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(54) **UNDRAWN MULTIFILAMENT, METHOD FOR PRODUCING THE SAME, MULTIFILAMENT, METHOD FOR PRODUCING THE SAME, STAPLE, AND METHOD FOR PRODUCING THE SAME**

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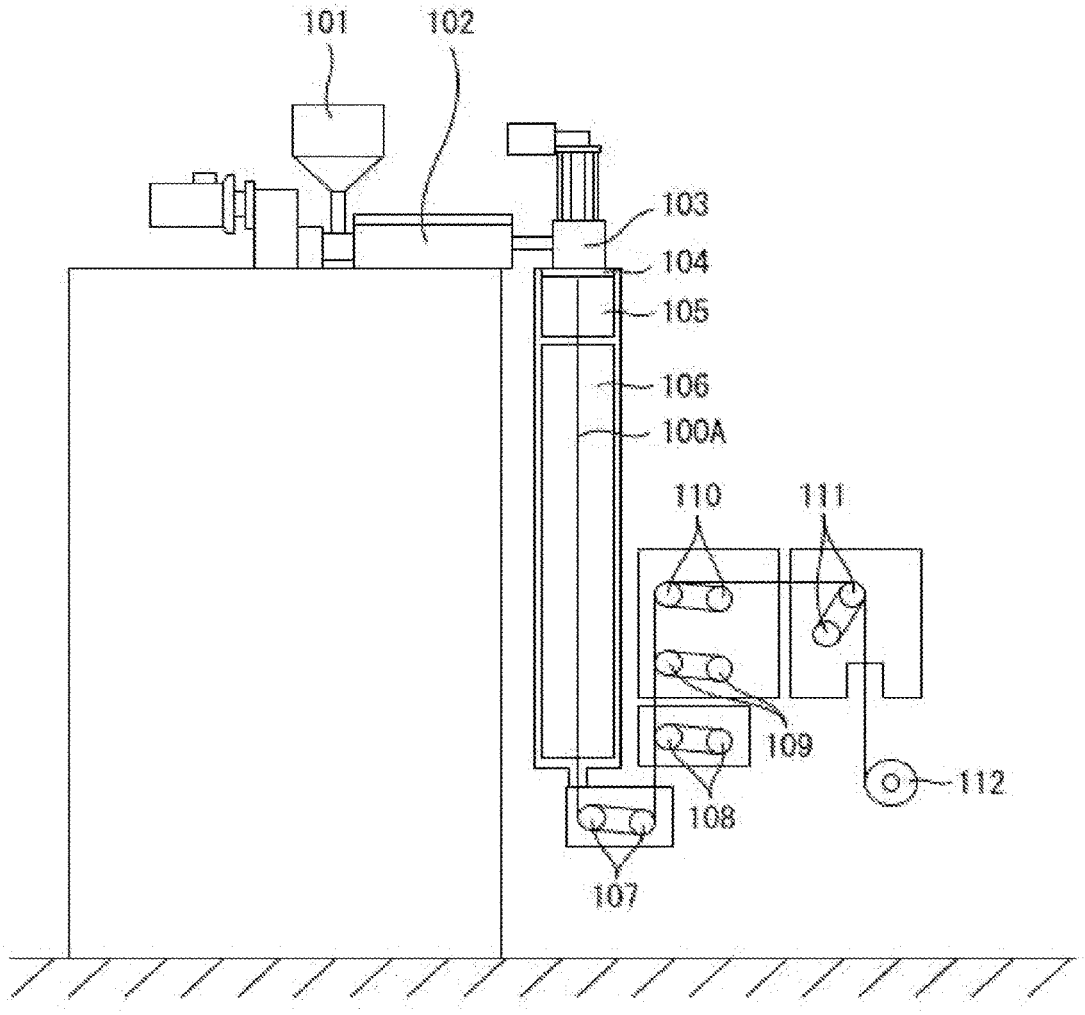
(57) **ABSTRACT**

The present invention is directed to an undrawn multifilament including 30 or more individual filaments. In the undrawn multifilament, the individual filaments contain a poly(3-hydroxyalkanoate) resin and a nucleating agent, the mean of the finenesses of the individual filaments is 30 dtex or less, and the coefficient of variation of the finenesses of the individual filaments is 33% or less.



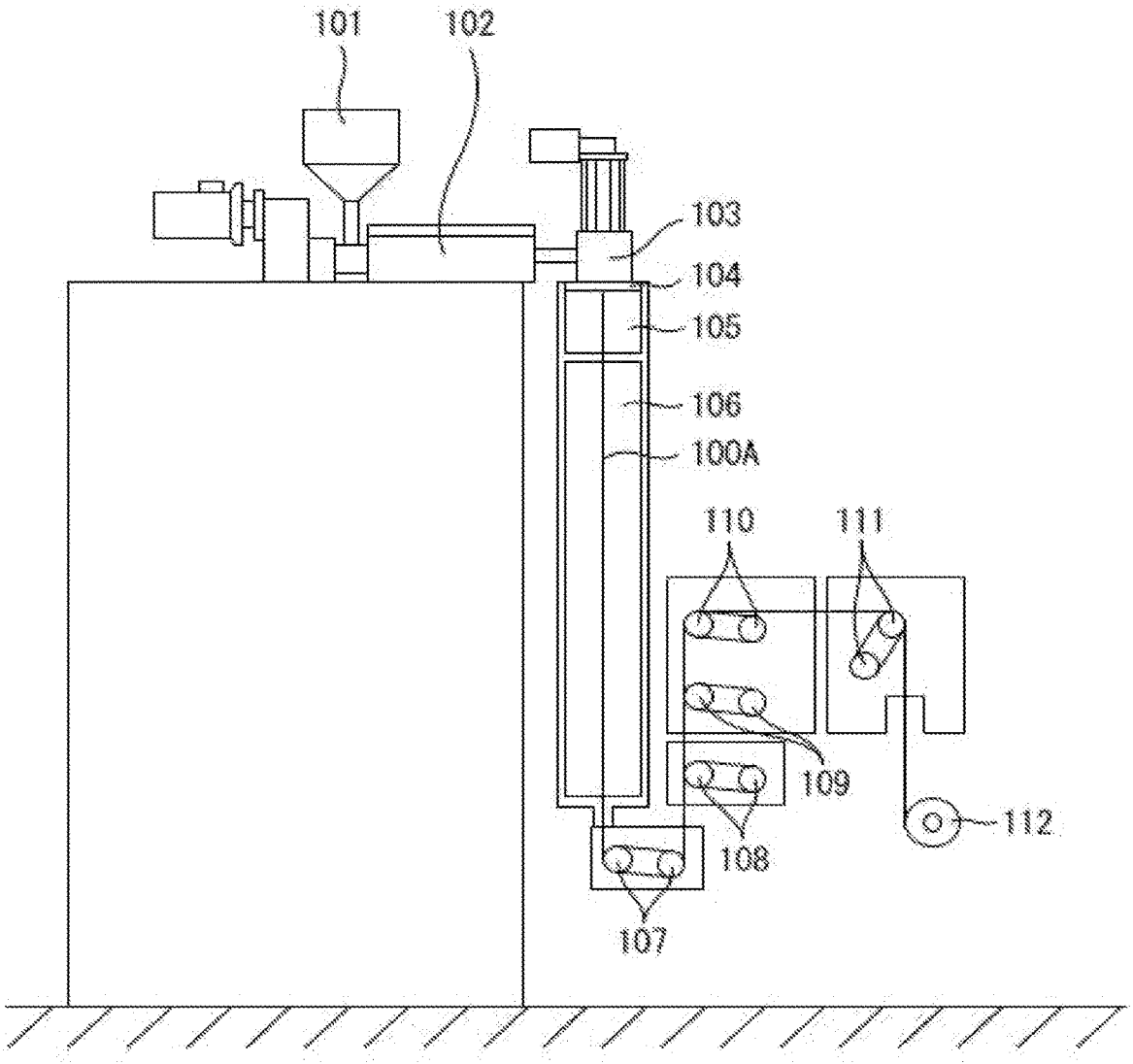


FIG. 1

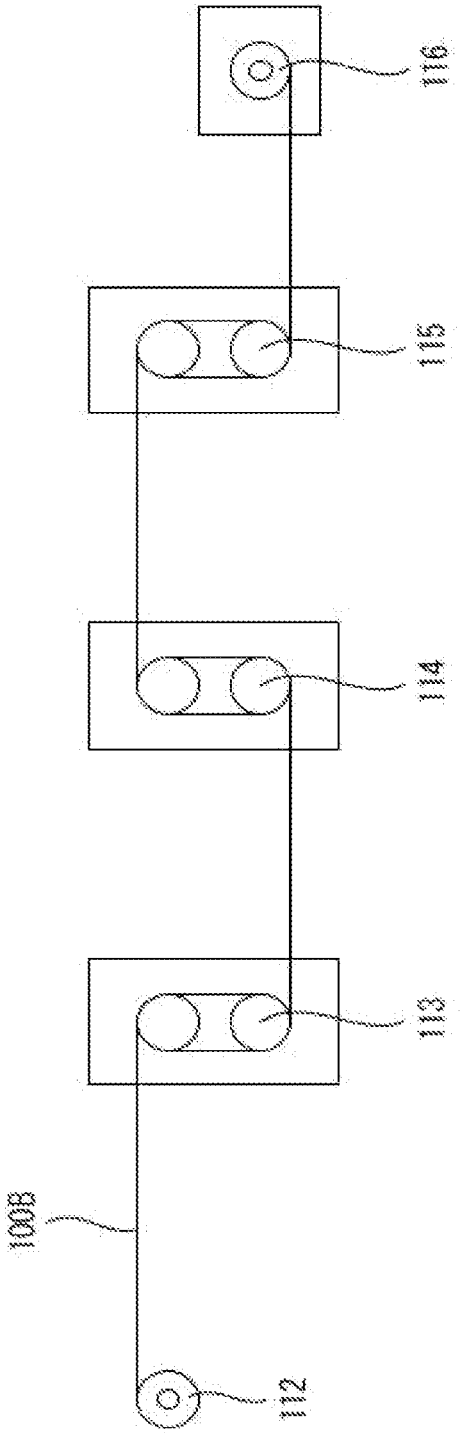


FIG. 2

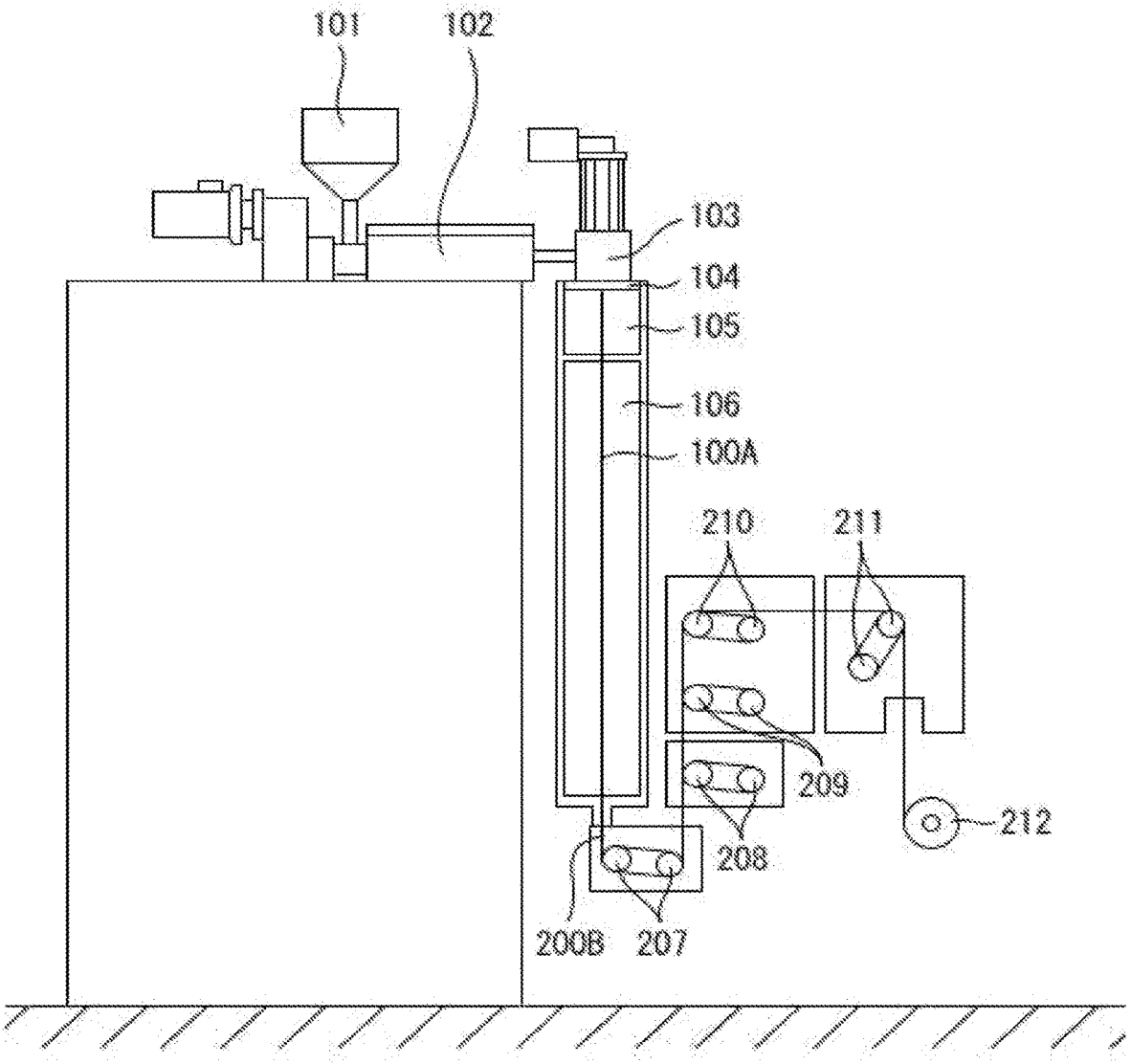


FIG. 3

UNDRAWN MULTIFILAMENT, METHOD FOR PRODUCING THE SAME, MULTIFILAMENT, METHOD FOR PRODUCING THE SAME, STAPLE, AND METHOD FOR PRODUCING THE SAME

TECHNICAL FIELD

[0001] The present invention relates to: an undrawn multifilament: a method for producing the undrawn multifilament: a multifilament: a method for producing the multifilament: a staple; and a method for producing the staple.

