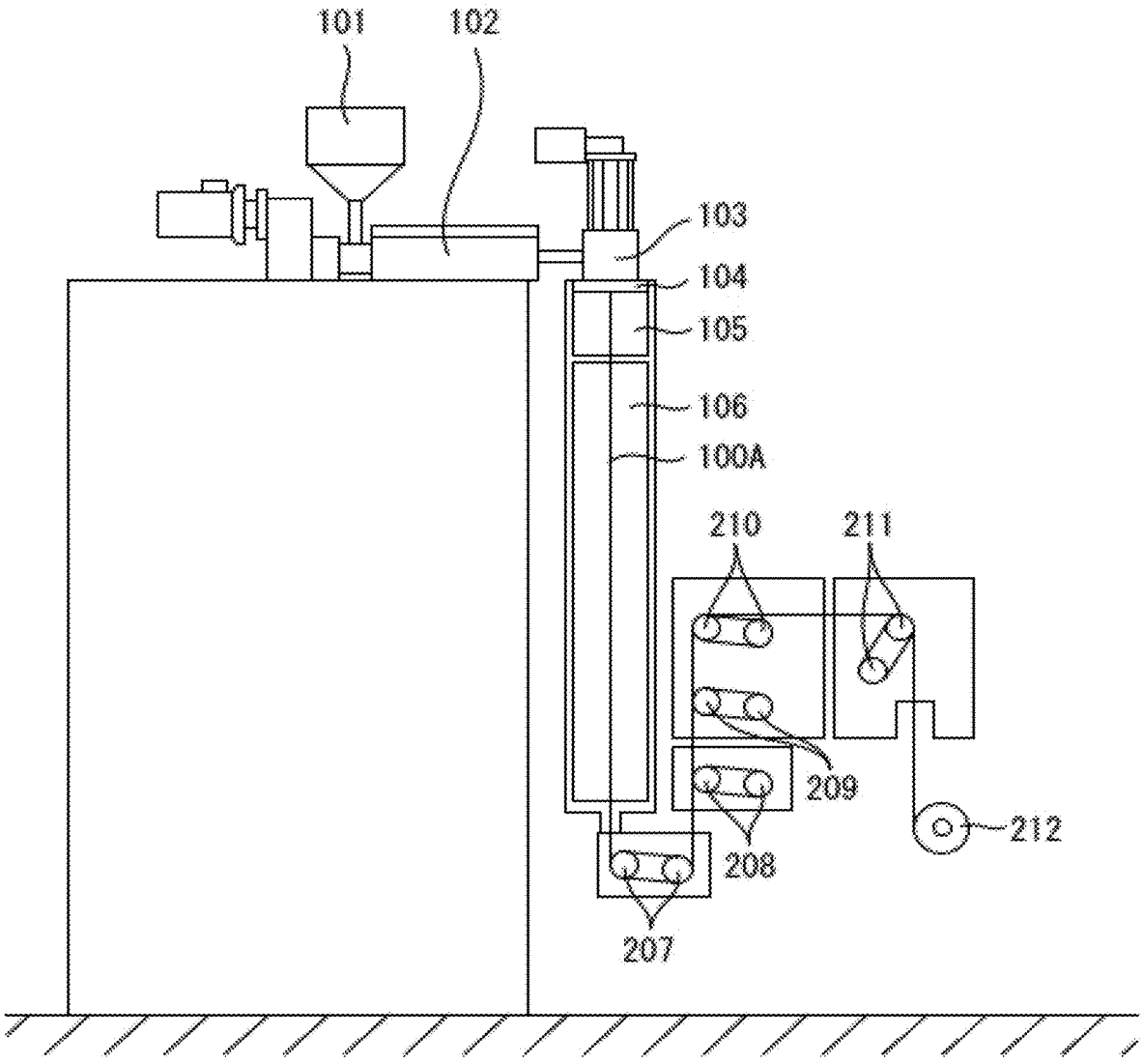


FIG. 3

MULTIFILAMENT AND METHOD FOR PRODUCING THE SAME

TECHNICAL FIELD

[0001] The present invention relates to a multifilament and a method for producing the same.

BACKGROUND ART

[0002] In recent years, there has been a problem in that plastic wastes cause heavy burdens on the global environment, such as harmful effects on ecosystems, generation of harmful gas during combustion of the plastic wastes, and global warming due to a large amount of heat generated by the combustion of the plastic wastes. Biodegradable plastics are the materials that can solve this problem, and the development of biodegradable plastics has been actively ongoing.

[0003] Among such biodegradable plastics, carbon dioxide that is generated when a biodegradable plastic obtained by using a plant-derived raw material is combusted originally exists in the air. Therefore, combusting such a biodegradable plastic does not cause an increase in carbon dioxide in the atmosphere. This is called carbon neutrality. Importance is given to carbon neutrality under the Kyoto Protocol, which specifies carbon dioxide reduction goals, and active use of carbon neutrality is desired.

[0004] Nowadays, in terms of biodegradability and carbon neutrality, aliphatic polyester resins are attracting attention as biodegradable plastics that are microbially produced by using plant-derived raw materials as carbon sources. Attention has been directed particularly to polyhydroxyalkanoate resins.

[0005] Patent Literatures 1 to 3 each disclose a method for producing a multifilament including a plurality of single filaments.

[0006] Patent Literature 1 discloses obtaining, by melt extrusion, a multifilament including a plurality of single filaments containing a polyhydroxyalkanoate.

[0007] Specifically, a production method described in Patent Literature 1 includes the steps of: (A) heat-melting a raw material composition, and discharging the molten raw material composition through four discharge holes to obtain four raw filaments; and (B) drawing the four raw filaments to obtain the multifilament.

CITATION LIST

Patent Literature

[0008] PTL 1: WO 2017/122679

[0009] PTL 2: WO 2021/206154

[0010] PTL 3: Japanese Laid-Open Patent Application Publication No. H08-134718

SUMMARY OF INVENTION

Technical Problem

[0011] In some cases, the average value of the fineness of the single filaments in the multifilament is required to be small.

[0012] The inventors of the present invention have conducted diligent studies, and as a result of the studies, they have found that when attempting to fabricate a multifilament in which the average value of the fineness of the single filaments is small, there is a case where the multifilament cannot be fabricated due to breakage of the raw filaments, or a case where the single filaments fuse to each other.

[0013] In view of the above, a first problem to be solved by the present invention is to provide a method for producing a multifilament, the method making it possible to suppress the breakage of raw filaments and to suppress the fusion of single filaments to each other regardless of a small average value of the fineness of the single filaments. A second problem to be solved by the present invention is to provide a multifilament in which the average value of the fineness of single filaments is small and the fusion of the single filaments to each other is suppressed.

Solution to Problem

[0014] A first aspect of the present invention relates to a method for producing a multifilament including a plurality of single filaments by melt spinning by using a spinning nozzle that includes a plurality of discharge holes. The method includes the steps of: (A) heat-melting a raw material composition to obtain a molten product and discharging the molten product through the discharge holes to obtain a plurality of raw filaments in a molten state; and (B) blowing gases onto the plurality of raw filaments. The raw material composition contains a poly(3-hydroxyalkanoate) resin. The step (B) includes the steps of (B1) blowing a first gas onto the plurality of raw filaments in the molten state to cool the plurality of raw filaments and (B2) blowing a second gas onto the plurality of raw filaments that have been cooled in the step (B1). In the step (B1), a temperature of the first gas is from (Tc−45° C.) to (Tc−30° C.) [Tc is a crystallization temperature of the poly(3-hydroxyalkanoate) resin]. In the step (B2), a temperature of the second gas is higher than the temperature of the first gas, and is from (Tc−30° C.) to (Tc−10° C.). An average value of fineness of the single filaments is 15 dtex or less.

[0015] A second aspect of the present invention relates to a multifilament including a plurality of single filaments. The single filaments each contain a poly(3-hydroxyalkanoate) resin. An average value of fineness of the single filaments is 15 dtex or less. A fusion rate of the single filaments is 10% or less.

Advantageous Effects of Invention

[0016] According to the first aspect of the present invention, regardless of a small average value of the fineness of the single filaments, the breakage of the raw filaments can be suppressed, and the fusion of the single filaments to each other can be suppressed.

[0017] The second aspect of the present invention makes it possible to provide a multifilament in which the average value of the fineness of the single filaments is small and the fusion of the single filaments to each other is suppressed.

BRIEF DESCRIPTION OF DRAWINGS

[0018] FIG. **1** is a schematic diagram showing an apparatus used in a step (A) and a step B of a first embodiment.

[0019] FIG. **2** is a schematic diagram showing an apparatus used in a step (C) of the first embodiment.

[0020] FIG. **3** is a schematic diagram showing an apparatus used in a second embodiment.

DESCRIPTION OF EMBODIMENTS

[0021] Hereinafter, one embodiment of the present invention is described with reference to the accompanying drawings.

Method for Producing Multifilament According to Present Embodiment>>

[0022] First, a method for producing a multifilament according to the present embodiment is described.

[0023] The method for producing a multifilament according to the present embodiment is a method for obtaining a multifilament including a plurality of single filaments by melt spinning by using a spinning nozzle that includes a plurality of discharge holes.

[0024] The method for producing a multifilament according to the present embodiment includes the steps of: (A) heat-melting a raw material composition to obtain a molten product and discharging the molten product through the discharge holes to obtain a plurality of raw filaments in a molten state; and (B) blowing gases onto the plurality of raw filaments.