BACKGROUND ART

[0002] In recent years, waste plastics have become problematic since they have caused a significant impact on the global environment, for example, by affecting ecosystems, emitting hazardous gases during combustion, or generating a huge amount of combustion heat which contributes to global warming. As a solution to this problem, biodegradable plastics are under active development.

[0003] The biodegradable plastics include those obtained using plant-derived materials. Carbon dioxide emitted upon combustion of plant-derived biodegradable plastics is that which originally existed in the air, and does not cause an increase in the amount of atmospheric carbon dioxide. This is called "carbon neutrality". The carbon neutrality is emphasized under the Kyoto Protocol which specifies a carbon dioxide reduction goal, and the active use of carbon-neutral plastics is desired.

[0004] Nowadays, in terms of biodegradability and carbon neutrality, aliphatic polyester resins are attracting attention as biodegradable plastics microbially produced using plant-derived materials as carbon sources. Particular attention is being directed to polyhydroxyalkanoate resins.

[0005] Patent Literature 1 discloses a multifilament including a plurality of individual filaments containing a 3-hydroxyalkanoate polymer.

[0006] Patent Literature 1 further discloses obtaining the multifilament by melt extrusion.

[0007] Specifically, the method of Patent Literature 1 includes the steps of: (A) in melt spinning, discharging a melt using a spinning nozzle having four discharge holes to obtain a plurality of raw filaments in a molten state; and (B) cooling the plurality of raw filaments in the molten state while transferring the plurality of raw filaments to obtain an undrawn multifilament.

[0008] The undrawn multifilament can be stretched by means of rolls to obtain a multifilament.

[0009] Modified cross-section fibers containing a wholly aromatic polyamide are known, and an example of such fibers is a wholly aromatic polyamide modified cross-section fiber in which the coefficient of variation of the finenesses of individual filaments is 9.0% or less and which meets other specific requirements (see Patent Literature 2, for example).

CITATION LIST

Patent Literature

[0010] PTL 1: WO 2015/029316

[0011] PTL 2: Japanese Laid-Open Patent Application Publication No. 2014-122448

SUMMARY OF INVENTION

Technical Problem

[0012] A demand for a high-strength multifilament including thin individual filaments containing a poly(3-hydroxyalkanoate) could arise in the future.

[0013] When an undrawn multifilament is stretched to obtain a multifilament, an increase in the stretching ratio leads to the resulting multifilament having an enhanced degree of polymer orientation and therefore high strength.

[0014] The present inventors attempted to obtain a multifilament including thin individual filaments and having high strength using a poly(3-hydroxyalkanoate) resin. The inventors prepared an undrawn multifilament including thin individual filaments and tried to stretch the undrawn multifilament at a high stretching ratio. However, the individual filaments broke during the stretching, and a multifilament was not able to be obtained.

[0015] A first object of the present invention is to obtain an undrawn multifilament including individual filaments containing a poly(3-hydroxyalkanoate) resin, the undrawn multifilament being easily processable into a multifilament that has high strength despite including individual filaments having finenesses whose mean is small.

[0016] A second object is to obtain a multifilament including individual filaments containing a poly(3-hydroxyalkanoate) resin, the multifilament having high strength despite the individual filaments having finenesses whose mean is small.

[0017] A third object is to obtain a staple including a cut piece of the multifilament.

Solution to Problem

[0018] A first aspect of the present invention relates to an undrawn multifilament including 30 or more individual filaments, wherein

[0019] the individual filaments contain a poly(3-hydroxyalkanoate) resin and a nucleating agent,

[0020] a mean of finenesses of the individual filaments is 30 dtex or less, and

[0021] a coefficient of variation of the finenesses of the individual filaments is 33% or less.

[0022] Preferably, the poly(3-hydroxyalkanoate) resin includes a poly(3-hydroxy butyrate) resin.

[0023] A second aspect of the present invention relates to a multifilament having been stretched, the multifilament including 30 or more individual filaments, wherein

[0024] the individual filaments contain a poly(3-hydroxyalkanoate) resin and a nucleating agent,

[0025] a mean of finenesses of the individual filaments is 20 dtex or less, and

[0026] a coefficient of variation of the finenesses of the individual filaments is 33% or less.

[0027] A third aspect of the present invention relates to a staple including a cut piece of the multifilament, the staple having a length of 20 cm or less.

[0028] A fourth aspect of the present invention relates to an undrawn multifilament production method for obtaining an undrawn multifilament by melt spinning, the undrawn multifilament production method including the steps of:

[0029] (A) in the melt spinning, discharging a melt using a spinning nozzle having 30 or more discharge holes to obtain 30 or more raw filaments in a molten state; and

[0030] (B) blowing a gas having a temperature of 0 to 50° C. onto the 30 or more raw filament in the molten state to cool the 30 or more raw filaments and obtain an undrawn multifilament, wherein

[0031] the melt contains a poly(3-hydroxyalkanoate) resin and a nucleating agent,

[0032] a mean of finenesses of individual filaments of the undrawn multifilament is 30 dtex or less, and

[0033] in the step (B), a coefficient of heat transfer between the gas and the 30 or more raw filament in the molten state is 60 $W/(m^2 \cdot K)$ or more.

[0034] Preferably, in the step (B), the coefficient of heat transfer is 125 $W/(m^2 \cdot K)$ or more.

[0035] Preferably, in the step (B), a speed of the gas blown onto the 30 or more raw filaments is 0.1 m/s or more.

[0036] A fifth aspect of the present invention relates to a multifilament production method including:

[0037] using the undrawn multifilament production method to obtain the undrawn multifilament; and

[0038] the step of (C) stretching the undrawn multifilament by a stretching roll unit at a stretching ratio of 1.5 or more to obtain a multifilament.

[0039] Preferably, in the step (B), the gas having a temperature of 0 to 50° C. is blown onto the 30 or more raw filaments in the molten state to cool the 30 or more raw filaments to 50° C. below and obtain the undrawn multifilament, and

[0040] in the step (C), the undrawn multifilament is heated, and the heated undrawn multifilament is stretched by the stretching roll unit.

[0041] A sixth aspect of the present invention relates to a staple production method including:

[0042] using the multifilament production method to obtain the multifilament; and

[0043] cutting the multifilament to obtain a staple having a length of 20 cm or less.

Advantageous Effects of Invention

[0044] The present invention can provide an undrawn multifilament including individual filaments containing a poly(3-hydroxyalkanoate) resin, the undrawn multifilament being easily processable into a multifilament that has high strength despite including individual filaments having finenesses whose mean is small.

[0045] The present invention can further provide a multifilament including individual filaments containing a poly(3-hydroxyalkanoate) resin, the multifilament having high strength despite the individual filaments having finenesses whose mean is small.

[0046] The present invention can further provide a staple including a cut piece of the multifilament.

BRIEF DESCRIPTION OF DRAWINGS

[0047] FIG. **1** is a schematic diagram of an apparatus used in steps (A) and (B) in a first embodiment.

[0048] FIG. **2** is a schematic diagram of an apparatus used in step (C) in the first embodiment.

[0049] FIG. **3** is a schematic diagram of an apparatus used in a second embodiment.

DESCRIPTION OF EMBODIMENTS

[0050] Hereinafter, one embodiment of the present invention will be described.

<Undrawn Multifilament>

[0051] An undrawn multifilament according to the present embodiment will be described first.

[0052] The undrawn multifilament according to the present embodiment includes 30 or more first individual filaments.

[0053] The first individual filaments contain a poly(3-hydroxyalkanoate) resin and a nucleating agent.

[0054] The mean of the finenesses of the first individual filaments is 30 dtex or less.

[0055] The coefficient of variation of the finenesses of the first individual filaments is 33% or less.

[0056] A multifilament can be obtained by stretching the undrawn multifilament according to the present embodiment.

[0057] A staple can be obtained by cutting the multifilament.

[0058] As previously mentioned, a wholly aromatic polyamide fiber is known in which the coefficient of variation of the finenesses of individual filaments is 9.0% or less (see Patent Literature 2 listed above, for example).

[0059] Unlike wholly aromatic polyamides, poly(3-hydroxyalkanoate) resins are difficult to subject to forming processes.

[0060] Thus, it has been difficult for an undrawn multifilament including first individual filaments containing a poly (3-hydroxyalkanoate) resin to be such that the mean of the finenesses of the first individual filaments is small and the coefficient of variation of the finenesses of the first individual filaments is also small.

[0061] The present inventors conducted an intensive study on an undrawn multifilament including 30 or more first individual filaments containing a poly(3-hydroxyalkanoate) resin. As a result, the present inventors have succeeded in controlling the mean of the finenesses of the first individual filaments to 30 dtex or less and the coefficient of variation of the finenesses of the first individual filaments to 33% or less.

[0062] The present inventors conducted a further study on the undrawn multifilament including the 30 or more first individual filaments containing a poly(3-hydroxyalkanoate) resin. As a result, the present inventors have found that when the mean of the finenesses of the first individual filaments is controlled to 30 dtex or less and the coefficient of variation of the finenesses of the first individual filaments is controlled to 33% or less, the undrawn multifilament provided is easily processable into a multifilament that has high strength despite including individual filaments having finenesses whose mean is small.

[0063] The first individual filaments are obtained by forming a polymer composition containing a polymer component into filaments.

[0064] The polymer component contains a poly (3-hydroxyalkanoate) resin.

[0065] The polymer component may contain an additional polymer as well as the poly(3-hydroxyalkanoate) resin.

[0066] The polymer composition contains a nucleating agent.

[0067] The polymer composition may contain an additional additive as well as the nucleating agent.

[0068] The poly(3-hydroxyalkanoate) resin is a polyester whose monomer is a 3-hydroxyalkanoate.

[0069] That is, the poly(3-hydroxyalkanoate) resin is a resin containing a 3-hydroxyalkanoate as a structural unit.

[0070] The poly(3-hydroxyalkanoate) resin is a biodegradable polymer.

[0071] As used in the present embodiment, the term "biodegradability" refers to the property of being degradable into low-molecular-weight compounds by microorganisms in nature. Specifically, the possession or lack of biodegradability can be determined based on any of various tests each of which is adapted for a different environment. Examples of tests adapted for aerobic conditions include ISO 14855 (compost) and ISO 14851 (activated sludge), and examples of tests adapted for anaerobic conditions include ISO 14853 (aqueous phase) and ISO 15985 (solid phase). The microbial degradability in seawater can be evaluated by measurement of biochemical oxygen demand.

[0072] The poly(3-hydroxyalkanoate) resin may be a homopolymer or a copolymer.

[0073] The poly(3-hydroxyalkanoate) resin preferably contains a structural unit represented by the following formula (1).

$$[—CHR—CH_2—CO—O—] \quad (1)$$

[0074] In the formula (1), R is an alkyl group represented by C_pH_{2p+1} and p is an integer from 1 to 15.

[0075] The poly (3-hydroxyalkanoate) resin preferably includes a poly(3-hydroxybutyrate) resin.

[0076] The poly(3-hydroxybutyrate) resin is a resin containing 3-hydroxy butyrate as a structural unit. The poly(3-hydroxybutyrate) resin may be a homopolymer or a copolymer.

[0077] Examples of the poly(3-hydroxyalkanoate) resin containing 3-hydroxybutyrate as a structural unit include P3HB, P3HB3HH, P3HB3HV, P3HB4HB, poly(3-hydroxy butyrate-co-3-hydroxyoctanoate), and poly (3-hydroxy butyrate-co-3-hydroxyoctadecanoate).

[0078] P3HB refers to poly(3-hydroxy butyrate).

[0079] P3HB3HH refers to poly (3-hydroxy butyrate-co-3-hydroxyhexanoate).

[0080] P3HB3HV refers to poly (3-hydroxy butyrate-co-3-hydroxyvalerate).

[0081] P3HB4HB refers to poly (3-hydroxy butyrate-co-4-hydroxy butyrate).

[0082] The poly (3-hydroxyalkanoate) resin preferably includes P3HB because P3HB has the function of accelerating its own crystallization and crystallization of another poly (3-hydroxy alkanoate) resin.

[0083] In terms of ensuring both high biodegradability and high formability, the poly (3-hydroxyalkanoate) resin is preferably, but not limited to, P3HB, P3HB3HH, P3HB3HV, or P3HB4HB.

[0084] In terms of increasing the strength of the multifilament obtained by stretching the undrawn multifilament according to the present embodiment and improving the formability into the undrawn multifilament and the multifilament, the poly (3-hydroxyalkanoate) resin is preferably P3HB3HH.

[0085] The poly (3-hydroxyalkanoate) resin preferably contains 85.0 to 99.5 mol %, more preferably 85.0 to 97.0 mol %, 3-hydroxy butyrate as a structural unit.

[0086] When the poly (3-hydroxyalkanoate) resin contains 85.0 mol % or more 3-hydroxy butyrate as a structural unit, the multifilament according to the present embodiment has high stiffness.

[0087] When the poly(3-hydroxyalkanoate) resin contains 99.5 mol % or less 3-hydroxy butyrate as a structural unit, the multifilament according to the present embodiment has high flexibility.

[0088] The polymer component may contain only one poly(3-hydroxyalkanoate) resin as described above or two or more such poly (3-hydroxyalkanoate) resins.

[0089] In the case where the poly (3-hydroxyalkanoate) resin includes a copolymer (such as P3HB3HH), the poly (3-hydroxyalkanoate) resin may include two or more copolymers differing in the average proportions of structural units.

[0090] The weight-average molecular weight of the poly (3-hydroxyalkanoate) resin is preferably from 50,000 to 3,000,000 and more preferably from 50,000 to 1,500,000.

[0091] When the weight-average molecular weight of the poly(3-hydroxyalkanoate) resin is 3,000,000 or less, the undrawn multifilament according to the present embodiment and the multifilament can be easily formed.

[0092] When the weight-average molecular weight of the poly(3-hydroxyalkanoate) resin is 50,000 or more, the strength of the multifilament can be increased.

[0093] The weight-average molecular weight in the present embodiment refers to that determined from a polystyrene-equivalent molecular weight distribution measured by gel permeation chromatography (GPC) using a chloroform eluent. The column used in the GPC may be any column suitable for measurement of the molecular weight.

[0094] The additional polymer preferably has biodegradability.

[0095] Examples of the additional polymer having biodegradability include polycaprolactone, polylactic acid, polybutylene succinate, poly butylene succinate adipate, polybutylene adipate terephthalate, polyethylene succinate, polyvinyl alcohol, polyglycolic acid, native starch, modified starch, cellulose acetate, and chitosan.

[0096] The polycaprolactone is a polymer resulting from ring-opening polymerization of ε-caprolactone.

[0097] The polymer composition may contain one additional polymer or two or more additional polymers.

[0098] The amount of the poly (3-hydroxy alkanoate) resin contained in the polymer component is preferably 50 mass % or more, more preferably 80 mass % or more, and even more preferably 90 mass % or more.

[0099] Since the undrawn multifilament according to the present embodiment contains a biodegradable polymer, a multifilament or staple obtained from the undrawn multifilament can be easily degraded in the environment when discarded into the environment. Thus, the use of the undrawn multifilament leads to a reduced impact on the environment.

[0100] The polymer composition contains a nucleating agent.

[0101] The nucleating agent is a compound that can accelerate crystallization of the poly (3-hydroxyalkanoate) resin. The nucleating agent has a higher melting point than the poly (3-hydroxyalkanoate) resin.

[0102] Examples of the nucleating agent include: inorganic substances (such as boron nitride, titanium oxide, talc, layered silicates, calcium carbonate, sodium chloride, and metal phosphates): sugar alcohol compounds derived from natural sources (such as pentaerythritol, erythritol, galactitol, mannitol, and arabitol): polyvinyl alcohol: chitin: chitosan: polyethylene oxide: salts of aliphatic carboxylic

acids: aliphatic alcohols: esters of aliphatic carboxylic acids; dicarboxylic acid derivatives (such as dimethyl adipate, dibutyl adipate, diisodecyl adipate, and dibutyl sebacate): cyclic compounds having in the molecule C═O and a functional group selected from NH, S, and O (such as indigo, quinacridone, and quinacridone magenta): sorbitol derivatives (such as bis(benzylidene) sorbitol and bis(p-methylbenzylidene) sorbitol); compounds (such as pyridine, triazine, and imidazole) which have a nitrogen-containing heteroaromatic core (such as a pyridine ring, a triazine ring, or an imidazole ring): phosphoric ester compounds: bis-amides of higher fatty acids: metal salts of higher fatty acids; and branched polylactic acid.

[0103] P3HB, which is an example of the poly(3-hydroxyalkanoate) resin, can be used also as the nucleating agent.

[0104] One of the above-mentioned substances may be used alone, or two or more thereof may be used in combination.

[0105] The sugar alcohol compounds, polyvinyl alcohol, chitin, and chitosan are preferred as the nucleating agent in terms of increasing the rate of crystallization of the poly (3-hydroxyalkanoate) resin and in terms of the compatibility with and affinity for the poly (3-hydroxyalkanoate) resin.

[0106] Among the sugar alcohol compounds, pentaerythritol is preferred.

[0107] The nucleating agent preferably has a crystal structure at normal temperature (25° C.).

[0108] When the nucleating agent has a crystal structure at normal temperature (25° C.), the nucleating agent has the advantage of further accelerating crystallization of the poly (3-hydroxyalkanoate) resin.

[0109] The nucleating agent which has a crystal structure at normal temperature (25° C.) is preferably in the form of a powder at normal temperature (25° C.).

[0110] Furthermore, the nucleating agent which is in the form of a powder at normal temperature (25° C.) preferably has an average particle size of 10 μm or less.

[0111] The amount of the nucleating agent contained in the polymer composition is preferably 0.05 parts by mass or more, more preferably 0.1 parts by mass or more, and even more preferably 0.5 parts by mass or more per 100 parts by mass of the poly (3-hydroxyalkanoate) resin. When the amount of the nucleating agent contained in the polymer composition is 0.05 parts by mass or more per 100 parts by mass of the poly (3-hydroxy alkanoate) resin, the advantage is that crystallization of the poly(3-hydroxyalkanoate) resin can be further accelerated.

[0112] The amount of the nucleating agent contained in the polymer composition is preferably 10 parts by mass or less, more preferably 8 parts by mass or less, and even more preferably 5 parts by mass or less per 100 parts by mass of the poly (3-hydroxyalkanoate) resin. When the amount of the nucleating agent contained in the polymer composition is 10 parts by mass or less per 100 parts by mass of the poly(3-hydroxyalkanoate) resin, the advantage is that during making of the undrawn multifilament from a melt of the polymer composition, the viscosity of the melt can be made low enough to easily accomplish the making of the undrawn multifilament.

[0113] P3HB can be used as the poly (3-hydroxyalkanoate) resin and can function as the nucleating agent. Thus, in the case where the polymer composition contains P3HB, the amount of P3HB is included both in the amount of the poly (3-hydroxyalkanoate) resin and in the amount of the nucleating agent.

[0114] Examples of the additional additive include a lubricant, a stabilizer (such as an antioxidant or an ultraviolet absorber), a colorant (a dye or a pigment), a plasticizer, a flame retardant, an inorganic filler, an organic filler, and an antistat.

[0115] The polymer composition preferably contains the lubricant. When the first individual filaments contain the lubricant, the lubricity of the first individual filaments is enhanced, and fusion between the first individual filaments can be prevented.

[0116] Examples of the lubricant include an amide bond-containing compound.

[0117] The amide bond-containing compound preferably includes at least one selected from lauramide, myristamide, stearamide, behenamide, and erucamide.

[0118] The amount of the lubricant contained in the polymer composition is preferably 0.05 parts by mass or more, more preferably 0.1 parts by mass or more, and even more preferably 0.5 parts by mass or more per 100 parts by mass of the polymer component. When the amount of the lubricant contained in the polymer composition is 0.05 parts by mass or more per 100 parts by mass of the polymer component, the advantage is that the first individual filaments have high lubricity:

[0119] The amount of the lubricant contained in the polymer composition is preferably 12 parts by mass or less, more preferably 10 parts by mass or less, even more preferably 8 parts by mass or less, and most preferably 5 parts by mass or less per 100 parts by mass of the polymer component. When the amount of the lubricant contained in the polymer composition is 12 parts by mass or less per 100 parts by mass of the polymer component, the advantage is that bleed-out of the lubricant to the surface of the undrawn multifilament, the multifilament, or the staple can be prevented.

[0120] The plasticizer is preferably a biodegradable plasticizer in terms of improving the formability into the undrawn multifilament.

[0121] Examples of the biodegradable plasticizer include polyglycerin fatty acid esters abbreviated as PGFEs (such as "Chirabasol" manufactured by Taiyo Kagaku Co., Ltd.), mixed dibasic acid esters (such as "DAIFATTY" manufactured by Daihachi Chemical Industry Co., Ltd.), and glycerin fatty acid esters (such as "RIKEMAL" manufactured by Riken Vitamin Co., Ltd.).

[0122] In terms of improving the formability into the undrawn multifilament, a plasticizer is also preferred which is a supercritical fluid at a temperature and pressure at which materials are heated and kneaded in the step (A) described later and which is a gas at normal temperature and pressure (25° C., 1 atmosphere).

[0123] Examples of such a plasticizer include nitrogen (N_2), carbon dioxide, and lower aliphatic hydrocarbons.

[0124] Examples of the lower aliphatic hydrocarbons include propane, butane, and isobutane.

[0125] The undrawn multifilament according to the present embodiment includes 30 or more first individual filaments, and the number of the first individual filaments is preferably from 30 to 500,000 and more preferably from 50 to 300,000.

[0126] The first individual filaments are, for example, circular in cross-section (the term "circular" is intended to

include a true circular shape, an approximately circular shape, an elliptical shape, and an approximately elliptical shape).

[0127] The mean of the finenesses of the first individual filaments is 30 dtex or less. The mean of the finenesses of the first individual filaments is preferably 20 dtex or less and more preferably 10 dtex or less.

[0128] The mean of the finenesses of the first individual filaments is preferably 1.5 dtex or more and more preferably 3.0 dtex or more.

[0129] In the present embodiment, the fineness of a filament refers to the thickness of the filament and is defined as the mass per unit length of the filament. Specifically, the fineness is expressed in units of mass (g) per 10,000 m (dtex).

[0130] In the present embodiment, the mean of the finenesses of the first individual filaments can be determined as follows.

[0131] First, the fineness of the undrawn multifilament (total fineness) is measured. The number of the first individual filaments in the undrawn multifilament is also determined.

[0132] The following equation is used to determine the mean of the finenesses of the first individual filaments.

[0133] Mean of finenesses of first individual filaments=fineness of undrawn multifilament/number of first individual filaments in undrawn multifilament

[0134] The coefficient of variation of the finenesses of the first individual filaments is 33% or less.

[0135] The coefficient of variation of the finenesses of the first individual filaments is preferably 32% or less, more preferably 30% or less, and even more preferably 28% or less.

[0136] The coefficient of variation of the finenesses of the first individual filaments is preferably as small as possible. However, the coefficient of variation of the finenesses of the first individual filaments is, for example, 5% or more and in particular 10% or more.

[0137] The fact that the coefficient of variation of the finenesses of the first individual filaments is 33% or less contributes to improving the stability of a bundling step ("bundling" will be described later) or a stretching step. The fact that the coefficient of variation of the finenesses of the first individual filaments is 33% or less further contributes to improving the mechanical properties (such as strength) of the multifilament obtained by stretching.

[0138] Specifically, the fact that the coefficient of variation of the finenesses of the first individual filaments is 33% or less means that the undrawn multifilament is less likely to include extremely thin or thick first individual filaments.

[0139] The low likelihood of inclusion of extremely thin filaments in the undrawn multifilament contributes to improving the stability of the bundling step ("bundling" will be described later) or the stretching step. Specifically, the ease of feed of the undrawn multifilament or the multifilament from a winding roll unit (in particular, a bobbin of the winding roll unit) is improved (the "winding roll unit" and "bobbin" will be described later: the term "bobbin" is intended to include a "paper core"). Additionally, the undrawn multifilament is resistant to breakage under stretching tension. Furthermore, the undrawn multifilament can be wound well on a stretching roll unit (the "stretching roll unit" will be described later). Moreover, the undrawn multifilament and the multifilament can be prevented from sagging during transfer.

[0140] The low likelihood of inclusion of extremely thick filaments in the undrawn multifilament leads to a stretching stress acting uniformly on the undrawn multifilament being stretched and to prevention of uneven stretching. As a result, the finenesses of the first individual filaments are uniformly decreased, and the mechanical properties (such as strength) of the resulting multifilament are improved.

[0141] The coefficient of variation of the finenesses of the first individual filaments can be determined as follows.

[0142] First, the undrawn multifilament is cut perpendicular to the length of the undrawn multifilament by means of a cutter, and the cut surface is imaged with a microscope to obtain a cross-sectional image.

[0143] Next, in the cross-sectional image, the cross-sectional areas of all the first individual filaments constituting the undrawn multifilament are measured. Alternatively, 30 or more of the first individual filaments in the undrawn multifilament are randomly selected, and the cross-sectional areas of the selected first individual filaments are measured. It is sometimes impractical to measure the cross-sectional areas of all the first individual filaments constituting the undrawn multifilament; in such a case, 30 or more of the first individual filaments in the undrawn multifilament may be randomly selected, and the cross-sectional areas of the selected first individual filaments may be measured.

[0144] The arithmetic mean and standard deviation of the measured cross-sectional areas of the first individual filaments are determined.

[0145] Finally, the following equation is used to determine the coefficient of variation of the finenesses of the first individual filaments.

Coefficient of variation (%) of finenesses of first individual filaments=(standard deviation of cross-sectional areas of first individual filaments/arithmetic mean of cross-sectional areas of first individual filaments)×100 (%)

[0146] How to measure the cross-sectional areas is described, for example, in JIS L 1015:2021 "Test methods for man-made staple fibres", "8.5.3 Fineness variation".