[0025] The raw material composition contains a poly(3-hydroxyalkanoate) resin.

[0026] The step (B) includes the steps of (B1) blowing a first gas onto the plurality of raw filaments in the molten state to cool the plurality of raw filaments and (B2) blowing a second gas onto the plurality of raw filaments that have been cooled in the step (B1).

[0027] In the step (B1), the temperature of the first gas is from (Tc−45° C.) to (Tc−30° C.) [Tc is the crystallization temperature of the poly(3-hydroxyalkanoate) resin].

[0028] In the step (B2), the temperature of the second gas is higher than the temperature of the first gas, and is from (Tc−30° C.) to (Tc−10° C.).

[0029] The average value of the fineness of the single filaments is 15 dtex or less.

[0030] As a result of the temperature of the first gas being (Tc−30° C.) or lower, the breakage of the raw filaments can be suppressed.

[0031] As a result of the temperature of the first gas being (Tc−30° C.) or lower, the raw filaments are cooled sufficiently. Accordingly, a time during which the raw filaments are in the molten state can be shortened, and consequently, it is considered that the raw filaments are less likely to break. Also, a time during which the temperature of the raw filaments is within a temperature range in which the poly (3-hydroxyalkanoate) resin of the raw filaments tends to be crystallized can be shortened, and consequently, it is considered that too much progress on the crystallization of the poly(3-hydroxyalkanoate) resin can be avoided. Further, it is considered that the raw filaments have excellent flexibility (i.e., the raw filaments have a reduced elongational viscosity), and therefore, the raw filaments do not easily break when hauled off by haul-off rolls described below.

[0032] As a result of the temperature of the first gas being (Tc−45° C.) or higher, the fusion of the single filaments to each other can be suppressed.

[0033] As a result of the temperature of the first gas being (Tc−45° C.) or higher, it is considered that the crystallization of the poly(3-hydroxyalkanoate) resin of the raw filaments is facilitated, so that the fusion of the raw filaments to each other is suppressed, and consequently, the fusion of the single filaments to each other is suppressed.

[0034] As a result of the temperature of the second gas being (Tc−10° C.) or lower, the breakage of the raw filaments can be suppressed.

[0035] As a result of the temperature of the first gas being (Tc−10° C.) or lower, it is considered that too much progress on the crystallization of the poly(3-hydroxyalkanoate) resin of the raw filaments can be avoided. Further, it is considered that the raw filaments have excellent flexibility (i.e., the raw filaments have a reduced elongational viscosity), and therefore, the raw filaments do not easily break when hauled off by haul-off rolls described below.

[0036] As a result of the temperature of the second gas being (Tc−30° C.) or higher, the fusion of the single filaments to each other can be suppressed.

[0037] As a result of the temperature of the second gas being (Tc−30° C.) or higher, it is considered that the crystallization of the poly(3-hydroxyalkanoate) resin of the raw filaments is facilitated, so that the fusion of the raw filaments to each other is suppressed, and consequently, the fusion of the single filaments to each other is suppressed.

[0038] Therefore, according to the present embodiment, regardless of a small average value of the fineness of the single filaments, the breakage of the raw filaments can be suppressed, and the fusion of the single filaments to each other can be suppressed.

[0039] The method for producing a multifilament according to the present embodiment further includes the step (C) of, after the step (B), drawing the plurality of raw filaments to obtain the multifilament.

[0040] The raw material composition contains a polymer component and an additive.

[0041] The polymer component includes the poly(3-hydroxyalkanoate) resin.

[0042] The polymer component may contain another polymer in addition to the poly(3-hydroxyalkanoate) resin.

[0043] The poly(3-hydroxyalkanoate) resin is a polyester including a 3-hydroxyalkanoic acid as a monomer.

[0044] Specifically, the poly(3-hydroxyalkanoate) resin is a resin including the 3-hydroxyalkanoic acid as a structural unit.

[0045] The poly(3-hydroxyalkanoate) resin is a biodegradable polymer.

[0046] It should be noted that being "biodegradable" in the present embodiment means being able to be decomposed into low molecular weight compounds by microorganisms in a natural environment. Being biodegradable or not can be determined based on tests suited for different environments. Specifically, for example, ISO 14855 (compost) and ISO 14851 (activated sludge) are suited for an aerobic condition, and ISO 14853 (aqueous phase) and ISO 15985 (solid phase) are suited for an anaerobic condition. Also, biodegradability by microorganisms in seawater can be evaluated by biochemical oxygen demand measurement.

[0047] The poly(3-hydroxyalkanoate) resin includes a homopolymer and/or a copolymer.

[0048] Preferably, the poly(3-hydroxyalkanoate) resin includes a structural unit expressed by an equation (1) shown below.

$$[—CHR—CH_2—CO—O—] \quad (1)$$

(In the above equation (1), R is an alkyl group represented by C_pH_{2p+1}, and p is an integer from 1 to 15.)

[0049] Preferably, the poly(3-hydroxyalkanoate) resin is a resin including 3-hydroxybutyrate as a structural unit (i.e., a poly(3-hydroxybutyrate) resin).

[0050] It should be noted that the poly(3-hydroxybutyrate) resin includes a homopolymer and/or a copolymer.

[0051] Examples of the poly(3-hydroxyalkanoate) resin including 3-hydroxybutyrate as a structural unit include P3HB, P3HB3HH, P3HB3HV, P3HB4HB, poly(3-hydroxybutyrate-co-3-hydroxyoctanoate), and poly(3-hydroxybutyrate-co-3-hydroxyoctadecanoate).

[0052] P3HB herein means poly(3-hydroxybutyrate), which is a homopolymer.

[0053] P3HB3HH herein means poly(3-hydroxybutyrate-co-3-hydroxyhexanoate).

[0054] P3HB3HV herein means poly(3-hydroxybutyrate-co-3-hydroxyvalerate).

[0055] P3HB4HB herein means poly(3-hydroxybutyrate-co-4-hydroxybutyrate).

[0056] It should be noted that P3HB has a function to facilitate the crystallization of P3HB itself and to facilitate the crystallization of the poly(3-hydroxyalkanoate) resin other than P3HB. Accordingly, preferably, the poly(3-hydroxyalkanoate) resin includes P3HB.

[0057] In order to achieve both excellent biodegradability and excellent molding processability, the poly(3-hydroxyalkanoate) resin is preferably, but not particularly limited to, P3HB, P3HB3HH, P3HB3HV, or P3HB4HB.

[0058] Further, in order to increase the strength of the multifilament according to the present embodiment and to increase the molding processability thereof, the poly(3-hydroxyalkanoate) resin is preferably P3HB3HH.

[0059] The poly(3-hydroxyalkanoate) resin preferably includes 80% by mole or greater of 3-hydroxybutyrate, more preferably includes 85.0% by mole or greater and 99.5% by mole or less of 3-hydroxybutyrate, or yet more preferably includes 85.0% by mole or greater and 97.0% by mole or less of 3-hydroxybutyrate, as a structural unit.

[0060] As a result of the poly(3-hydroxyalkanoate) resin including 80% by mole or greater of 3-hydroxybutyrate as a structural unit, the stiffness of the multifilament is increased.

[0061] As a result of the poly(3-hydroxyalkanoate) resin including 99.5% by mole or less of 3-hydroxybutyrate as a structural unit, the multifilament has excellent flexibility.

[0062] It should be noted that the content ratio of the 3-hydroxybutyrate unit in the poly(3-hydroxyalkanoate) resin can be determined in a manner described in Examples below.

[0063] The polymer component may include only one kind of the poly(3-hydroxyalkanoate) resin, or may include two or more kinds of the poly(3-hydroxyalkanoate) resins.

[0064] In a case where the poly(3-hydroxyalkanoate) resin includes a copolymer (e.g., P3HB3HH), the poly(3-hydroxyalkanoate) resin may include two or more kinds of copolymers having different average composition ratios of the structural unit.

[0065] The weight-average molecular weight of the poly(3-hydroxyalkanoate) resin in the raw material composition is preferably from 3.0×10^5 to 7.0×10^5, more preferably from 3.5×10^5 to 7.0×10^5, yet more preferably from 4.0×10^5 to 7.0×10^5, or most preferably from 4.5×10^5 to 6.5×10^5.

[0066] As a result of the weight-average molecular weight of the poly(3-hydroxyalkanoate) resin in the raw material composition being 3.0×10^5 or greater, the weight-average molecular weight of the poly(3-hydroxyalkanoate) resin in the single filaments can be readily increased, which consequently makes it possible to readily increase the strength of the multifilament.

[0067] As a result of the weight-average molecular weight of the poly(3-hydroxyalkanoate) resin in the raw material composition being 7.0×10^5 or less, the forming of the multifilament can be readily performed.

[0068] The weight-average molecular weight of the poly(3-hydroxyalkanoate) resin in the raw material composition means the weight-average molecular weight of the poly(3-hydroxyalkanoate) resin in the raw material composition before it is subjected to heat-melting.

[0069] It should be noted that the weight-average molecular weight in the present embodiment is measured based on a molecular weight distribution in terms of polystyrene by using gel permeation chromatography (GPC) using a chloroform eluent. The column used in the GPC may be any column suitable for measuring the molecular weight.

[0070] For example, the weight-average molecular weight in the present embodiment can be measured under the conditions indicated below.

[0071] Measurement device: SHIMADZU 20A available from Shimadzu Corporation

[0072] Column: ShodexK-806M available from Showa Denko K. K.

[0073] Detector: RI detector

[0074] Reference material: polystyrene

[0075] Eluent: chloroform (HPLC grade)

[0076] Flow rate: 1 mL/min

[0077] Temperature: 40° C.

[0078] The aforementioned another polymer is preferably biodegradable.

[0079] Examples of this other polymer that is biodegradable include polycaprolactone, polylactic acid, polybutylene succinate, polybutylene succinate adipate, polybutylene adipate terephthalate, polyethylene succinate, polyvinyl alcohol, polyglycolic acid, unmodified starch, modified starch, cellulose acetate, chitosan, and poly(4-hydroxyalkanoate) resin.

[0080] The polycaprolactone is a polymer obtained by ring-opening polymerization of ε-caprolactone.

[0081] The polymer component may include one kind of this other polymer, or two or more kinds of these other polymers.

[0082] The polymer component preferably contains 50% by weight or greater of the poly(3-hydroxyalkanoate) resin, more preferably 80% by weight or greater of the poly(3-hydroxyalkanoate) resin, or yet more preferably 90% by weight or greater of the poly(3-hydroxyalkanoate) resin.

[0083] As a result of the raw material composition including the biodegradable polymer, even if the multifilament is discarded in an environment, since the multifilament is readily decomposed in the environment, the load on the environment can be reduced.

[0084] Examples of the additive include a crystal nucleating agent, a lubricant, a plasticizer, a spinning oil, a stabilizer (such as an oxidation inhibitor or ultraviolet absorber), a colorant (such as a dye or pigment), an inorganic filler, an organic filler, and an antistatic agent.

[0085] In order to facilitate the crystallization of the poly(3-hydroxyalkanoate) resin, the raw material composition preferably contains a crystal nucleating agent.

[0086] The crystal nucleating agent is a compound that has an effect of facilitating the crystallization of the poly(3-

hydroxyalkanoate) resin. The crystal nucleating agent has a melting point higher than that of the poly(3-hydroxyalkanoate) resin.

[0087] Examples of the crystal nucleating agent include: inorganic substances (e.g., boron nitride, titanium oxide, talc, layered silicate, calcium carbonate, sodium chloride, metal phosphate, etc.); sugar alcohol compounds derived from natural products (e.g., pentaerythritol, erythritol, galactitol, mannitol, arabitol, etc.); polyvinyl alcohol; chitin; chitosan; polyethylene oxides; aliphatic carboxylates; aliphatic alcohols; aliphatic carboxylic acid esters; dicarboxylic acid derivatives (e.g., dimethyl adipate, dibutyl adipate, di-isodecyl adipate, dibutyl sebacate, etc.); cyclic compounds having, in their molecule, C═O and a functional group selected from the group consisting of NH, S, and O (e.g., indigo, quinacridone, quinacridone magenta, etc.); sorbitol derivatives (e.g., bis-benzylidene sorbitol, bis(p-methylbenzylidene)sorbitol, etc.); compounds including a nitrogen-containing heteroaromatic nucleus (e.g., pyridine ring, triazine ring, imidazole ring, etc.) (e.g., pyridine, triazine, imidazole, etc.); phosphate ester compounds; bisamides of higher fatty acids; metal salts of higher fatty acids; and branched polylactic acid.

[0088] It should be noted that P3HB, which is the poly (3-hydroxyalkanoate) resin, can be used as the crystal nucleating agent.

[0089] One of these crystal nucleating agents may be used alone, or two or more of these crystal nucleating agents may be used in combination.

[0090] As the crystal nucleating agent, sugar alcohol compounds, polyvinyl alcohol, chitin, and chitosan are preferable in light of the effect of improving the crystallization rate of the poly(3-hydroxyalkanoate) resin as well as in light of compatibility and affinity with the poly(3-hydroxyalkanoate) resin.

[0091] Among the sugar alcohol compounds, pentaerythritol is preferable.

[0092] The crystal nucleating agent preferably has a crystal structure at normal temperature (25° C.).

[0093] Since the crystal nucleating agent has a crystal structure at normal temperature (25° C.), the crystallization of the poly(3-hydroxyalkanoate) resin is further facilitated, which is advantageous.

[0094] The crystal nucleating agent that has a crystal structure at normal temperature (25° C.) is preferably powdery at normal temperature (25° C.).

[0095] The crystal nucleating agent that is powdery at normal temperature (25° C.) preferably has a mean particle diameter of 10 μm or less.

[0096] The content of the crystal nucleating agent in the raw material composition is preferably 0.05 parts by weight or greater, more preferably 0.1 parts by weight or greater, or yet more preferably 0.5 parts by weight or greater, with respect to 100 parts by weight of the poly(3-hydroxyalkanoate) resin. As a result of the content of the crystal nucleating agent in the raw material composition being 0.05 parts by weight or greater with respect to 100 parts by weight of the poly(3-hydroxyalkanoate) resin, the crystallization of the poly(3-hydroxyalkanoate) resin can be further facilitated, which is advantageous.

[0097] The content of the crystal nucleating agent in the raw material composition is preferably 10 parts by weight or less, more preferably 8 parts by weight or less, or yet more preferably 5 parts by weight or less, with respect to 100 parts by weight of the poly(3-hydroxyalkanoate) resin. As a result of the content of the crystal nucleating agent in the raw material composition being 10 parts by weight or less with respect to 100 parts by weight of the poly(3-hydroxyalkanoate) resin, the viscosity of the molten product when fabricating the multifilament from the molten product can be reduced, which consequently makes it possible to readily fabricate the multifilament, which is advantageous.

[0098] It should be noted that P3HB is the poly(3-hydroxyalkanoate) resin, and can also function as the crystal nucleating agent. Therefore, in a case where the raw material composition contains P3HB, the amount of the P3HB is included both in the amount of the poly(3-hydroxyalkanoate) resin and in the amount of the crystal nucleating agent.

[0099] The raw material composition may contain a lubricant.

[0100] Examples of the lubricant include a lauric acid amide, a myristic acid amide, a stearic acid amide, a behenic acid amide, and an erucic acid amide.

[0101] The content of the lubricant in the raw material composition is preferably 0.05 parts by weight or greater, more preferably 0.1 parts by weight or greater, or yet more preferably 0.5 parts by weight or greater, with respect to 100 parts by weight of the poly(3-hydroxyalkanoate) resin. As a result of the content of the lubricant in the raw material composition being 0.05 parts by weight or greater with respect to 100 parts by weight of the poly(3-hydroxyalkanoate) resin, the single filaments have excellent slipperiness, which is advantageous.

[0102] The content of the lubricant in the raw material composition is preferably 12 parts by weight or less, more preferably 10 parts by weight or less, yet more preferably 8 parts by weight or less, or most preferably 5 parts by weight or less, with respect to 100 parts by weight of the poly(3-hydroxyalkanoate) resin. As a result of the content of the lubricant in the raw material composition being 12 parts by weight or less with respect to 100 parts by weight of the poly(3-hydroxyalkanoate) resin, the lubricant can be advantageously suppressed from bleeding out on the surface of the multifilament.

First Embodiment: Sequential Drawing Process (Post-Drawing Process)

[0103] Hereinafter, a method for producing a multifilament according to a first embodiment is described with reference to FIGS. **1** and **2** by taking, as an example, a method for producing a multifilament by a sequential drawing process (which is also referred to as a "post-drawing process").

[0104] The method for producing a multifilament according to the first embodiment includes: winding the plurality of raw filaments by a winding roll unit; and drawing the plurality of raw filaments that have been wound by the winding roll unit.

(Step (A))

[0105] In the step (A), first, materials are subjected to dry blending to obtain a raw material composition, and the raw material composition is melt-kneaded by an extruder to obtain pellets.

[0106] Then, as shown in FIG. **1**, the pellets are put into a raw material feeder **101**.

[0107] Next, the raw material feeder **101** feeds the pellets into a kneading extruder **102**, and the kneading extruder **102** heat-melts the pellets to obtain a molten product, i.e., a molten raw material composition.

[0108] The kneading extruder **102** is a screw extruder. The kneading extruder **102** may be a single screw extruder, or may be a twin screw extruder.

[0109] With use of a spinning nozzle **104** including a plurality of discharge holes, the molten product obtained by the kneading extruder **102** is discharged through the plurality of discharge holes to obtain a plurality of raw filaments **100**A in a molten state.

[0110] It should be noted that the flow rate of the molten product discharged from the spinning nozzle **104** through the plurality of discharge holes is adjusted by a gear pump **103**.

[0111] The temperature of the spinning nozzle **104** is, for example, from 140 to 180° C.

[0112] The number of discharge holes included in the spinning nozzle **104** is plural, preferably 30 or greater, more preferably from 30 to 10,000, or yet more preferably from 30 to 5,000.

[0113] The shape and the size of each discharge hole are selected in accordance with required characteristics (e.g., appearance, fineness, strength, sectional shape, etc.) of the multifilament.

[0114] In the present embodiment, the discharge holes have substantially the same shape as each other. Also, the discharge holes have substantially the same area as each other.

[0115] The area of each discharge hole is preferably from 1.0×10^{-3} to 20 mm^2, or more preferably from 5.0×10^{-3} to 10 mm^2.