[0147] In terms of preventing fusion between the adjacent first individual filaments and preventing the adjacent first individual filaments from moving away from each other due to static electricity, the undrawn multifilament according to the present embodiment preferably further includes a spinning oil on the surfaces of the first individual filaments.

[0148] Examples of the spinning oil include a cationic surfactant, an anionic surfactant, a non-ionic surfactant, a refined esterified oil, a mineral oil, a poly(oxyethylene) alkyl ether, a silicone oil, and a paraffin wax. One of these materials may be used alone, or two or more thereof may be used in combination.

[0149] A silicone oil is preferred as the spinning oil in terms of preventing fusion between the adjacent first individual filaments.

[0150] An anionic surfactant or a non-ionic surfactant is preferred as the spinning oil in terms of preventing the adjacent first individual filaments from moving away from each other due to static electricity.

[0151] For example, the spinning oil used may be one that contains a silicone oil and an anionic surfactant (an example

of such a spinning oil is "Polymax FKY" manufactured by Marubishi Yuka Kogyo Co., Ltd.).

<Multifilament>

[0152] The multifilament according to the present embodiment is a multifilament having been stretched.

[0153] The multifilament according to the present embodiment includes 30 or more second individual filaments.

[0154] The second individual filaments contain a poly(3-hydroxyalkanoate) resin and a nucleating agent.

[0155] The mean of the finenesses of the second individual filaments is 20 dtex or less.

[0156] The coefficient of variation of the finenesses of the second individual filaments is 33% or less.

[0157] The second individual filaments are obtained by forming the above-described polymer composition into filaments.

[0158] The number of the second individual filaments in the multifilament according to the present embodiment is 30 or more, preferably from 30 to 500,000, and more preferably from 50 to 300,000.

[0159] The second individual filaments are, for example, circular in cross-section (the term "circular" is intended to include a true circular shape, an approximately circular shape, an elliptical shape, and an approximately elliptical shape).

[0160] The mean of the finenesses of the second individual filaments is 20 dtex or less.

[0161] The mean of the finenesses of the second individual filaments may be chosen in the range up to 20 dtex depending on the quality required for the intended use of the multifilament or the quality required of a staple obtained from the multifilament.

[0162] The mean of the finenesses of the second individual filaments is preferably more than 1.0 dtex, more preferably 1.2 dtex or more, and even more preferably 1.5 dtex or more.

[0163] The mean of the finenesses of the second individual filaments is preferably 18 dtex or less and more preferably 16 dtex or less.

[0164] In the present embodiment, the mean of the finenesses of the second individual filaments can be determined as follows.

[0165] First, the fineness of the multifilament (total fineness) is measured. The number of the second individual filaments in the multifilament is also determined.

[0166] The following equation is used to determine the mean of the finenesses of the second individual filaments.

$$\text{Mean of finenesses of second individual filaments} = \text{fineness of multifilament} / \text{number of second individual filaments in multifilament}$$

[0167] The coefficient of variation of the finenesses of the second individual filaments is 33% or less.

[0168] The coefficient of variation of the finenesses of the second individual filaments is preferably 32% or less, more preferably 30% or less, and even more preferably 28% or less.

[0169] The coefficient of variation of the finenesses of the second individual filaments is preferably as small as possible. However, the coefficient of variation of the finenesses of the second individual filaments is, for example, 5% or more and in particular 10% or more.

[0170] The coefficient of variation of the finenesses of the second individual filaments can be determined as follows.

[0171] First, the multifilament is cut perpendicular to the length of the multifilament by means of a cutter, and the cut surface is imaged with a microscope to obtain a cross-sectional image.

[0172] Next, in the cross-sectional image, the cross-sectional areas of all the second individual filaments constituting the multifilament are measured. Alternatively, 30 or more of the second individual filaments in the multifilament are randomly selected, and the cross-sectional areas of the selected second individual filaments are measured. It is sometimes impractical to measure the cross-sectional areas of all the second individual filaments constituting the multifilament: in such a case, 30 or more of the second individual filaments in the multifilament may be randomly selected, and the cross-sectional areas of the selected second individual filaments may be measured.

[0173] The arithmetic mean and standard deviation of the measured cross-sectional areas of the second individual filaments are determined.

[0174] Finally, the following equation is used to determine the coefficient of variation of the finenesses of the second individual filaments.

$$\text{Coefficient of variation (\%) of finenesses of second individual filaments} = \left(\text{standard deviation of cross-sectional areas of second individual filaments} / \text{arithmetic mean of cross-sectional areas of second individual filaments}\right) \times 100\ (\%)$$

[0175] How to measure the cross-sectional areas is described, for example, in JIS L 1015:2021 "Test methods for man-made staple fibres", "8.5.3 Fineness variation".

[0176] The mean of the tensile strengths of the second individual filaments is preferably 1.5 cN/dtex or more, more preferably 1.7 cN/dtex or more, and even more preferably 2.0 cN/dtex or more.

[0177] The mean of the tensile strengths of the second individual filaments is preferably as large as possible. However, the mean of the tensile strengths of the second individual filaments is, for example, 20 cN/dtex or less (in particular, 10 cN/dtex or less).

[0178] The mean of the tensile strengths of the second individual filaments can be determined as follows.

[0179] First, the tensile strengths of all the second individual filaments constituting the multifilament are measured. Alternatively, 10 or more of the second individual filaments in the multifilament are randomly selected, and the tensile strengths of the selected second individual filaments are measured. It is sometimes impractical to measure the tensile strengths of all the second individual filaments constituting the multifilament: in such a case, 10 or more of the second individual filaments in the multifilament may be randomly selected, and the tensile strengths of the selected second individual filaments may be measured.

[0180] The arithmetic mean of the measured tensile strengths of the second individual filaments is determined as the mean of the tensile strengths of the second individual filaments.

[0181] The tensile strength of each second individual filament can be measured at an initial length of 20 mm and

a tensile speed of 20 mm/min in accordance with JIS L 1015:2021 "Test methods for man-made staple fibres".

[0182] For example, the tensile strength of each second individual filament can be determined as follows.

[0183] First, the load (CN) at which the second individual filament breaks is measured using a tensile testing machine named Autograph AG-I (manufactured by Shimadzu Corporation) under the conditions listed below.

[0184] Initial length of second individual filament: 20 mm

[0185] Tensile speed: 20 mm/min

[0186] Load cell: A load cell with a rated capacity of 5 N

[0187] The fineness of each second individual filament is also measured. The measurement of the fineness of each second individual filament can be performed using an automatic vibroscope method.

[0188] The following equation is used to calculate the tensile strength of the second individual filament.

Tensile strength (cN/dtex) of second individual filament=load (CN) at which second individual filament breaks/fineness of second individual filament

<Staple>

[0189] A staple according to the present embodiment is a staple including a cut piece of the multifilament according to the present embodiment.

[0190] The length (also referred to as "fiber length") of the staple according to the present embodiment is 20 cm or less and in particular from 0.1 to 10 cm.

[0191] The length of the staple refers to "mean of fiber lengths" as determined by "c) Method C (replacement method)" as specified in JIS L 1015:2021 "Test methods for man-made staple fibers", "8.4 Fiber length", "8.4.1 Average fiber length".

[0192] The staple according to the present embodiment may be a crimped yarn. In other words, the staple according to the present embodiment may have crimps.

[0193] The length (fiber length) of the staple having crimps can be chosen as appropriate depending on the intended use of the staple and is, for example, from 1.5 to 16 cm. The length (fiber length) of the staple having crimps may be from 2.0 to 11 cm or from 2.5 to 7.6 cm.

[0194] The crimp number of the staple is preferably from 5 to 25/25 mm, more preferably from 6 to 20/25 mm, even more preferably from 7 to 18/25 mm, and particularly preferably from 8 to 17/25 mm in terms of increasing the ease of passage through a carding machine used to obtain a non-woven fabric from such staples, improving the texture of the obtained non-woven fabric, and reducing the water absorbency of the non-woven fabric to improve the quick drying properties of the non-woven fabric.

[0195] The crimp number of a staple refers to the number of crimps per 25 mm of the staple. The crimp number refers to the mean of the crimp numbers of 15 randomly selected staples. In the case where the number of staples is less than 15, the crimp number refers to the mean of the crimp numbers of all the staples. The crimp number of each staple can be determined by counting the number of crimp peaks in 25 mm of the staple with the aid of a microscope. In the case where the length of the staple is less than 25 mm, the number of crimp peaks in the entire length of the staple may be counted with the aid of a microscope, and the number of crimps per 25 mm may be calculated from the counted number of crimp peaks.

<Undrawn Multifilament Production Method and Multifilament Production Method>

[0196] An undrawn multifilament production method according to the present embodiment is a method for obtaining an undrawn multifilament by melt spinning.

[0197] The undrawn multifilament production method according to the present embodiment includes the steps of: (A) in the melt spinning, discharging a melt using a spinning nozzle having 30 or more discharge holes to obtain 30 or more raw filaments in a molten state; and (B) blowing a gas having a temperature of 0 to 50° C. onto the 30 or more raw filaments in the molten state to cool the 30 or more raw filaments and obtain an undrawn multifilament.

[0198] The melt contains a poly(3-hydroxyalkanoate) resin and a nucleating agent.

[0199] The mean of the finenesses of individual filaments of the undrawn multifilament is 30 dtex or less.

[0200] In the step (B), the coefficient of heat transfer between the gas and the 30 or more raw filaments in the molten state is 60 $W/(m^2 \cdot K)$ or more.

[0201] In the step (B), the speed of the gas blown onto the 30 or more raw filaments is preferably 0.3 m/s or more.

[0202] In the step (A), the melt is the above-described polymer composition in a molten state.

[0203] In the multifilament production method according to the present embodiment, the undrawn multifilament production method according to the present embodiment is used to obtain the undrawn multifilament.

[0204] The multifilament production method according to the present embodiment includes the step of (C) stretching the undrawn multifilament by a stretching roll unit at a stretching ratio of 1.5 or more to obtain a multifilament.

[0205] Preferably, in the step (B), the gas having a temperature of 0 to 50° C. is blown onto the 30 or more raw filaments in the molten state to cool the 30 or more raw filaments to 50° C. or below and obtain the undrawn multifilament, and in the step (C), the undrawn multifilament is heated, and the heated undrawn multifilament is stretched by the stretching roll unit.

First Embodiment: Sequential Stretching Process

[0206] Hereinafter, an undrawn multifilament production method and a multifilament production method according to a first embodiment will be described with reference to FIGS. **1** and **2**. The example described below is one in which an undrawn multifilament and a multifilament are produced by a sequential stretching process (also referred to as a "post-stretching process").

(Step (A))

[0207] In the step (A), as shown in FIG. **1**, materials of the melt are first placed into a material feeder **101**.

[0208] Next, the materials fed from the material feeder **101** are kneaded under heating by a kneading extruder **102** to obtain the melt.

[0209] A screw extruder is suitable for use as the kneading extruder **102**. The kneading extruder **102** may be a single-screw extruder or a twin-screw extruder.

[0210] Subsequently, a spinning nozzle **104** having 30 or more discharge holes is used; specifically, the melt obtained in the kneading extruder **102** is discharged from the 30 or more discharge holes to obtain 30 or more raw filaments **100**A in a molten state.

[0211] The flow rate of the melt discharged from the discharge holes of the spinning nozzle **104** is adjusted by a gear pump **103**.

[0212] The temperature of the spinning nozzle **104** is, for example, from 140 to 180° C.

[0213] The number of the discharge holes of the spinning nozzle **104** is 30 or more, preferably from 30 to 10000, and more preferably from 30 to 5000.

[0214] The shapes and sizes of the discharge holes are selected depending on the properties (such as appearance, fineness, strength, and cross-sectional shape) required of the undrawn multifilament. For example, the discharge holes are circular (the term "circular" is intended to include a true circular shape, an approximately circular shape, an elliptical shape, and an approximately elliptical shape).

[0215] The area of each discharge hole is, for example, from 10 to 5000 times the cross-sectional area of a corresponding one of the first individual filaments of the undrawn multifilament.

[0216] In the present embodiment, all the discharge holes have substantially the same shape. Additionally, all the discharge holes have substantially the same area.

[0217] The area of each discharge hole is preferably from 1.0×10^{-3} to 20 mm^2 and more preferably from 5.0×10^{-3} to 10 mm^2.

[0218] The speed at which the melt is discharged from the spinning nozzle **104** (the speed is hereinafter also referred to as "spinning nozzle flow speed") is preferably from 0.02 to 20 m/min, more preferably from 0.05 to 10 m/min, and even more preferably from 0.1 to 5.0 m/min.

[0219] In the first embodiment, the spinning oil as previously described may be applied to the surfaces of the 30 or more cooled raw filaments **100**A.

(Step (B))

[0220] In the step (B), a gas having a temperature of 0 to 50° C. is blown onto the 30 or more raw filaments obtained in a molten state in the step (A), and thus the 30 or more raw filaments are cooled to obtain an undrawn multifilament.

[0221] In the first embodiment, the raw filaments **100**A are cooled by a gas having a temperature of 0 to 50° C. in a first cooling box **105**.

[0222] In the first embodiment, the raw filament **100**A cooled in the first cooling box **105** may be further cooled by a gas having a temperature of 0 to 50° C. in a second cooling box **106**.

[0223] In the step (B), the temperature of the gas blown onto the raw filaments **100**A obtained in a molten state in the step (A) is from 0 to 50° C., preferably from 0 to 40° C., and even more preferably from 15 to 40° C.