[0116] The speed at which the molten product is discharged from the spinning nozzle **104** (which may be hereinafter referred to as "spinning nozzle flow speed") is preferably from 0.02 m/min to 20 m/min, more preferably from 0.05 m/min to 10 m/min, or yet more preferably from 0.1 m/min to 5.0 m/min.

[0117] In the first embodiment, from the viewpoint of, for example, suppressing single filaments adjacent to each other from fusing to each other and suppressing single filaments adjacent to each other from separating from each other due to static electricity, spinning oil may be applied onto the surface of each of the plurality of raw filaments **100**A that have been cooled.

[0118] Examples of the spinning oil include a cationic surfactant, an anionic surfactant, a nonionic surfactant, a refined esterified oil, a mineral oil, a poly(oxyethylene) alkyl ether, a silicone oil, and a paraffin wax. One of these spinning oils may be used alone, or two or more of these spinning oils may be used in combination.

[0119] From the viewpoint of suppressing single filaments adjacent to each other from fusing to each other, a silicone oil is preferable as the spinning oil.

[0120] From the viewpoint of suppressing single filaments adjacent to each other from separating from each other due to static electricity, an anionic surfactant or a nonionic surfactant is preferable as the spinning oil.

[0121] For example, as the spinning oil, one that includes a silicone oil and an anionic surfactant can be used (e.g., "Polymax FKY" available from Marubishi Oil Chemical Co., Ltd.).

(Step (B))

[0122] In the step (B), gases are blown onto the plurality of raw filaments **100**A.

[0123] Examples of the gases include air, inert gases (nitrogen gas, argon gas, etc.), and steam.

[0124] In the step (B), each gas is blown onto the plurality of raw filaments **100**A in a box.

[0125] Examples of a gas blowing method to adopt in the step (B) includes a circular method and a back-side method.

[0126] The back-side method is a method for blowing the gas onto the plurality of raw filaments in the box from one direction when the raw filaments are seen in their longitudinal direction (i.e., when the raw filaments are seen in a cross-sectional view of the raw filaments, the cross-sectional view being perpendicular to the longitudinal direction of the raw filaments).

[0127] The circular method uses a box having a cylindrical side wall, and is a method for blowing the gas onto the plurality of raw filaments by blowing the gas into the cylindrical box helically along the inner circumferential surface of the cylindrical side wall. It should be noted that a flow direction of the raw filaments is substantially parallel to a virtual axis of the cylindrical side wall.

[0128] The box may include a cylindrical perforated metal inside the cylindrical side wall, and may further include a cylindrical mesh (e.g., 80 mesh) inside the cylindrical perforated metal. The external diameter of the cylindrical perforated metal is less than the internal diameter of the cylindrical side wall. The external diameter of the cylindrical mesh is less than the internal diameter of the cylindrical perforated metal.

[0129] In this case, in the circular method, the plurality of raw filaments pass through the inside of the cylindrical mesh.

[0130] The circular method is preferable as the gas blowing method. The circular method makes it possible to blow the gas onto the plurality of raw filaments relatively uniformly, and consequently, variation in the fineness of the raw filaments can be suppressed.

[0131] In the step (B), preferably, the gas that has come into contact with the raw filaments is discharged from the box to the outside in the flow direction of the raw filaments. In order to discharge the gas that has come into contact with the raw filaments from the box to the outside in the flow direction of the raw filaments, for example, a flow-straightening plate, a flow-straightening fin, an ejector, a venturi tube, or a Transvector available from KOGI CORPORATION Co., Ltd., can be used.

[0132] The step (B) includes the steps of (B1) blowing a first gas onto the plurality of raw filaments **100**A in a molten state to cool the plurality of raw filaments and (B2) blowing a second gas onto the plurality of raw filaments **100**A that have been cooled.

[0133] In the step (B1), in a first box **105**, the first gas is blown onto the plurality of raw filaments **100**A in a molten state to cool the plurality of raw filaments **100**A.

[0134] In the step (B1), the temperature of the first gas is from (Tc−45° C.) to (Tc−30° C.) [Tc is the crystallization temperature of the poly(3-hydroxyalkanoate) resin], preferably from (Tc−40° C.) to (Tc−30° C.), or more preferably from (Tc−38° C.) to (Tc−33° C.).

[0135] It should be noted that the crystallization temperature (Tc) of the poly(3-hydroxyalkanoate) resin can be

measured in accordance with JIS K7121-1987 "Testing Methods for Transition Temperatures of Plastics".

[0136] Specifically, with use of a differential scanning calorimeter (e.g., Differential Scanning Calorimeter DSC 25 available from TA Instruments), a sample of the poly(3-hydroxyalkanoate) resin in an amount of about 6.0 mg put in a measurement container is subjected to both heating and cooling at a heating rate of 10° C./min and a cooling rate of 10° C./min within a temperature range of −30° C. to 180° C. while flowing a nitrogen gas at a flow rate of 50 ml/min. The peak top temperature of the exothermic peak when the sample is subjected to the cooling for the second time is determined as the crystallization temperature.

[0137] In a case where there are two or more exothermic peaks, the peak top temperature of the exothermic peak having the largest peak area among the two or more exothermic peaks is determined as the crystallization temperature.

[0138] The temperature of the gas in each of the step (B1) and the step (B2) of the present embodiment means the temperature of the gas when the gas comes into contact with the raw filaments **100**A.

[0139] In the step (B1), the speed of the first gas is preferably from 0.1 to 1.0 m/s, more preferably from 0.15 to 0.6 m/s, or yet more preferably from 0.17 to 0.3 m/s.

[0140] As a result of the speed of the first gas being 0.1 m/s or greater, the raw filaments **100**A can be sufficiently cooled by the first gas. Consequently, the breakage of the raw filaments **100**A can be suppressed more.

[0141] As a result of the speed of the first gas being 1.0 m/s or less, shaking of the raw filaments **100**A by the first gas can be suppressed.

[0142] Accordingly, the breakage of the raw filaments **100**A due to the shaking can be suppressed.

[0143] Further, the raw filaments **100**A can be suppressed from colliding with each other and fusing to each other due to the shaking. Consequently, the fusion of the single filaments to each other can be further suppressed.

[0144] The distance from the discharge holes of the spinning nozzle **104** to a position where the gas in the step (B1) comes into contact with the raw filaments **100**A, which are obtained as a result of the discharging through the discharge holes, is set depending on required characteristics of the multifilament. However, generally speaking, this distance is preferably short.

[0145] As a gas blowing method to adopt in the step (B1), the above-described circular method is preferred, because, with the circular method, variation in the fineness of the raw filaments **100**A can be suppressed.

[0146] In the step (B2), in a second box **106**, the second gas is blown onto the plurality of raw filaments **100**A that have been cooled.

[0147] In the step (B2), the temperature of the second gas is higher than the temperature of the first gas.

[0148] In the step (B2), the temperature of the second gas is from (Tc−30° C.) to (Tc−10° C.), or preferably from (Tc−27° C.) to (Tc−15° C.).

[0149] In the step (B2), the speed of the second gas is preferably from 0.005 to 1.5 m/s, more preferably from 0.05 to 1.0 m/s, or yet more preferably from 0.10 to 0.5 m/s.

[0150] As a result of the speed of the second gas being 0.005 m/s or greater, the fusion of the single filaments to each other can be further suppressed.

[0151] As a result of the speed of the second gas being 0.005 m/s or greater, it is considered that the crystallization of the poly(3-hydroxyalkanoate) resin of the raw filaments **100**A is facilitated, so that the fusion of the raw filaments **100**A to each other is suppressed, and consequently, the fusion of the single filaments to each other is suppressed.

[0152] As a result of the speed of the second gas being 1.5 m/s or less, shaking of the raw filaments **100**A by the second gas can be suppressed.

[0153] Accordingly, the breakage of the raw filaments **100**A due to the shaking can be suppressed.

[0154] Further, the raw filaments **100**A can be suppressed from colliding with each other and fusing to each other due to the shaking. Consequently, the fusion of the single filaments to each other can be further suppressed.

[0155] In the step (B2), preferably, the second gas is blown onto the plurality of raw filaments **100**A that have been cooled in the step (B1) to warm up the plurality of raw filaments **100**A.

[0156] In the step (B2), the second gas is blown onto the plurality of raw filaments **100**A that have been cooled in the step (B1), and thereby the plurality of raw filaments **100**A are warmed up. In this case, as compared to a case where the plurality of raw filaments **100**A are cooled in the step (B2), the temperature of the plurality of raw filaments **100**A can be adjusted more easily, and consequently, the plurality of raw filaments **100**A can be crystallized to a suitable degree more easily.

[0157] In the step (B2), the temperature of the second gas is higher than the temperature of the first gas.

[0158] A value obtained by subtracting the temperature of the first gas from the temperature of the second gas is preferably from 5 to 25° C., more preferably from 7 to 23° C., or yet more preferably from 9 to 20° C.

[0159] In the step (B) of the first embodiment, after the step (B2), the plurality of raw filaments **100**A are hauled off by a first haul-off roll unit **107**.

[0160] The first haul-off roll unit **107** includes two rolls. It should be noted that the number of rolls included in the first haul-off roll unit **107** may be one, or may be three or more.

[0161] Then, in the step (B), the plurality of raw filaments **100**A that have been hauled off by the first haul-off roll unit **107** are wound by a first winding roll unit **112**.