[0224] When the temperature of the gas is 0° C. or above, fusion between the first individual filaments of the undrawn multifilament is prevented. Additionally, when the temperature of the gas is 0° C. or above, the mechanical properties (such as strength) of the undrawn multifilament are improved.

[0225] When the temperature of the gas is 50° C. or below, the variation in fineness among the first individual filaments is reduced (the coefficient of variation of the finenesses of the first individual filaments can be made small). Additionally, when the temperature of the gas is 50° C. or below; breakage of any of the raw filaments **100**A can be prevented.

[0226] In the step (B), the temperature of the gas is preferably equal to or higher than the glass transition temperature of the polymer composition. When the temperature of the gas is equal to or higher than the glass transition temperature of the polymer composition, the polymer composition is easy to plastically deform, and the raw filaments **100**A are resistant to breakage.

[0227] The "temperature of the gas blown onto the raw filaments **100**A obtained in a molten state in the step (A)" refers to the temperature that the gas has when contacting the raw filaments **100**A.

[0228] In the step (B), the speed of the gas blown onto the 30 or more raw filaments is preferably 0.10 m/s or more, more preferably from 0.20 to 5.0 m/s, even more preferably from 0.20 to 3.0 m/s, still even more preferably from 0.30 to 3.0 m/s, and particularly preferably from 0.32 to 3.0 m/s.

[0229] When the speed of the gas is 0.10 m/s or more, the cooling effect of the gas can be easily achieved.

[0230] When the speed of the gas is 5.0 m/s or less, the raw filaments **100**A discharged in a molten state from the spinning nozzle **104** are not much shaken by the gas. This prevents fusion between, and/or breakage of, the raw filaments **100**A in a molten state and therefore ensures high spinning stability.

[0231] The "speed of the gas blown onto the raw filaments **100**A obtained in a molten state in the step (A)" refers to the relative speed that the gas has relative to the raw filaments **100**A when contacting the raw filaments **100**A.

[0232] Examples of the gas include air, inert gases (such as nitrogen gas and argon gas), and steam.

[0233] The rate of heat flow Q between a gas and a solid satisfies the following relationship with the coefficient of heat transfer h between the gas and the solid, the area of contact A between the gas and the solid, and the temperature difference ΔT between the gas and the solid.

$$Q=h\times A\times\Delta T$$

[0234] Thus, an increase in the coefficient of heat transfer h between a gas and a solid can lead to an increase in the rate of heat flow Q between the gas and the solid.

[0235] This means that increasing the coefficient of heat transfer between the gas and the 30 or more raw filaments in a molten state makes it easier to satisfactorily cool the 30 or more raw filaments in a molten state.

[0236] In the step (B), the coefficient of heat transfer between the gas and the 30 or more raw filaments in a molten state is 60 $W/(m^2\cdot K)$ or more, preferably 65 $W/(m^2\cdot K)$ or more, more preferably 70 $W/(m^2\cdot K)$ or more, even more preferably 125 $W/(m^2\cdot K)$ or more, particularly preferably 130 $W/(m^2\cdot K)$ or more, and most preferably 135 $W/(m^2\cdot K)$ or more.

[0237] In the step (B), the coefficient of heat transfer between the gas and the 30 or more raw filaments in a molten state is, for example, 500 $W/(m^2\cdot K)$ or less (in particular, 350 $W/(m^2\cdot K)$ or less).

[0238] The coefficient of heat transfer can be determined from the temperature T of the gas, the speed u of the gas, and the diameter d of a cross-section of the raw filament.

[0239] The "cross-section of the raw filament" refers to a cross-section perpendicular to the length of the raw filament.

[0240] The value of the "discharge hole diameter" is used as the "diameter of the cross-section of the raw filament".

[0241] In the case where the discharge hole is not in the shape of a true circle, the area of the discharge hole is determined, then the determined area is used to calculate the diameter of the discharge hole assumed to be in the shape of a true circle, and the calculated diameter is used as the "diameter of the cross-section of the raw filament".

[0242] Specifically, the coefficient of heat transfer can be determined through the following procedures [1] to [5].

[0243] [1]

[0244] The density ρ, viscosity coefficient μ, specific heat C_p, and thermal conductivity λ of the gas are determined from the temperature T of the gas.

[0245] For example, when the gas is air, the density ρ (kg/m^3) of the gas can be determined from the temperature T (K) of the gas by using the following equation.

$$\rho = 351.99/T + 344.84/T^2$$

[0246] For example, when the gas is air, the viscosity coefficient μ (Pa·S) of the gas can be determined from the temperature T (K) of the gas by using the following equation.

$$\mu = \left(1.4592 \times 10^{-6} \times T^{3/2}\right)/(109.10 + T)$$

[0247] For example, when the gas is air, the specific heat C_p (J/(kg·K)) of the gas can be determined from the temperature T (K) of the gas by using the following equation.

$$C_p = 1030.5 - 0.19975 \times T + 3.9734 \times 10^{-4} \times T^2$$

[0248] For example, when the gas is air, the thermal conductivity λ (W/(m·K)) of the gas can be determined from the temperature T (K) of the gas by using the following equation.

$$\lambda = \left(2.3340 \times 10^{-3} \times T^{3/2}\right)/(164.54 + T)$$

[0249] When the gas is not air, as in the case where the gas is air, the density p, viscosity coefficient μ, specific heat C_p, and thermal conductivity λ of the gas can be determined from the temperature T of the gas by using hitherto known equations related to the gas.

[0250] [2]

[0251] The Reynolds number Re is determined from the density ρ of the gas, the speed u of the gas, the diameter d of the cross-section of the raw filament (discharge hole diameter), and the viscosity coefficient μ of the gas by using the following equation.

$$\mathrm{Re} = \rho \times u \times d/\mu$$

[0252] [3]

[0253] The Prandtl number Pr is determined from the viscosity coefficient μ, specific heat C_p, and thermal conductivity λ of the gas by using the following equation.

$$Pr = \mu \times C_p/\lambda$$

[0254] [4]

[0255] The Nusselt number Nu is determined from the Reynolds number Re and the Prandtl number Pr by using the following equation.

$$Nu = C \times \mathrm{Re}^m \times Pr^{1/3}$$

[0256] C and m are coefficients dependent on the Reynolds number Re. The values of C and m for different Reynolds numbers Re are listed in Table 1 below.

TABLE 1

Re (—)	C (—)	m (—)
From 0.4 to below 4	0.999	0.330
From 4 to below 4×10	0.920	0.385
From 4×10 to below 4×10^3	0.689	0.466
From 4×10^3 to below 4×10^4	0.195	0.618
From 4×10^4 to below 4×10^5	0.0268	0.805

[0257] [5]

[0258] The coefficient of heat transfer h is determined from the Nusselt number Nu, the diameter d of the cross-section of the raw filament (discharge hole diameter d), and the thermal conductivity λ of the gas by using the following equation.

$$h = Nu \times \lambda/d$$

[0259] The calculations in the above procedures [1] to [5] can be performed by means such as "Science. Tools" (searched on Jul. 26, 2021, URL:https://cattech-lab.com/science-tools/) available on the website of CATTech.LAB Co., Ltd.

[0260] A preferred method for blowing the gas onto the 30 or more raw filaments in a molten state is a method in which the gas is blown onto each raw filament from at least four directions with respect to the raw filament as viewed in the direction of the length of the raw filament, namely, as viewed in a cross-section perpendicular to the length of the raw filament (this method is called "circular quenching").

[0261] In the circular quenching, the gas is preferably blown onto each raw filament from eight or more directions, more preferably 16 or more directions.

[0262] The directions from which the gas is blown onto each raw filament preferably lie between the flow direction of the raw filament and a direction perpendicular to the flow direction of the raw filament.

[0263] The distance between each discharge hole of the spinning nozzle **104** and the location where the gas contacts the corresponding raw filament discharged from the dis-

charge hole is defined depending on the properties required of the undrawn multifilament.

[0264] Controlling the degree of orientation and the crystallinity of the raw filaments **100**A to suitable ranges makes it possible to stably perform the step of obtaining a multifilament from the undrawn multifilament and improve the mechanical properties of the multifilament.

[0265] In the step (B), the gas having contacted the raw filaments is preferably discharged out of the cooling box along the flow direction of the raw filaments. For example, the following tools can be used to allow the gas having contacted the raw filaments to be discharged out of the cooling box along the flow direction of the raw filaments: a flow control plate, a flow control fin, an ejector, a Venturi tube, and Transvector which is manufactured by Kogi Corporation.

[0266] In the step (B), the 30 or more raw filaments **100**A cooled by the gas having a temperature of 0 to 50° C. are received on a first receiving roll unit **107**. The first receiving roll unit **107** includes two rolls. The first receiving roll unit **107** may include one roll or three or more rolls.

[0267] In the first embodiment, the 30 or more raw filaments **100**A received on the first receiving roll unit **107** are transferred by using a first transfer roll unit **108**, a second transfer roll unit **109**, a third transfer roll unit **110**, and a fourth transfer roll unit **111**, and the 30 or more raw filaments **100**A transferred by the transfer roll units **108**, **109**, **110**, and **111** are wound on a first winding roll unit **112** to obtain an undrawn multifilament.

[0268] The first winding roll unit **112** includes a bobbin. The term "bobbin" is intended to include a paper core. The bobbin may or may not include a flange.

[0269] In the step (C), specifically, the raw filaments **100**A are wound on the bobbin of the first winding roll unit **112** to obtain an undrawn multifilament.

[0270] Each of the transfer roll units includes two rolls in FIG. **1**. Each of the transfer roll units may include one roll or three or more rolls.

[0271] In the step (B), the 30 or more raw filaments **100**A are preferably cooled to 70° C. or below, more preferably 60° C. or below, even more preferably 50° C. or below; particularly preferably 40° C. or below: In the step (B), the 30 or more raw filaments **100**A are cooled to, for example, 0° C. or above, preferably 10° C. or above.

[0272] In the step (B), the 30 or more raw filaments **100**A are preferably cooled to a temperature equal to or higher than the glass transition temperature of the polymer composition.

[0273] In the step (B), the 30 or more raw filaments may be cooled to 70° C. or below by the blowing of the gas having a temperature of 0 to 50° C. In the step (B), the 30 or more raw filaments **100**A may be cooled to a certain extent by the blowing of the gas having a temperature of 0 to 50° C., and then the 30 or more raw filaments **100**A may be cooled to 70° C. or below by ambient air during transfer of the 30 or more raw filaments **100**A from the first receiving roll unit **107** to the first winding roll unit **112**.

[0274] In view of the stretching of the undrawn multifilament in the step (C), it is preferable that the 30 or more raw filaments **100**A should not be substantially stretched or should not be stretched very much in the step (B).

[0275] Specifically, the stretching ratio in the step (B) is preferably 1.5 or less, more preferably 1.2 or less, and even more preferably 1.1 or less.

[0276] The stretching ratio in the step (B) can be determined by the following equation.

[0277] Stretching ratio in step (B)=speed (m/min) of transfer roll unit/speed (m/min) of receiving roll unit used in step (B) ("first receiving roll unit **107**" in the case of the first embodiment)

[0278] The "speed (m/min) of receiving roll unit used in the step (B)" refers to the length by which the 30 or more raw filaments **100**A are received on the receiving roll unit used in the step (B) ("first receiving roll unit **107**" in the case of the first embodiment) per unit time.

[0279] The "speed (m/min) of transfer roll unit" refers to the length by which the 30 or more raw filaments **100**A are transferred by the transfer roll unit per unit time.

[0280] In the case where a plurality of transfer roll units are used, the highest of the speeds of the transfer roll units is used as the "speed (m/min) of transfer roll unit".

[0281] The fineness of each first individual filament of the undrawn multifilament approximately satisfies the following relationship.

$$\text{Fineness } (dtex) \text{ of first individual filament of undrawn multifilament} = (((a \times 1000/60)/b \times 10000)/c)/d$$

[0282] a: Amount (kg/h) of melt discharged from spinning nozzle **104**

[0283] b: Speed (m/min) of receiving roll unit used in step (B) ("first receiving roll unit **107**" in the case of the first embodiment)

[0284] c: Number of discharge holes of spinning nozzle **104**

[0285] d: Stretching ratio (-) in step (B)

[0286] Thus, the finenesses of the first individual filaments of the undrawn multifilament can be controlled by adjusting the parameters such as b.

[0287] In the step (B) of FIG. **1**, the 30 or more raw filaments **100**A are wound on the first winding roll unit **112**. In the first embodiment, the 30 or more raw filaments **100**A need not be wound on the first winding roll unit **112** but may be placed into a container to obtain the undrawn multifilament.

[0288] In the case where any transfer roll unit is not used, the stretching ratio in the step (B) is 1.0.

(Step (C))

[0289] In the step (C), as shown in FIG. **2**, the undrawn multifilament **100**B is heated, and the heated undrawn multifilament **100**B is stretched by a stretching roll unit **114**.

[0290] In the step (C), the undrawn multifilament is fed from the first winding roll unit **112** and received on a second receiving roll unit **113**.

[0291] Next, in the step (C), the undrawn multifilament **100**B received on the second receiving roll unit **113** is stretched by the stretching roll unit **114**.

[0292] Subsequently, in the step (C), the undrawn multifilament **100**B stretched by the stretching roll unit **114** is wound on a second winding roll unit **116** to obtain a multifilament.

[0293] The second winding roll unit **116** includes a bobbin. The term "bobbin" is intended to include a paper core. The bobbin may or may not include a flange.

[0294] Specifically, in the step (C), the undrawn multifilament **100**B having been stretched is wound on the bobbin of the second winding roll unit **116** to obtain a multifilament.

[0295] Although in the step (C) of FIG. **2**, the undrawn multifilament **100**B stretched by the stretching roll unit **114** is wound on the second winding roll unit **116** to obtain a multifilament, the undrawn multifilament **100**B stretched by the stretching roll unit **114** need not be wound on the second winding roll unit **116** to obtain a multifilament.

[0296] In the step (C), the undrawn multifilament **100**B stretched by the stretching roll unit **114** may be transferred by a take-off roll unit **115**.

[0297] The second receiving roll unit **113** includes two rolls. The second receiving roll unit **113** may include one roll or three or more rolls.

[0298] In the step (C), the undrawn multifilament **100**B is preferably heated by the second receiving roll unit **113**.

[0299] In the step (C), heating the undrawn multifilament **100**B by the second receiving roll unit **113** makes it easy to control the temperature of the first individual filaments of the undrawn multifilament **100**B within a temperature range suitable for increasing the degree of orientation of the polymer component contained in the first individual filaments, thus making it easy to increase the degree of orientation of the polymer component of the first individual filaments.

[0300] The temperature of the second receiving roll unit **113** is preferably 15° C. or above but below 60° C. and more preferably from 20 to 55° C.

[0301] When the temperature of the environment where the step (C) is performed is 15° C. or above, the undrawn multifilament **100**B need not be heated by the second receiving roll unit **113**.

[0302] The stretching roll unit **114** includes two rolls. The stretching roll unit **114** may include one roll or three or more rolls.

[0303] In the step (C), the undrawn multifilament **100**B may or may not be heated by the stretching roll unit **114**. That is, in the first embodiment, the stretching roll unit **114** may serve as a heat treatment roll unit.

[0304] In the step (C), heating the undrawn multifilament **100**B by the stretching roll unit **114** makes it possible to accelerate crystallization of the polymer component contained in the first individual filaments of the undrawn multifilament **100**B or increase the heat resistance of the polymer component contained in the first individual filaments.

[0305] The temperature of the stretching roll unit (heat treatment roll unit) **114** is preferably from 30 to 100° C. and more preferably from 40 to 90° C.

[0306] In the first embodiment, the take-off roll unit **115** preferably serves as a heat treatment roll unit.

[0307] The take-off roll unit **115** (heat treatment roll unit **115**) includes two rolls. The take-off roll unit **115** (heat treatment roll unit **115**) may include one roll or three or more rolls.

[0308] In the step (C), heating the undrawn multifilament **100**B by the heat treatment roll unit **115** makes it possible to accelerate crystallization of the polymer component contained in the first individual filaments of the undrawn multifilament **100**B or increase the heat resistance of the polymer component contained in the first individual filaments.

[0309] The temperature of the take-off roll unit (heat treatment roll unit) **115** is preferably from 30 to 100° C. and more preferably from 40 to 90° C.

[0310] Either the stretching roll unit **114** or the take-off roll unit **115** may serve as a heat treatment roll unit, or both the stretching roll unit **114** and the take-off roll unit **115** may serve as heat treatment roll units.

[0311] In the step (C) of the first embodiment, the first individual filaments are heated by the receiving roll unit **113**, the stretching roll unit **114**, and the take-off roll unit **115**. The heating of the first individual filaments may be performed in any suitable manner for the purpose of controlling the degree or orientation, the crystallization, and the heat resistance of the polymer component of the first individual filaments.

[0312] For example, the first individual filaments may be heated by the first winding roll unit **112**.

[0313] Alternatively, the first individual filaments may be heated by the second winding roll unit **116** to obtain a multifilament.

[0314] The first individual filaments may be heated by all of the series of roll units starting with the first winding roll unit **112** and ending with the second winding roll unit **116**.

[0315] Alternatively, the first individual filaments may be heated by only one or some of the series of roll units starting with the first winding roll unit **112** and ending with the second winding roll unit **116** without being heated by the other roll units.

[0316] The heating of the first individual filaments by the roll units is preferably controlled for each roll unit.

[0317] The method for heating the polymer component of the first individual filaments in the step (C) of the first embodiment (this method is also simply referred to as "heating method" hereinafter) may be to heat the polymer component of the first individual filaments by heating the rolls of any of the roll units.

[0318] Any of the roll units may include a container holding the rolls and a liquid (such as water) held in the container together with the rolls, and the heating method may be to heat the polymer component of the first individual filaments by heating the liquid. In the step (C), for example, stretching may be performed in a bath.

[0319] The heating method may be to heat the polymer component of the first individual filaments by blowing a heated gas (such as air) onto or around any of the roll units.

[0320] The heating methods mentioned above may be used in combination.

[0321] The stretching ratio in the step (C) is 1.5 or more and preferably 1.7 or more. The stretching ratio in the step (C) is, for example, 20 or less.

[0322] When the stretching ratio in the step (C) is 1.5 or more, the degree of orientation of the polymer component of the first individual filaments of the undrawn multifilament **100**B is further increased.

[0323] The stretching ratio in the step (C) can be determined by the following equation.

[0324] Stretching ratio in step (C)=speed (m/min) of stretching roll unit/speed (m/min) of receiving roll unit used in step (C) ("second receiving roll unit **113**" in the case of the first embodiment)

[0325] In the step (C), the relaxation rate determined by the following equation is preferably from 1 to 30% and more preferably from 1 to 15%.

Relaxation rate (%)=((speed of stretching roll unit 114−speed of winding roll unit on which undrawn multifilament is wound ("second winding roll unit 116"in the case of the first embodiment)/speed of winding roll unit on which undrawn multifilament is wound)×100

[0326] The "speed (m/min) of stretching roll unit" refers to the length by which the undrawn multifilament is transferred by the stretching roll unit per unit time.

[0327] In the first embodiment, only one stretching roll unit is used. Alternatively, a plurality of stretching roll units may be used. In the case where a plurality of stretching roll units are used, the highest of the speeds of the stretching roll units is used as the "speed of stretching roll unit".

[0328] The "speed (m/min) of receiving roll unit used in the step (C)" refers to the length by which the undrawn multifilament is transferred by the receiving roll unit per unit time. The "speed (m/min) of winding roll unit on which undrawn multifilament is wound" refers to the length by which the undrawn multifilament is wound on the winding roll unit per unit time.

[0329] In the step (C), only one undrawn multifilament may be stretched to obtain a multifilament. Alternatively, a plurality of undrawn multifilaments may be bundled, and the plurality of bundled undrawn multifilaments may be stretched to obtain a multifilament.

Second Embodiment: Spin Draw Process

[0330] Hereinafter, a second embodiment will be described with reference to FIG. **3**.

[0331] Descriptions already given in the first embodiment are omitted. Features that are not described in the second embodiment should be understood to be the same as those described in the first embodiment.

[0332] A multifilament production method according to the second embodiment is a method for producing an undrawn multifilament and a multifilament by a spin draw process.

[0333] The spin draw process is a process in which the step of discharging a melt from a plurality of discharge holes to obtain a plurality of raw filaments in a molten state and the step of stretching an undrawn multifilament by a stretching roll unit are carried out in one stage. The spin draw process is also called "SDY process" or "direct spin draw process".

[0334] In the second embodiment, a gas having a temperature of 0 to 50° C. is blown onto the 30 or more raw filaments **100**A in a molten state to cool the 30 or more raw filament **100**A and obtain an undrawn multifilament **200**B in the step (B), and the undrawn multifilament **200**B obtained in the step (B) is received on a receiving roll unit **207**.

[0335] Next, in the step (C), the undrawn multifilament **200**B received on the receiving roll unit **207** is stretched by three stretching roll units (a first stretching roll unit **208**, a second stretching roll unit **209**, and a third stretching roll unit **210**).

[0336] Subsequently, in the step (C), the undrawn multifilament **200**B having been stretched is wound on a winding roll unit **212** to obtain a multifilament.

[0337] The winding roll unit **212** includes a bobbin. The term "bobbin" is intended to include a paper core. The bobbin may or may not include a flange.

[0338] Specifically, in the step (C), the undrawn multifilament **200**B having been stretched is wound on the bobbin of the winding roll unit **212** to obtain a multifilament.

[0339] Although in the step (C) of FIG. **3**, the undrawn multifilament **200**B stretched by the stretching roll units is wound on the winding roll unit **212** to obtain a multifilament, the undrawn multifilament **200**B stretched by the stretching roll units need not be wound on the winding roll unit **212** to obtain a multifilament.

[0340] In the step (C), the undrawn multifilament **200**B stretched by the stretching roll units may be transferred by a take-off roll unit **211**.

[0341] In the step (B), the 30 or more raw filaments **100**A are cooled in the first cooling box

[0342] 105 to obtain the undrawn multifilament **200**B, and in the step (C) the undrawn multifilament **200**B is received on the receiving roll unit **207**.

[0343] The 30 or more raw filaments **100**A cooled in the first cooling box **105** may be further cooled in the second cooling box **106** to obtain the undrawn multifilament **200**B.

[0344] The receiving roll unit **207** includes two rolls in FIG. **1**. The receiving roll unit **207** may include one roll or three or more rolls.

[0345] In the second embodiment, each of the stretching roll units may serve as a heat treatment roll unit.

[0346] Each of the stretching roll units **208**, **209**, and **210** (heat treatment roll units **208**, **209**, and **210**) includes two rolls in FIG. **1**. Each of the stretching roll units **208**, **209**, and **210** (heat treatment roll units **208**, **209**, and **210**) may include one roll or three or more rolls.

[0347] In terms of accelerating crystallization of the polymer component contained in the first individual filaments of the undrawn multifilament **200**B or increasing the heat resistance of the polymer component contained in the first individual filaments, the temperatures of the heat treatment roll units are preferably from 30 to 100° C. and more preferably from 40 to 90° C.

[0348] When the temperature of the environment where the step (C) is performed is 30° C. or above, crystallization of the polymer component contained in the first individual filaments can be accelerated without using any heat treatment roll unit.

[0349] In the present embodiment, the spinning draft ratio (NDR) is preferably 50 or more and more preferably 80 or more. The NDR is usually 5000 or less.

[0350] The NDR can be determined by the following equation.

NDR=speed (m/min) of receiving roll unit (first receiving roll unit) that first receives filaments from spinning nozzle/spinning nozzle flow speed (m/min)

[0351] When the NDR is 50 or more, the degree of orientation of the polymer component contained in the first individual filaments of the undrawn multifilament **100**B or **200**B can be increased, and consequently the strength of the resulting multifilament can be further increased.

[0352] In the first embodiment (sequential stretching process), the "first receiving roll unit" is the first receiving roll unit **107** which receives the 30 or more raw filaments **100**A.

[0353] In the second embodiment (spin draw process), the "first receiving roll unit" is the receiving roll unit **207** that receives the undrawn multifilament **200**B.

<Staple Production Method>

[0354] In a staple production method according to the present embodiment, the multifilament production method according to the present embodiment is used to obtain the multifilament.

[0355] In the staple production method according to the present embodiment, the multifilament is cut to obtain a staple having a length of 20 cm or less.

[0356] A plurality of multifilaments may be bundled together, and the plurality of bundled multifilaments may be cut to obtain a staple having a length of 20 cm or less.

[0357] In the staple production method according to the present embodiment, the multifilament may be subjected to crimping and then cut to obtain a staple in the form of a crimped yarn.

[0358] In the case where the undrawn multifilament having been stretched is wound on the winding roll unit **116** or **212** to obtain a multifilament in the step (C), the undrawn multifilament having been stretched may be subjected to crimping to obtain a crimped multifilament before the undrawn multifilament having been stretched is wound on the winding roll unit **116** or **212**.

[0359] Alternatively, the undrawn multifilament having been stretched may be wound on the winding roll unit **116** or **212** (in particular, on the bobbin such as a paper core of the winding roll unit **116** or **212**) to obtain a multifilament, and then the multifilament may be subjected to crimping.

[0360] A multifilament obtained without the use of any winding roll unit may be subjected to crimping.

[0361] The undrawn multifilament having been stretched may be subjected to crimping during transfer from the take-off roll unit **115** or **211** to the winding roll unit **116** or **212**.

[0362] The crimping is not limited to using particular means and can be performed by a known crimping method (such as a gear crimping method or a stuffing box method).

[0363] As a result of the crimping, the staple has crimps (in particular, mechanical crimps).

[0364] Where necessary, the yarn (multifilament or undrawn multifilament having been stretched) to be subjected to the crimping may be pre-heated in a pre-heating step before the crimping.

[0365] In the pre-heating step, the surface temperature of the yarn to be subjected to the crimping is measured, and suitable conditions are chosen in view of factors such as degree of orientation, crystallinity, strength, and heat resistance. The surface temperature is typically from 40 to 140° C., preferably from 40 to 120° C., and more preferably from 50 to 120° C. When the surface temperature is 40° C. or above, mechanical properties suitable for the crimping can be achieved. When the surface temperature is 140° C. or below; draw-down can be reduced, and the process stability of the crimping is improved. The pre-heating step may include a moist heat treatment or a dry heat treatment. In the moist heat treatment, for example, steam may be used. In the dry heat treatment, for example, a hot air oven or an electric heater may be used.

[0366] In the case where the yarn to be subjected to the crimping is pre-heated such that the surface temperature of the yarn reaches 40 to 140° C. and where the pre-heated multifilament is subjected to the crimping by a stuffing box method, the multifilament is preferably crimped at a stuffing box pressure of 0.001 to 0.1 MPa. The stuffing box pressure is more preferably from 0.001 to 0.08 MPa, even more preferably from 0.001 to 0.06 MPa, and still even more preferably from 0.001 to 0.04 MPa.