[0162] In the first embodiment, by using a first feeding roll unit **108**, a second feeding roll unit **109**, a third feeding roll unit **110**, and a fourth feeding roll unit **111**, the plurality of raw filaments **100**A that have been hauled off by the first haul-off roll unit **107** are fed to the first winding roll unit **112**.

[0163] In FIG. **1**, each feeding roll unit includes two rolls. However, alternatively, the number of rolls included in each feeding roll unit may be one, or may be three or more.

[0164] In order to perform drawing on the raw filaments in the step (C), preferably, in the step (B), substantially no drawing is performed on the plurality of raw filaments **100**A, or not so much drawing is performed on the plurality of raw filaments **100**A.

[0165] Specifically, the draw ratio in the step (B) is preferably 1.5 times or less, more preferably 1.2 times or less, or yet more preferably 1.05 times or less.

[0166] The draw ratio in the step (B) can be determined by using an equation shown below.

Draw ratio in the step (*B*)=the speed (m/min) of the feeding roll unit/the speed (m/min) of the haul-

off roll unit used in the step (*B*) (in the first embodiment, the "first haul-off roll unit 107")

[0167] It should be noted that the speed (m/min) of the haul-off roll unit used in the step (B) is the length of the plurality of raw filaments **100**A hauled off per unit time by the haul-off roll unit used in the step (B) (in the first embodiment, the "first haul-off roll unit **107**").

[0168] The speed of the feeding roll unit is the length of the plurality of raw filaments **100**A fed per unit time by the feeding roll unit.

[0169] In the case of using a plurality of feeding roll units, the highest feeding roll unit speed among the plurality of feeding roll units is determined as the "speed of the feeding roll unit".

[0170] In the case of using no feeding roll unit, the draw ratio in the step (B) is 1.0 time.

[0171] In the step (B) in FIG. **1**, the plurality of raw filaments **100**A are wound by the first winding roll unit **112**. Alternatively, in the first embodiment, the plurality of raw filaments **100**A may be, without being wound by the first winding roll unit **112**, put into an accommodating container to obtain the raw filaments.

(Step (C))

[0172] As shown in FIG. **2**, in the step (C), the plurality of raw filaments **100**A are heated and drawn.

[0173] In the step (C), the plurality of raw filaments **100**A are hauled off by a second haul-off roll unit **113** from the first winding roll unit **112**.

[0174] Next, in the step (C), the plurality of raw filaments **100**A that have been hauled off by the second haul-off roll unit **113** are drawn by a drawing roll unit **114**.

[0175] Then, in the step (C), the plurality of raw filaments **100**A that have been drawn by the drawing roll unit **114** are wound by a second winding roll unit **116**, and thus the multifilament is obtained.

[0176] Further, in the step (C), the plurality of raw filaments **100**A that have been drawn by the drawing roll unit **114** may be then subjected to heating by a heat treatment roll unit **115** while being fed.

[0177] The second haul-off roll unit **113** includes two rolls. It should be noted that the number of rolls included in the second haul-off roll unit **113** may be one, or may be three or more.

[0178] In the step (C), preferably, the plurality of raw filaments **100**A are heated by the second haul-off roll unit **113**.

[0179] In the step (C), heating the plurality of raw filaments **100**A by the second haul-off roll unit **113** makes it possible to readily adjust the temperature of the plurality of raw filaments **100**A to fall within a temperature range that is suitable for increasing the orientation of the polymer component included in the plurality of raw filaments **100**A, and consequently, the orientation of the polymer component in the plurality of raw filaments **100**A can be readily increased.

[0180] The temperature of the second haul-off roll unit **113** is preferably 15° C. or higher but lower than 60° C., more preferably from 15 to 55° C., or yet more preferably from 15 to 30° C.

[0181] It should be noted that in a case where the temperature of an environment in which the step (C) is performed is 15° C. or higher, it is not necessary to heat the plurality of raw filaments **100**A by the second haul-off roll unit **113**.

[0182] The drawing roll unit **114** includes two rolls. It should be noted that the number of rolls included in the drawing roll unit **114** may be one, or may be three or more.

[0183] In the step (C), the plurality of raw filaments **100**A may be either heated or not heated by the drawing roll unit **114**.

[0184] In the step (C), heating the plurality of raw filaments **100**A by the drawing roll unit **114** makes it possible to facilitate the crystallization of the polymer component included in the plurality of raw filaments **100**A, or to increase the thermal resistance of the polymer component.

[0185] The temperature of the drawing roll unit **114** is preferably from 30 to 100° C., or more preferably from 40 to 90° C.

[0186] The heat treatment roll unit **115** includes two rolls. It should be noted that the number of rolls included in the heat treatment roll unit **115** may be one, or may be three or more.

[0187] In the step (C), heating the plurality of raw filaments **100**A by the heat treatment roll unit **115** makes it possible to facilitate the crystallization of the polymer component included in the plurality of raw filaments **100**A, or to increase the thermal resistance of the polymer component included in the first single filaments.

[0188] The temperature of the heat treatment roll unit **115** is preferably from 60 to 110° C., or more preferably from 80 to 100° C.

[0189] In the step (C) of the first embodiment, the plurality of raw filaments **100**A are heated by the haul-off roll unit **113**, the drawing roll unit **114**, and the heat treatment roll unit **115**. However, the plurality of raw filaments **100**A may be heated in any suitable manner so as to achieve the purpose of controlling the orientation, crystallization, and thermal resistance of the polymer component in the plurality of raw filaments **100**A.

[0190] For example, the plurality of raw filaments **100**A may be heated by the raw filament winding roll unit **112**.

[0191] Further, the plurality of raw filaments **100**A may be heated by the second winding roll unit **116** to obtain the multifilament.

[0192] The plurality of raw filaments **100**A may be heated by all of the roll units from the raw filament winding roll unit **112** to the second winding roll unit **116**. Among all of the roll units from the raw filament winding roll unit **112** to the second winding roll unit **116**, only some roll units may heat the plurality of raw filaments **100**A while the other roll units may not heat the plurality of raw filaments **100**A.

[0193] It should be noted that the heating of the plurality of raw filaments **100**A by each roll unit is preferably controlled by each roll unit.

[0194] A method to adopt in the step (C) of the first embodiment to heat the polymer component in the plurality of raw filaments **100**A (which may hereinafter be simply referred to as "the heating method") may be one in which the polymer component in the plurality of raw filaments **100**A is heated by heating the rolls of the roll units.

[0195] Alternatively, each roll unit may include a container accommodating their rolls therein and also include a liquid (e.g., water) stored in the container together with the rolls, and the heating method may be one in which the polymer component in the plurality of raw filaments **100**A is heated by heating the liquid. In the step (C), for example, the drawing may be performed in a bath.

[0196] Further, the heating method may be one in which the polymer component in the plurality of raw filaments **100**A is heated by blowing a heated gas (e.g., air) onto the roll units or to the vicinity of the roll units.

[0197] These heating methods may be used in combination.

[0198] The draw ratio in the step (C) is 1.5 times or greater, or preferably 1.7 times or greater. The draw ratio in the step (C) is, for example, 3.0 times or less.

[0199] As a result of the draw ratio in the step (C) being 1.5 times or greater, the orientation of the polymer component in the plurality of raw filaments **100**A is further increased.

[0200] The draw ratio in the step (C) can be determined by using an equation shown below.

> Draw ratio in the step (*C*)=the speed (m/min) of the drawing roll unit/the speed (m/min) of the haul-off roll unit used in the step (*C*) (in the first embodiment, the "second haul-off roll unit 113")

[0201] In the step (C), a relaxation rate determined by using an equation shown below is preferably from 1 to 15%.

> Relaxation rate (%)=((the speed of the drawing roll unit 114−the speed of the winding roll unit that winds the plurality of raw filaments that have been drawn by the drawing roll unit (in the first embodiment, the "second winding roll unit 116"))/the speed of the winding roll unit that winds the plurality of raw filaments that have been drawn by the drawing roll unit)×100

[0202] It should be noted that the speed (m/min) of the drawing roll unit is the length of the to-be-drawn multifilament fed per unit time by the drawing roll unit.

[0203] In the first embodiment, only one drawing roll unit is used. However, alternatively, a plurality of drawing roll units may be used. In the case of using a plurality of drawing roll units, the highest drawing roll unit speed among the plurality of drawing roll units is determined as the "speed of the drawing roll unit".

[0204] The speed (m/min) of the haul-off roll unit used in the step (C) is the length of the to-be-drawn multifilament fed per unit time by the haul-off roll unit.

[0205] The speed (m/min) of the winding roll unit that winds the plurality of raw filaments that have been drawn by the drawing roll unit is the length of the plurality of raw filaments wound per unit time by the winding roll unit.

Second Embodiment: Spin-Draw Process

[0206] Next, a second embodiment is described with reference to FIG. **3**.

[0207] It should be noted that the same descriptions as those already given in the first embodiment are omitted below, and unless additional descriptions are particularly given in the second embodiment, it is assumed that the same descriptions as those given in the first embodiment apply to the second embodiment.

[0208] A method for producing a multifilament according to the second embodiment is a method for producing a multifilament by a spin-draw process.

[0209] The spin-draw process is a process in which multiple steps from a step of obtaining a plurality of raw filaments in a molten state by discharging a molten product through a plurality of discharge holes to a step of drawing the plurality of raw filaments by a drawing roll unit are performed as one process. The spin-draw process is also referred to as a "SDY process" or a "direct spin-draw process".

[0210] In the step (C) of the second embodiment, as shown in FIG. **3**, after the step (B2), the plurality of raw filaments **100**A are hauled off by a haul-off roll unit **207**.

[0211] Next, the plurality of raw filaments **100**A that have been hauled off by the haul-off roll unit **207** are drawn by three drawing roll units (a first drawing roll unit **208**, a second drawing roll unit **209**, and a third drawing roll unit **210**).

[0212] Then, in the step (C), the plurality of raw filaments **100**A that have been drawn by these drawing roll units are wound by a winding roll unit **212**, and thus the multifilament is obtained.

[0213] In the step (C), the feeding of the plurality of raw filaments that have been drawn by the drawing roll units may be performed by a take-off roll unit **211**.

[0214] In FIG. **3**, the haul-off roll unit **207** includes two rolls. However, alternatively, the number of rolls included in the haul-off roll unit **207** may be one, or may be three or more.

[0215] In FIG. **3**, each of the drawing roll units **208**, **209**, and **210** includes two rolls. However, alternatively, the number of rolls included in each of the drawing roll units **208**, **209**, and **210** may be one, or may be three or more.

[0216] From the viewpoint of facilitating the crystallization of the polymer component included in the plurality of raw filaments **100**A or increasing the thermal resistance of the polymer component included in the plurality of raw filaments **100**A, the temperature of each of the drawing roll units **208**, **209**, and **210** is preferably from 30 to 100° C., or more preferably from 40 to 90° C.

[0217] In the present embodiment, a spinning draft ratio (NDR) is preferably 50 or greater, or more preferably 80 or greater. Usually, the NDR is 5,000 or less.

[0218] The NDR can be determined by using an equation shown below.

> NDR=the speed (m/min) of the haul-off roll unit that first hauls off the filaments from the spinning nozzle (i.e., first haul-off roll unit)/the spinning nozzle flow speed (m/min)

[0219] As a result of the NDR being 50 or greater, the orientation of the polymer component included in the plurality of raw filaments **100**A can be increased, and consequently, the strength of the multifilament can be further increased.

[0220] It should be noted that, in the first embodiment (sequential drawing process), the first haul-off roll unit is the first haul-off roll unit **107**, which hauls off the plurality of raw filaments **100**A.

[0221] On the other hand, in the second embodiment (spin-draw process), the first haul-off roll unit is the haul-off roll unit **207**, which hauls off the plurality of raw filaments **100**A.

Multifilament According to Present Embodiment>>

[0222] Next, a multifilament according to the present embodiment is described.

[0223] The multifilament according to the present embodiment includes a plurality of single filaments.

[0224] The single filaments each contain the poly(3-hydroxyalkanoate) resin.

[0225] The average value of the fineness of the single filaments is 15 dtex or less.

[0226] The fusion rate of the single filaments is 10% or less.

[0227] The single filaments are each formed from a resin composition.

[0228] The resin composition contains a polymer component and an additive.

[0229] The polymer component includes the poly(3-hydroxyalkanoate) resin.

[0230] The polymer component may contain the aforementioned another polymer in addition to the poly(3-hydroxyalkanoate) resin.

[0231] Examples of the additive are those exemplified as the additive to be contained in the raw material composition.

[0232] The multifilament can be fabricated by the above-described method for producing a multifilament.

[0233] The weight-average molecular weight of the resin composition is preferably from 2.0×10^5 to 6.0×10^5 or more preferably from 2.3×10^5 to 4.0×10^5 so as to achieve excellent processability when processing the multifilament to obtain a processed product.

[0234] The number of single filaments included in the multifilament is preferably 30 or greater, more preferably from 30 to 300,000, or yet more preferably from 50 to 300,000.

[0235] Since the average value of the fineness of the single filaments is 15 dtex or less, the multifilament can be used for various applications. For example, the multifilament can be used as a material for fabricating a spun yarn.

[0236] The average value of the fineness of the single filaments is preferably 0.5 dtex or greater, or more preferably 1.0 dtex or greater.

[0237] The average value of the fineness of the single filaments is preferably 10 dtex or less, or more preferably 7.0 dtex or less.

[0238] In the present embodiment, the average value of the fineness of the single filaments can be determined in a manner described below.

[0239] First, the fineness of the multifilament (i.e., total fineness) is measured. Also, the number of single filaments included in the multifilament is determined.

[0240] Then, the average value of the fineness of the single filaments is determined by using an equation shown below.

$$\text{Average value of the fineness of the single filaments} = \text{the fineness of the multifilament} / \text{the number of single filaments included in the multifilament}$$

[0241] The fusion rate of the single filaments is 10% or less, preferably 7% or less, more preferably 5% or less, or yet more preferably 3% or less.

[0242] As a result of the fusion rate of the single filaments being 10% or less, an advantage owing to the average value of the fineness of the single filaments being 15 dtex or less, i.e., an advantage owing to the single filaments being thin, is easily exerted. In addition, as a result of the fusion rate of the single filaments being 10% or less, excellent processability is achieved when processing the multifilament to obtain a processed product. Further, as a result of the fusion rate of the single filaments being 10% or less, for example, when staples are produced by cutting the multifilament, the staples can be produced at a high yield.

[0243] The less the fusion rate of the single filaments, the better. For example, the fusion rate of the single filaments may be 0.00%.

[0244] The fusion rate of the single filaments can be determined in a manner described below.

[0245] First, the multifilament is cut along a plane perpendicular to the longitudinal direction of the multifilament, and thereby all the single filaments included in the multifilament are cut.

[0246] Next, by using a scanning electron microscope (SEM), the cut surface of the multifilament is observed, and the total number of single filaments included in the multifilament is counted at the cut surface, and the number of single filaments fused to other single filaments at the cut surface (in other words, a number obtained by subtracting "the number of single filaments not fused to other single filaments" from "the total number of single filaments included in the multifilament") is counted.

[0247] Then, the fusion rate is determined by using an equation shown below.

$$\text{Fusion rate (\%)} = \left(\frac{\text{the number of single filaments fused to other single filaments at the cut surface}}{\text{the total number of single filaments included in the multifilament at the cut surface}} \times 100\right)$$

[0248] The maximum height roughness of the single filaments is preferably from 0.10 to 0.50 μm, more preferably from 0.12 to 0.42 μm, or yet more preferably from 0.15 to 0.40 μm.

[0249] As a result of the maximum height roughness of the single filaments being 0.10 μm or greater, the fusion of the single filaments to each other is advantageously suppressed.

[0250] As a result of the maximum height roughness of the single filaments being 0.50 μm or less, when the multifilament is processed to obtain a processed product, for example, the single filaments are suppressed from getting caught on a processing machine or the like, and as a result, excellent processability is achieved, which is advantageous.

[0251] The maximum height roughness of the single filaments can be determined in a manner described below in Examples.

[0252] The multifilament may be used in the form of a yarn as it is.

[0253] The multifilament may be cut to obtain a staple having a length of 20 cm or less. The staple may be used in the form of a yarn as it is.

[0254] The multifilaments and/or the staples may be used to fabricate a fibrous product (a fibrous body).

[0255] The fibrous product can be made into various shapes (e.g., made into a nonwoven fabric).

[0256] The multifilaments, the staples, and the fibrous product can be suitably used for conventionally known use applications.

[0257] The multifilaments, the staples, and the fibrous product can be suitably used in the fields of, for example, agriculture (e.g., horticulture), fishery, forestry, medical care, and food industry.

[0258] Examples of the fibrous product include clothes, curtains, carpets, bags, shoes, wiping materials, sanitary items, automobile parts, building materials, and filtration materials (filters).

[Disclosure Items]

[0259] The following items each disclose a preferred embodiment.

[Item 1]

[0260] A method for producing a multifilament including a plurality of single filaments by melt spinning by using a spinning nozzle that includes a plurality of discharge holes, the method including the steps of: (A) heat-melting a raw material composition to obtain a molten product and discharging the molten product through the discharge holes to obtain a plurality of raw filaments in a molten state; and (B) blowing gases onto the plurality of raw filaments, wherein: the raw material composition contains a poly(3-hydroxyalkanoate) resin; the step (B) includes the steps of (B1) blowing a first gas onto the plurality of raw filaments in the molten state to cool the plurality of raw filaments and (B2) blowing a second gas onto the plurality of raw filaments that have been cooled in the step (B1); in the step (B1), a temperature of the first gas is from (Tc−45° C.) to (Tc−30° C.) [Tc is a crystallization temperature of the poly(3-hydroxyalkanoate) resin]; in the step (B2), a temperature of the second gas is higher than the temperature of the first gas, and is from (Tc−30° C.) to (Tc−10° C.); and an average value of fineness of the single filaments is 15 dtex or less.

[Item 2]

[0261] The method for producing a multifilament according to item 1, wherein in the step (B1), the temperature of the first gas is from (Tc−40° C.) to (Tc−30° C.).

[Item 3]

[0262] The method for producing a multifilament according to item 1 or 2, wherein in the step (B1), a speed of the first gas is from 0.1 to 1.0 m/s.

[Item 4]

[0263] The method for producing a multifilament according to any one of items 1 to 3, wherein in the step (B2), a speed of the second gas is from 0.005 to 1.5 m/s.