[0367] The present embodiment has the features as described above and thus offers the following advantages.

[0368] That is, an undrawn multifilament according to the present embodiment includes 30 or more first individual filaments.

[0369] The first individual filaments contain a poly(3-hydroxyalkanoate) resin and a nucleating agent.

[0370] The mean of the finenesses of the first individual filaments is 30 dtex or less.

[0371] The coefficient of variation of the finenesses of the first individual filaments is 33% or less.

[0372] The fact that the coefficient of variation of the finenesses of the first individual filaments of the undrawn multifilament according to the present embodiment is as small as 33% or less means that the undrawn multifilament according to the present embodiment is less likely to include extremely thin second individual filaments. Thus, when the undrawn multifilament according to the present embodiment is stretched to obtain a multifilament, the first individual filaments resist breaking even if the stretching ratio is increased to reduce the mean of the finenesses of the second individual filaments.

[0373] When the undrawn multifilament according to the present embodiment is stretched to obtain a multifilament, increasing the stretching ratio leads to an increase in the degree of orientation of the poly (3-hydroxyalkanoate) resin in the multifilament and therefore an increase in the strength of the resulting multifilament.

[0374] Thus, with the use of the undrawn multifilament according to the present embodiment, a multifilament can be obtained which has high strength despite the second individual filaments having finenesses whose mean is small.

[0375] A multifilament according to the present embodiment is a multifilament having been stretched.

[0376] The multifilament according to the present embodiment includes 30 or more second individual filaments.

[0377] The second individual filaments contain a poly(3-hydroxyalkanoate) resin and a nucleating agent.

[0378] The mean of the finenesses of the second individual filaments is 20 dtex or less.

[0379] The coefficient of variation of the finenesses of the second individual filaments is 33% or less.

[0380] The fact that the coefficient of variation of the finenesses of the second individual filaments of the multifilament according to the present embodiment is 33% or less means that the coefficient of variation of the finenesses of the first individual filaments of the undrawn multifilament used to make the multifilament is small.

[0381] The fact that the coefficient of variation of the finenesses of the first individual filaments of the undrawn multifilament is small means that the undrawn multifilament is less likely to include extremely thin second individual filaments. Thus, when the undrawn multifilament is stretched to obtain the multifilament, the individual filaments resist breaking even if the stretching ratio is increased to reduce the mean of the finenesses of the second individual filaments.

[0382] When the undrawn multifilament is stretched to obtain the multifilament, increasing the stretching ratio leads to an increase in the degree of orientation of the poly

(3-hydroxyalkanoate) resin in the multifilament and therefore an increase in the strength of the resulting multifilament.

[0383] Thus, the multifilament according to the present embodiment is a multifilament that can have high strength despite the second individual filaments having finenesses whose mean is small.

[0384] An undrawn multifilament production method according to the present embodiment is a method for obtaining an undrawn multifilament by melt spinning.

[0385] The undrawn multifilament production method according to the present embodiment includes the steps of: (A) in the melt spinning, discharging a melt using a spinning nozzle having 30 or more discharge holes to obtain 30 or more raw filaments in a molten state; and (B) blowing a gas having a temperature of 0) to 50° C. onto the 30 or more raw filaments in the molten state to cool the 30 or more raw filaments and obtain an undrawn multifilament.

[0386] The melt contains a poly(3-hydroxyalkanoate) resin and a nucleating agent.

[0387] The mean of the finenesses of the first individual filaments of the undrawn multifilament is 30 dtex or less.

[0388] In the step (B), the coefficient of heat transfer between the gas and the 30 or more raw filaments in the molten state is 60 W/(m^2·K) or more.

[0389] In the step (B), where a gas having a temperature of 0) to 50° C. is blown onto the 30 or more raw filaments in a molten state to cool the 30 or more raw filaments and where the coefficient of heat transfer between the gas and the 30 or more raw filaments in the molten state is 60 W/(m^2·K) or more, the time during which the temperature of the raw filaments is in a temperature range where the poly(3-hydroxyalkanoate) resin contained in the raw filaments crystallize can be suitably controlled to achieve desired crystallization of the poly(3-hydroxyalkanoate) resin. Thus, the undrawn multifilament can have suitable stretchability. As such, when the undrawn multifilament is stretched to obtain a multifilament, the individual filaments resist breaking even if the stretching ratio is increased.

[0390] In the step (B), the raw filaments are slightly stretched due to being received on a receiving roll unit. However, those of the raw filaments which are at inner locations (such filaments are hereinafter also referred to as "inner individual filaments") and those of the raw filaments which are at outer locations (such filaments are hereinafter also referred to as "outer individual filaments) are cooled relatively uniformly by the gas having a temperature of 0) to 50° C., and thus the inner and outer individual filaments are uniformly stretched. This results in a small coefficient of variation of the finenesses of the first individual filaments of the undrawn multifilament (for example, the coefficient of variation is 33% or less). That is, the undrawn multifilament is less likely to include extremely thin first individual filaments. Thus, when the undrawn multifilament is stretched to obtain a multifilament, the first individual filaments of the undrawn multifilament resist breaking even if the stretching ratio is increased.

[0391] When the undrawn multifilament is stretched to obtain a multifilament, increasing the stretching ratio leads to an increase in the degree of orientation of the poly(3-hydroxyalkanoate) resin in the multifilament and therefore an increase in the strength of the resulting multifilament.

[0392] Thus, with the use of the undrawn multifilament production method according to the present embodiment, an undrawn multifilament can be obtained which is easily processable into a multifilament that has high strength despite including second individual filaments having finenesses whose mean is small.

[0393] In a multifilament production method according to the present embodiment, the undrawn multifilament production method according to the present embodiment is used to obtain the undrawn multifilament described above.

[0394] The multifilament production method according to the present embodiment includes the step of (C) stretching the undrawn multifilament by a stretching roll unit at a stretching ratio of 1.5 or more to obtain a multifilament.

[0395] In the multifilament production method according to the present embodiment, where the undrawn multifilament production method according to the present embodiment is used to obtain the undrawn multifilament and where the undrawn multifilament is stretched by a stretching roll unit at a stretching ratio of 1.5 or more to obtain a multifilament in the step (C), the multifilament obtained can have high strength despite including second individual filaments having finenesses whose means is small.

[0396] In the multifilament production method according to the present embodiment, a gas having a temperature of 0 to 50° C. is blown onto the 30 or more raw filaments in a molten state to cool the 30 or more raw filaments to 50° C. or below and obtain the undrawn multifilament in the step (B), followed by the step (C) in which the undrawn multifilament is heated and the heated undrawn multifilament is stretched by the stretching roll unit.

[0397] In the step (C), stretching the undrawn multifilament can increase the degree of orientation of the poly(3-hydroxyalkanoate) resin contained in the undrawn multifilament and thus can increase the strength of the resulting multifilament.

[0398] To increase the degree of orientation of the poly (3-hydroxyalkanoate) resin, it is desired to stretch the undrawn multifilament in a temperature range suitable for increasing the degree of orientation of the poly (3-hydroxyalkanoate) resin. This is because, if the undrawn multifilament is stretched at a temperature above the temperature range, the poly (3-hydroxyalkanoate) resin is brought into a molten state and thus the stretching does not increase the degree of orientation of the poly (3-hydroxyalkanoate) resin very much. Another reason is that if the undrawn multifilament is stretched at a temperature below the temperature range, the poly (3-hydroxyalkanoate) resin becomes so hard as to make stretching of the raw filaments difficult and that in this case, forcibly pulling the undrawn multifilament to stretch the undrawn multifilament could cause breakage of the undrawn multifilament, leading to a failure to produce the multifilament.

[0399] In the present embodiment, a gas having a temperature of 0 to 50° C. is blown onto the 30 or more raw filaments in a molten state to cool the 30 or more raw filaments to 50° C. or below and obtain the undrawn multifilament in the step (B), followed by the step (C) in which the undrawn multifilament is heated and the heated undrawn multifilament is stretched by the stretching roll unit. Thus, the temperature of the undrawn multifilament to be stretched is easier to control within a temperature range suitable for increasing the degree of orientation of the poly (3-hydroxyalkanoate) resin than in the case of a SDY process (spin draw process) in which the undrawn multifilament is cooled by ambient air while being stretched. As

such, the degree of orientation of the poly (3-hydroxyalkanoate) resin of the undrawn multifilament can be easily increased.

[0400] Thus, in the present embodiment, the strength of the multifilament can be easily increased.

[0401] The multifilament or staple according to the present embodiment may be used in the form of a yarn.

[0402] The multifilament or staple according to the present embodiment may be used to make a fibrous product (fabric).

[0403] The fibrous product may take any of various forms (such as a non-woven fabric).

[0404] The multifilament, staple, and fibrous product according to the present embodiment are suitable for use in known applications.

[0405] The multifilament, staple, and fibrous product according to the present embodiment are suitable for use in various fields such as agricultural industry (e.g., horticulture), fishery industry, forestry industry, medical industry, and food industry.

[0406] Examples of the fibrous product include clothes, curtains, carpets, bags, shoes, wiping materials, hygiene products, automobile parts, building materials, and filtration materials (filters).

[Disclosed Items]

[0407] The following items are disclosures of preferred embodiments.

[Item 1]

[0408] An undrawn multifilament including 30 or more individual filaments, wherein

[0409] the individual filaments contain a poly(3-hydroxyalkanoate) resin and a nucleating agent,

[0410] a mean of finenesses of the individual filaments is 30 dtex or less, and a coefficient of variation of the finenesses of the individual filaments is 33% or less.

[Item 2]

[0411] The undrawn multifilament according to item 1, wherein the poly(3-hydroxyalkanoate) resin includes a poly (3-hydroxybutyrate) resin.

[Item 3]

[0412] A multifilament having been stretched, the multifilament including 30 or more individual filaments, wherein

[0413] the individual filaments contain a poly(3-hydroxyalkanoate) resin and a nucleating agent,

[0414] a mean of finenesses of the individual filaments is 20 dtex or less, and

[0415] a coefficient of variation of the finenesses of the individual filaments is 33% or less.

[Item 4]

[0416] A staple including a cut piece of the multifilament according to item 3, the staple having a length of 20 cm or less.

[Item 5]

[0417] An undrawn multifilament production method for obtaining an undrawn multifilament by melt spinning, the undrawn multifilament production method including the steps of:

[0418] (A) in the melt spinning, discharging a melt using a spinning nozzle having 30 or more discharge holes to obtain 30 or more raw filaments in a molten state; and

[0419] (B) blowing a gas having a temperature of 0 to 50° C. onto the 30 or more raw filaments in the molten state to cool the 30 or more raw filaments and obtain an undrawn multifilament, wherein

[0420] the melt contains a poly(3-hydroxyalkanoate) resin and a nucleating agent,

[0421] a mean of finenesses of individual filaments of the undrawn multifilament is 30 dtex or less, and

[0422] in the step (B), a coefficient of heat transfer between the gas and the 30 or more raw filaments in the molten state is 60 $W/(m^2 \cdot K)$ or more.

[Item 6]

[0423] The undrawn multifilament production method according to item 5, wherein in the step (B), the coefficient of heat transfer is 125 $W/(m^2 \cdot K)$ or more.

[Item 7]

[0424] The undrawn multifilament production method according to item 5 or 6, wherein in the step (B), a speed of the gas blown onto the 30 or more raw filaments is 0.3 m/s or more.

[Item 8]

[0425] A multifilament production method including:

[0426] using the undrawn multifilament production method according to any one of items 5 to 7 to obtain the undrawn multifilament; and

[0427] the step of (C) stretching the undrawn multifilament by a stretching roll unit at a stretching ratio of 1.5 or more to obtain a multifilament.

[Item 9]

[0428] The multifilament production method according to item 8, wherein

[0429] in the step (B), the gas having a temperature of 0 to 50° C. is blown onto the 30 or more raw filaments in the molten state to cool the 30 or more raw filaments to 50° C. below and obtain the undrawn multifilament, and

[0430] in the step (C), the undrawn multifilament is heated, and the heated undrawn multifilament is stretched by the stretching roll unit.

[Item 10]

[0431] A staple production method including:

[0432] using the multifilament production method according to item 8 or 9 to obtain the multifilament; and

[0433] cutting the multifilament to obtain a staple having a length of 20 cm or less.

[0434] The present invention is not limited to the above embodiment. The present invention is not limited by the advantageous effects described above. The present invention may be modified in various ways without departing from the gist of the present invention.

[0435] Although the undrawn multifilament according to the present embodiment is obtained by the production

method as described above, an undrawn multifilament according to the present invention may be obtained, for example, as follows.

[0436] That is, the undrawn multifilament may be obtained by selectively gathering 30 or more first individual filaments such that the mean of the finenesses of the first individual filaments is 30 dtex or less and the coefficient of variation of the finenesses of the first individual filaments is 33% or less.

EXAMPLES

[0437] Hereinafter, the present invention will be described in more detail using Examples and Comparative Examples. The present invention is not limited by these Examples in any respect.

Example 1

[0438] A multifilament was made by the method of the first embodiment (sequential stretching process).

(Step (A))

[0439] First, the materials listed below were dry-blended in the proportions indicated below, and the mixture resulting from the dry blending was melted and kneaded by an extruder at 150° C. to obtain pellets.