[Item 5]

[0264] The method for producing a multifilament according to any one of items 1 to 4, wherein a value obtained by subtracting the temperature of the first gas from the temperature of the second gas is from 5 to 25° C.

[Item 6]

[0265] The method for producing a multifilament according to any one of items 1 to 5, wherein the poly(3-hydroxyalkanoate) resin includes a poly(3-hydroxybutyrate) resin.

[Item 7]

[0266] A multifilament comprising a plurality of single filaments, wherein: the single filaments each contain a poly(3-hydroxyalkanoate) resin; an average value of fineness of the single filaments is 15 dtex or less; and a fusion rate of the single filaments is 10% or less.

[Item 8]

[0267] The multifilament according to item 7, wherein a maximum height roughness of the single filaments is from 0.10 to 0.50 μm.

[0268] It should be noted that the present invention is not limited to the above-described embodiments. Also, the present invention is not limited by the above-described functional advantages. Further, various modifications can be made to the present invention without departing from the scope of the present invention.

EXAMPLES

[0269] Next, the present invention is described more specifically with Examples and Comparative Examples. It should be noted that the present invention is not limited by these Examples in any way.

Example 1

[0270] A multifilament was fabricated by a method described in the first embodiment (specifically, by a sequential drawing process).

(Step (A))

[0271] First, materials listed below were subjected to dry blending at a blending ratio indicated below, and thereby a raw material composition was obtained. Then, the raw material composition was melt-kneaded by an extruder at 150° C., and thereby pellets were obtained.

[0272] As a poly(3-hydroxyalkanoate) resin (P3HA), a (3-hydroxybutyrate-co-3-hydroxyhexanoate) copolymer resin (with a content ratio of a 3-hydroxybutyrate unit of 94.0 mol %, a content ratio of a 3-hydroxyhexanoate unit of 6 mol %, a crystallization temperature (Tc) of 60° C., and a weight-average molecular weight (Mw) of 582,936) (P3HB3HH): 100 parts by mass

[0273] An erucic acid amide (EA) as an amide bond-containing lubricant: 0.5 parts by mass

[0274] A behenic acid amide (BA) as an amide bond-containing lubricant: 0.5 parts by mass

[0275] Pentaerythritol (PETL) as a crystal nucleating agent (Neulizer P available from The Nippon Synthetic Chemical Industry Co., Ltd.): 1.0 part by mass

[0276] It should be noted that the crystallization temperature and the weight-average molecular weight of the P3HA were each measured in the above-described manner.

[0277] The content ratio of the 3-hydroxybutyrate unit and the content ratio of the 3-hydroxyhexanoate (3HH) unit in the P3HA were determined in a manner described below.

[0278] First, 2 mL of a mixed solution of sulfuric acid and methanol (the volume of sulfuric acid:the volume of methanol=15:85) and 2 mL of chloroform were added to 20 mg of the P3HA in a dry state. The resulting sample was placed in a container, and the container was sealed. The sample in the sealed container was heated at 100° C. for 140 minutes, and thereby a first reaction solution was obtained, the first reaction solution including a methyl ester that was a P3HA degradation product.

[0279] Then, the first reaction solution was cooled, and 1.5 g of sodium hydrogen carbonate was added to the cooled first reaction solution little by little for neutralization. The

resulting mixture was left stand until generation of carbon dioxide stopped. In this manner, a second reaction solution was obtained.

[0280] Further, 4 mL of diisopropyl ether was added to and mixed well with the second reaction solution, and thereby a mixture was obtained.

[0281] Next, the mixture was subjected to centrifugal separation, and thereby a supernatant solution was obtained.

[0282] Then, the monomer unit composition of the aforementioned degradation product in the supernatant solution was analyzed by capillary gas chromatography under the conditions indicated below, and thereby the content ratio of the 3-hydroxybutyrate unit and the content ratio of the 3-hydroxyhexanoate (3HH) unit in the P3HA were determined.

[0283] Gas chromatograph: GC-17A available from Shimadzu Corporation

[0284] Capillary column: NEUTRABOND-1 (column length: 25 m, column inner diameter: 0.25 mm, liquid film thickness: 0.4 μm) available from GL Sciences Inc.

[0285] Carrier gas: He

[0286] Column inlet pressure: 100 kPa

[0287] Sample amount: 1 μL

[0288] As the temperature condition, the temperature was raised from 100 to 200° C. at a rate of 8° C./min, and then raised from 200 to 290° C. at a rate of 30° C./min.

[0289] Then, as shown in FIG. **1**, the kneading extruder **102** (single screw extruder with a screw diameter of 25 mm) was used to melt the pellets, and thereby a molten product was obtained.

[0290] Then, the molten product was discharged from the spinning nozzle **104** (at a spinning temperature of 175° C. and with **180** circular discharge holes having an discharge hole diameter of 0.5 mm), and thereby 180 raw filaments **100**A were obtained.

[0291] It should be noted that the flow rate of the molten product was adjusted to 3.0 kg/h by the gear pump **103**.

(Step (B))

[0292] In the step B1, in the first box **105**, the first gas (air) having a temperature of 23.8° C. was blown onto the 180 raw filaments **100**A in a molten state by the circular method at a gas speed of 0.22 m/s, and thereby the 180 raw filaments **100**A were cooled.

[0293] Next, in the step B2, in the second box **106**, the second gas (air) having a temperature of 34.1° C. was blown onto the 180 raw filaments **100**A by the back-side method at a gas speed of 0.20 m/s, and thereby the 180 raw filaments **100**A were warmed up.

[0294] It should be noted that Table 1 below shows the conditions in the step (B1) and the step (B2), including "a value (T2−T1) obtained by subtracting a temperature (T1) of the first gas from a temperature (T2) of the second gas", "T1−Tc", and "T2−Tc".

[0295] Subsequently, the 180 raw filaments **100**A were hauled off by the first haul-off roll unit **107** (at 560 m/min), and then the 180 raw filaments **100**A were passed through the first feeding roll unit **108** (at 560 m/min), the second feeding roll unit **109** (at 560 m/min, 70° C.), the third feeding roll unit **110** (at 560 m/min), and the fourth feeding roll unit **111** (at 560 m/min) sequentially. Thereafter, the 180 raw filaments **100**A were wound by the first winding roll unit (at 530 m/min), which were then kept at room temperature (from 5 to 35° C.) for 18 hours.

[0296] It should be noted that the NDR was 175, and the draw ratio was 1.05.

(Step (C))

[0297] As shown in FIG. **2**, the 180 raw filaments **100**A were hauled off from the first winding roll unit **112** by the second haul-off roll unit **113** (at 55.5 m/min and 30° C.), drawn by the drawing roll unit **114** (at 110 m/min and 90° C.), fed by the heat treatment roll unit **115** (at 100 m/min and 100° C.), and wound by the second winding roll unit **116** (at 100 m/min). In this manner, a multifilament was obtained.

[0298] The draw ratio was 2.0 times, and the relaxation rate was 10%.

[0299] It should be noted that each of the haul-off roll units and feeding roll units used above includes two rolls that roll at the same speed and that have the same temperature.

Examples 2 to 7, Comparative Example 1

[0300] A multifilament was obtained in the same manner as in Example 1 except that the conditions in the step (B-1) and the step (B-2) were changed as shown in Table 1 below.

Comparative Example 2

[0301] An attempt was made to obtain a multifilament in the same manner as in Example 1 except that the 180 raw filaments **100**A were cooled in the step (B-2) and the conditions in the step (B-1) and the step (B-2) were changed as shown in Table 1 below. However, between the discharge holes and the first haul-off roll unit **107**, the breakage of some of the raw filaments occurred.

[0302] Consequently, the multifilament could not be obtained.

Comparative Example 3

[0303] A multifilament was obtained in the same manner as in Example 1 except that the 180 raw filaments **100**A were cooled in the step (B-2) and the conditions in the step (B-1) and the step (B-2) were changed as shown in Table 1 below.

Comparative Example 4

[0304] An attempt was made to obtain a multifilament in the same manner as in Example 1 except that the conditions in the step (B-1) and the step (B-2) were changed as shown in Table 1 below. However, between the discharge holes and the first haul-off roll unit **107**, the breakage of some of the raw filaments occurred.

[0305] Consequently, the multifilament could not be obtained.

Comparative Example 5

[0306] An attempt was made to obtain a multifilament in the same manner as in Example 1 except that the conditions in the step (B-2) were changed as shown in Table 1 below and the step (B-1) was not performed. However, between the discharge holes and the first haul-off roll unit **107**, the breakage of some of the raw filaments occurred.

[0307] Consequently, the multifilament could not be obtained.

Comparative Example 6

[0308] A multifilament was obtained in the same manner as in Example 1 except that the conditions in the step (B-1) were changed as shown in Table 1 below and the step (B-2) was not performed.

<Spinnability>

[0309] Spinnability was evaluated as Good in a case where a multifilament was successfully fabricated, and evaluated as Bad in a case where a multifilament could not be fabricated due to the breakage of raw filaments. Table 1 below shows evaluation results.

<Average Value of Fineness of Single Filaments>

[0310] For each multifilament obtained in Examples and Comparative Examples, the average value of the fineness of the single filaments in the multifilament was measured in the above-described manner.

[0311] Table 1 below shows the measured average value of the fineness of the single filaments.

<Fusion Rate of Single Filaments>

[0312] For each multifilament obtained in Examples and Comparative Examples, the fusion rate of the single filaments in the multifilament was measured in the above-described manner.

[0313] Table 1 below shows the measured fusion rate of the single filaments.

<Arithmetic Mean Roughness of Single Filaments and Maximum Height Roughness of Single Filaments>

[0314] For each multifilament obtained in Examples and Comparative Examples, the surface roughness of the single filaments in the multifilament was measured in accordance with JIS B0601: 2001. Also, the arithmetic mean roughness Ra of the single filaments and the maximum height roughness Rz of the single filaments were determined in accordance with JIS B0601: 2001.

[0315] It should be noted that for the measurement of the surface roughness of the single filaments, five or more single filaments were randomly taken out from the multifilament. Then, the surface roughness of each single filament was measured in the longitudinal direction of each single filament, and the arithmetic mean roughness of each single filament and the maximum height roughness of each single filament were calculated. Then, the average of the arithmetic mean roughness calculated values of the respective single filaments was defined as the arithmetic mean roughness Ra of the single filaments, and the average of the maximum height roughness calculated values of the respective single filaments was defined as the maximum height roughness Rz of the single filaments.

[0316] In the measurement, a laser microscope was used. As the laser microscope, "VK-9500" available from KEYENCE CORPORATION was used.

[0317] The surface roughness measurement was performed under the conditions indicated below.

[0318] Cutoff value: 0.08 mm

[0319] Evaluated length: 80 μm

[0320] Table 1 below shows the arithmetic mean roughness of the single filaments and the maximum height roughness of the single filaments.

		Ex. 1	Ex. 2	EX. 3	EX. 4	EX. 5	EX. 6	EX. 7	Comp. Ex. 1	Comp. Ex. 2	Comp. Ex. 3	Comp. Ex. 4	Comp. Ex. 5	Comp. Ex. 6
Step (B1)	Gas blowing method	Circular	Circular	Circular	Circular	Circular	Circular	Circular	Backside	Circular	Circular	Circular	No gas blowing	Circular
	First gas temperature T1 (° C.)	23.80	24.50	22.50	24.40	23.60	22.60	18.40	12.50	47.00	23.40	26.10		25.50
	(T1 − Tc) (° C.)	−36.20	−35.50	−37.50	−35.60	−36.40	−37.40	−41.60	−47.50	−13.00	−36.60	−33.90		−34.50
	First gas speed (m/s)	0.22	0.21	0.19	0.22	0.43	0.18	0.36	0.14	0.10	0.19	0.28		0.25
Step (B2)	Gas blowing method	Backside	Backside	Backside	Backside	Backside	Backside	Backside	Backside	Backside	Backside	Backside	Backside	No gas blowing
	Second gas temperature T2 (° C.)	34.10	34.40	33.40	43.80	39.40	35.70	36.20	33.20	32.20	8.70	53.40	34.70	
	(T2 − Tc) (° C.)	−25.90	−25.60	−26.60	−16.20	−20.60	−24.30	−23.80	−26.80	−27.80	−51.30	−6.60	25.30	
	Second gas speed (m/s)	0.20	0.22	0.21	0.23	0.23	0.01	0.25	0.20	0.23	0.24	0.22	0.23	
(T2 − T1) (° C.)		10.30	9.90	10.90	19.40	15.80	13.10	17.80	20.70	−14.80	−14.70	27.30	—	—
Spinnability		Good	Good	Good	Good	Good	Good	Good	Good	Bad	Good	Bad	Bad	Good
Multifilament	Single filament fineness average value (dtex)	2.27	5.57	1.77	2.32	2.13	2.38	2.57	2.71	Not fabricatable	2.28	Not fabricatable	Not fabricatable	2.54
	Single filament fusion rate (%)	0.00	0.54	4.43	4.38	7.85	7.97	9.23	13.54		17.66			26.40
	Single filament arithmetic mean roughness Ra (μm)	0.016	0.033	0.028	0.015	0.021	0.014	0.022	0.012		0.014			0.017
	Single filament maximum height	0.22	0.36	0.40	0.19	0.24	0.17	0.28	0.22		0.14			0.17

-continued

	Ex. 1	Ex. 2	EX. 3	EX. 4	EX. 5	EX. 6	EX. 7	Comp. Ex. 1	Comp. Ex. 2	Comp. Ex. 3	Comp. Ex. 4	Comp. Ex. 5	Comp. Ex. 6
roughness Rz (μm)													

[0321] As shown in Table 1, the fusion rate of the single filaments in each of Examples 1 to 7, which fall within the scope of the present invention, was less than the fusion rate of the single filaments in Comparative Example 1, in which the temperature of the first gas in the step (B1) was lower than (Tc−45° C.), the fusion rate of the single filaments in Comparative Example 3, in which the temperature of the second gas in the step (B2) was lower than (Tc−30° C.), and the fusion rate of the single filaments in Comparative Example 6, in which the step (B2) was not performed.

[0322] In Comparative Example 2, in which the temperature of the first gas in the step (B1) was higher than (Tc−30° C.), Comparative Example 4, in which the temperature of the second gas in the step (B2) was higher than (Tc−10° C.), and Comparative Example 5, in which the step (B1) was not performed, the breakage of raw filaments occurred, and the multifilament could not be fabricated.

[0323] Therefore, according to the present invention, regardless of a small average value of the fineness of the single filaments, the breakage of the raw filaments can be suppressed, and the fusion of the single filaments to each other can be suppressed.

[0324] It should be noted that in the Examples of the aforementioned Patent Literature 2 (WO2021/206154), the temperatures of air blown onto raw filaments are about the same as the gas temperatures in Comparative Examples 1 and 3 in the present specification. Accordingly, it is considered that in the Examples of Patent Literature 2, the fusion rate of the single filaments is high.

[0325] The fusion rate of the single filaments in each of Examples 1 to 5 was even less than the fusion rate of the single filaments in Example 6, in which the speed of the second gas was a low speed of 0.01 m/s.

[0326] Further, the fusion rate of the single filaments in each of Examples 1 to 4 was even less than the fusion rate of the single filaments in Example 5, in which the speed of the first gas was a high speed of 0.43 m/s.

REFERENCE SIGNS LIST

[0327] **100**A: raw filament, **101**: raw material feeder, **102**: kneading extruder, **103**: gear pump, **104**: spinning nozzle, **105**: first box, **106**: second box, **107**: first haul-off roll unit, **108**: first feeding roll unit, **109**: second feeding roll unit, **110**: third feeding roll unit, **111**: fourth feeding roll unit, **112**: first winding roll unit, **113**: second haul-off roll unit, **114**: drawing roll unit, **115**: heat treatment roll unit, **116**: second winding roll unit

[0328] **207**: haul-off roll unit, **208**: first drawing roll unit, **209**: second drawing roll unit, **210**: third drawing roll unit, **211**: take-off roll unit, **212**: winding roll unit

1: A method for producing a multifilament comprising a plurality of single filaments by melt spinning by using a spinning nozzle that includes a plurality of discharge holes, the method comprising:

(A) heat-melting a raw material composition to obtain a molten product and discharging the molten product through the discharge holes to obtain a plurality of raw filaments in a molten state; and

(B) blowing gases onto the plurality of raw filaments,

wherein:

the raw material composition comprises a poly(3-hydroxyalkanoate) resin;

(B) comprises (B1) blowing a first gas onto the plurality of raw filaments in the molten state to cool the plurality of raw filaments and (B2) blowing a second gas onto the plurality of raw filaments that have been cooled in (B1);

in (B1), a temperature of the first gas is from (Tc−45° C.) to (Tc−30° C.), wherein Tc is a crystallization temperature of the poly(3-hydroxyalkanoate) resin;

in (B2), a temperature of the second gas is higher than the temperature of the first gas, and is from (Tc−30° C.) to (Tc−10° C.); and

an average value of fineness of single filaments is 15 dtex or less.

2: The method according to claim **1**, wherein in (B1), the temperature of the first gas is from (Tc−40° C.) to (Tc−30° C.).

3: The method according to claim **1**, wherein in (B1), a speed of the first gas is from 0.1 to 1.0 m/s.

4: The method according to claim **1**, wherein in (B2), a speed of the second gas is from 0.005 to 1.5 m/s.

5: The method according to claim **1**, wherein a value obtained by subtracting the temperature of the first gas from the temperature of the second gas is from 5 to 25° C.

6: The method according to claim **1**, wherein the poly(3-hydroxyalkanoate) resin includes a poly(3-hydroxybutyrate) resin.

7: A multifilament comprising a plurality of single filaments, wherein:

the single filaments each contain a poly(3-hydroxyalkanoate) resin;

an average value of fineness of the single filaments is 15 dtex or less; and

a fusion rate of the single filaments is 10% or less.

8: The multifilament according to claim **7**, wherein a maximum height roughness of the single filaments is from 0.10 to 0.50 μm.

9: The method according to claim **2**, wherein in (B1), a speed of the first gas is from 0.1 to 1.0 m/s.

10: The method according to claim **2**, wherein in (B2), a speed of the second gas is from 0.005 to 1.5 m/s.

11: The method for producing a multifilament according to claim **2**, wherein a value obtained by subtracting the temperature of the first gas from the temperature of the second gas is from 5 to 25° C.

12: The method for producing a multifilament according to claim **2**, wherein the poly(3-hydroxyalkanoate) resin includes a poly(3-hydroxybutyrate) resin.

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