[0440] Poly(3-hydroxyalkanoate) resin: 100 parts by mass

[0441] The resin was a (3-hydroxy butyrate-co-3-hydroxyhexanote) copolymer resin (P3HB3HH) (3-hydroxyhexanoate content: 6 mol %, Mw: 35×10^4, melt flow rate (MFR) at 165° C., 5 kg: 12 g/10 min

[0442] Pentaerythritol used as nucleating agent (Neulizer P manufactured by Nippon Synthetic Chemical Industry Co., Ltd.): 1.0 parts by mass

[0443] Erucamide used as amide bond-containing lubricant: 0.5 parts by mass

[0444] Behenamide used as amide bond-containing lubricant: 0.5 parts by mass

[0445] The glass transition temperature of the pellets was 2° C. The crystallization temperature of the pellets was 100° C. The melting point of the pellets was 146° C. The pyrolysis temperature of the pellets was 180° C.

[0446] As shown in FIG. **1**, the pellets were melted by the kneading extruder **102** (single-screw extruder, screw diameter: 25 mm) to obtain a melt.

[0447] The melt was discharged from the spinning nozzle **104** (temperature: 175° C., number of discharge holes: 368, shape of discharge holes: circular, diameter of discharge holes: 0.3 mm) to obtain 368 raw filaments **100**A.

[0448] The flow rate of the melt was adjusted to 5.6 kg/h by the gear pump **103**.

(Step (B))

[0449] In the cooling box **105**, the 368 raw filaments **100**A were subjected to circular quenching in which 20° C. air was blown onto the 368 raw filaments **100**A at a speed of 0.7 m/s.

[0450] The coefficient of heat transfer between the air and the 368 raw filaments **100**A in a molten state was determined from the temperature of the air, the speed of the air, and the diameter of the discharge holes by the method previously described. The coefficient of heat transfer was 194 $W/(m^2\cdot K)$. Any gas was not blown onto the raw filaments in the cooling box **106**.

[0451] Next, the 368 raw filaments **100**A cooled in the cooling boxes **105** and **106** were received on the first receiving roll unit **107** (448 m/min). The 368 raw filaments **100**A were passed successively through the first transfer roll unit **108** (471 m/min), the second transfer roll unit **109** (471 m/min, 70° C.), the third transfer roll unit **110** (471 m/min), and the fourth transfer roll unit **111** (471 m/min) and then wound on the first winding roll unit (461 m/min). The wound raw filaments **100**A were stored at room temperature (5 to 35° C.) for 18 hours to obtain an undrawn multifilament.

(Step (C))

[0452] As shown in FIG. **2**, the undrawn multifilament was fed from the first winding roll unit **112** and received on the second receiving roll unit **113** (4.8 m/min, 30° C.). The undrawn multifilament was then stretched by the stretching roll unit **114** (11.5 m/min, 25° C.), transferred by the take-off roll unit (heat treatment roll unit) **115** (10.4 m/min, 90° C.), and wound on the second winding roll unit **116** (10.4 m/min) to obtain a multifilament.

[0453] The stretching ratio was 2.4.

[0454] In the multifilament, the second individual filaments remained unbroken. Additionally, no fusion between the second individual filaments was found.

[0455] Thus, the multifilament had good appearance.

[0456] Each of the receiving and transfer roll units used was a roll unit including two rolls rotating at the same speed and having the same temperature.

[0457] The multifilament obtained was used to make a staple as follows.

[0458] First, a plurality of such multifilaments were bundled in order to obtain a staple having a suitable fineness.

[0459] Next, the plurality of bundled multifilaments were pre-heated with steam such that the surface temperature of the bundled multifilaments reached 65° C.

[0460] The pre-heated multifilaments were delivered to a stuffing box at a transfer speed of 30 m/min and were crimped at a nip pressure of 0.20 MPa and a stuffing pressure of 0.03 MPa to obtain a crimped yarn.

[0461] The crimped yarn was then cut by means of a tow cutter to obtain a staple having crimps and a length of 51 mm. The crimp number of the staple was 14/25 mm.

Examples 2 to 7

[0462] Undrawn multifilaments, multifilaments, and staples were obtained in the same manner as in Example 1, expect that the conditions in the steps (A) to (C) were changed as shown in Table 2 below.

[0463] In any of Examples 2 to 7, the crimp number of the staple was 14/25 mm.

Comparative Examples 1 and 5

[0464] Undrawn multifilaments and multifilaments were obtained in the same manner as in Example 1, except that the conditions in the steps (A) to (C) were changed as shown in Table 2 below.

Comparative Example 2

[0465] An undrawn multifilament was obtained in the same manner as in Example 1, except that the conditions in the steps (A) and (C) were changed as shown in Table 2 below.

[0466] The undrawn multifilament was used in an attempt to obtain a multifilament in the same manner as in Example 1, except that the condition in the step (C) was changed as shown in Table 2 below. However, some of the first individual filaments broke, and a multifilament was not able to be made.

Comparative Examples 3 and 4

[0467] An attempt was made to obtain an undrawn multifilament in the same manner as in Example 1, except that the conditions in the steps (A) and (B) were changed as shown in Table 2 below.

[0468] However, in Comparative Example 3, the adjacent first individual filaments fused together, and an undrawn multifilament was not able to be obtained.

[0469] In Comparative Example 4, some of the raw filaments broke on the path from the spinning nozzle **104** to the first winding roll unit **112**, and an undrawn multifilament was not able to be obtained.

<Mean and Coefficient of Variation of Finenesses of First Individual Filaments of Undrawn Multifilament>

[0470] The mean and coefficient of variation of the finenesses of the first individual filaments of each undrawn multifilament were determined by the methods previously described.

[0471] The mean and coefficient of variation of the finenesses of the first individual filaments of each undrawn multifilament are listed in Table 2 below.

<Mean and Coefficient of Variation of Finenesses of Second Individual Filaments of Multifilament>

[0472] The mean and coefficient of variation of the finenesses of the second individual filaments of each multifilament were determined by the methods previously described.

[0473] The mean and coefficient of variation of the finenesses of the second individual filaments of each multifilament are listed in Table 2 below.

<Mean of Tensile Strengths of Second Individual Filaments of Multifilament>

[0474] The mean of the tensile strengths of the second individual filaments of each multifilament was determined by the method previously described.

[0475] The mean of the tensile strengths of the second individual filaments of each multifilament is listed in Table 2 below.

TABLE 2

	Step (A)			Step (B)			Stretchable multifilament
	Spinning nozzle			Air		Coefficient of heat transfer ($W/(m^2 \cdot K)$)	Finenesses of first individual filaments Mean (dtex)
	Shape of discharge holes	Number of discharge holes	Diameter of discharge holes (mm)	Temperature (° C.)	Speed (m/s)		
Ex. 1	Circular	368	0.3	20	0.70	194	5.5
Ex. 2	Circular	368	0.3	20	0.47	166	
Ex. 3	Circular	368	0.3	20	0.37	152	
Ex. 4	Circular	180	0.3	20	0.47	166	
Ex. 5	Circular	180	0.5	20	0.47	121	
Ex. 6	Circular	180	0.5	30	0.47	122	
Ex. 7	Circular	180	0.5	40	0.47	122	
Comp. 1	Circular	368	0.3	20	0.01	45	
Comp. 2	Circular	368	0.3	20	0.01	45	
Comp. 3	Circular	368	0.3	20	0.00	0	Not able to be made
Comp. 4	Circular	368	0.3	60	0.47	169	
Comp. 5	Circular	368	0.5	20	0.01	32	5.5

	Stretchable multifilament			Multifilament			
	Finenesses of first individual filaments			Finenesses of second individual filaments		Mean oftensile strengths	
	Coefficient of variation (%)	Shape offirst individual filaments	Step (C) Stretching ratio (%)	Mean (dtex)	Coefficient of variation (%)	of second individual filaments (cN/dtex)	Shape of second individual filaments
Ex. 1	18.5	Circular	2.4	2.4	18.2	2.5	Circular
Ex. 2	21.2	Circular	2.2	2.5	21.7	2.2	Circular
Ex. 3	26.7	Circular	2.0	2.8	27.1	2.1	Circular
Ex. 4	19.8	Circular	2.3	2.5	19.5	2.3	Circular
Ex. 5	16.4	Circular	2.2	2.5	17.1	2.3	Circular
Ex. 6	15.8	Circular	2.2	2.5	15.5	2.3	Circular
Ex. 7	17.6	Circular	2.2	2.5	16.9	2.2	Circular
Comp. 1	38.1	Circular	1.7	3.2	34.0	1.4	Circular

TABLE 2-continued

Comp. 2	38.1	Circular	2.0		Not able to be made		
Comp. 3	Not able to be made				—		
Comp. 4							
Comp. 5	44.6	Circular	1.5	3.9	42.7	1.2	Circular

[0476] As seen from Table 2 above, in Examples 1 to 7 falling within the scope of the present invention, the tensile strength of the second individual filaments of the multifilament was higher than in Comparative Examples 1 and 5 where the coefficient of variation of the finenesses of the first individual filaments of the undrawn multifilament was 38.1% or more.

[0477] Additionally, a multifilament was not able to be obtained in Comparative Example 2 where an undrawn multifilament in which the coefficient of variation of the finenesses of the first individual filaments was 38.1% was used in an attempt to obtain a multifilament at a stretching ratio equal to that in Example 3.

[0478] The above results have demonstrated that the present invention can provide an undrawn multifilament easily processable into a multifilament that has high strength despite including individual filaments having finenesses whose mean is small.

[0479] As seen from Table 2 above, in Examples 1 to 7 falling within the scope of the present invention, the coefficient of variation of the finenesses of the first individual filaments of the undrawn multifilament was smaller than in Comparative Examples 1 and 5 where the coefficient of heat transfer was 45 W/(m^2·K) or less.

[0480] An undrawn multifilament was able to be obtained neither in Comparative Example 3 where air was not blown onto the raw filaments (the speed of air was 0.0 m/s) nor in Comparative Example 4 where the air temperature was 60° C.

REFERENCE SIGNS LIST

[0481] **100**A: raw filament, **100**B: undrawn multifilament, **101**: material feeder, **102**: kneading extruder, **103**: gear pump, **104**: spinning nozzle, **105**: first cooling box, **106**: second cooling box, **107**: first receiving roll unit, **108**: first transfer roll unit, **109**: second transfer roll unit, **110**: third transfer roll unit, **111**: fourth transfer roll unit, **112**: first winding roll unit, **113**: second receiving roll unit, **114**: stretching roll unit (heat treatment roll unit), **115**: take-off roll unit (heat treatment roll unit), **116**: second winding roll unit

[0482] **200**B: undrawn multifilament, **207**: receiving roll unit, **208**: first stretching roll unit (heat treatment roll unit), **209**: second stretching roll unit (heat treatment roll unit), **210**: third stretching roll unit (heat treatment roll unit), **211**: take-off roll unit, **212**: winding roll unit

1. An undrawn multifilament comprising at least 30 individual filaments, wherein

the individual filaments comprise a poly(3-hydroxyalkanoate) resin and a nucleating agent,

a mean of finenesses of the individual filaments is 30 dtex or less, and

a coefficient of variation of the finenesses of the individual filaments is 33% or less.

2. The undrawn multifilament according to claim **1**, wherein the poly(3-hydroxyalkanoate) resin comprises a poly(3-hydroxybutyrate) resin.

3. A stretched multifilament comprising at least 30 individual filaments, wherein

the individual filaments comprise a poly(3-hydroxyalkanoate) resin and a nucleating agent,

a mean of finenesses of the individual filaments is 20 dtex or less, and

a coefficient of variation of the finenesses of the individual filaments is 33% or less.

4. A staple comprising a cut piece of the multifilament according to claim **3**, wherein the staple has a length of 20 cm or less.

5. An undrawn multifilament production method for obtaining an undrawn multifilament by melt spinning, the method comprising:

(A) conducting the melt spinning comprising discharging a melt using a spinning nozzle having at least 30 discharge holes to obtain at least 30 raw filaments in a molten state; and

(B) blowing a gas having a temperature of from 0 to 50° C. onto the at least 30 raw filaments in the molten state to cool the at least 30 raw filaments and obtain an undrawn multifilament, wherein

the melt comprises a poly(3-hydroxyalkanoate) resin and a nucleating agent,

a mean of finenesses of individual filaments of the undrawn multifilament is 30 dtex or less, and

in (B), a coefficient of heat transfer between the gas and the at least 30 raw filaments in the molten state is at least 60 W/(m^2·K).

6. The undrawn multifilament production method according to claim **5**, wherein in (B), the coefficient of heat transfer is at least 125 W/(m^2·K).

7. The undrawn multifilament production method according to claim **5**, wherein in (B), a speed of the gas blown onto the at least 30 raw filaments is at least 0.1 m/s.

8. A multifilament production method comprising:

obtaining an undrawn multifilament using the undrawn multifilament production method according to claim **5**; and

the step of (C) stretching the undrawn multifilament by a stretching roll unit at a stretching ratio of at least 1.5 to obtain a multifilament.

9. The multifilament production method according to claim **8**, wherein

in (B), the gas having a temperature of from 0 to 50° C. is blown onto the at least 30 raw filaments in the molten state to cool the at least 30 raw filaments to below 50° C. and obtain the undrawn multifilament, and

in (C), the undrawn multifilament is heated, and a heated undrawn multifilament is stretched by the stretching roll unit.

10. A staple production method comprising:
obtaining a multifilament using the multifilament production method according to claim **8**; and
cutting the multifilament to obtain a staple having a length of 20 cm or less.

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