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(71) Applicants:
- **Spiber Inc.**
  Tsuruoka-shi, Yamagata 997-0052 (JP)
- **Nakagawa Silk Inc.**
  Nagahama-city, Shiga 526-0111 (JP)

(72) Inventors:
- **SATO Akito**
  Tsuruoka-shi, Yamagata 997-0052 (JP)
- **NISHIKADO Mizuki**
  Tsuruoka-shi, Yamagata 997-0052 (JP)
- **SEKIYAMA Kazuhide**
  Tsuruoka-shi, Yamagata 997-0052 (JP)
- **HIGASHI Kenji**
  Tsuruoka-shi, Yamagata 997-0052 (JP)
- **NAKAGAWA Yoshitaka**
  Nagahama-city, Shiga 5260111 (JP)

(74) Representative: **Handley, Matthew Edward**
Venner Shipley LLP
St James's
79 Oxford Street
Manchester M1 6EG (GB)

Remarks:
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(54) LOFTY BLENDED YARN AND METHOD FOR PRODUCING SAME

(57) The present invention relates to a lofty blended yarn containing: a first fiber including an artificial protein fiber that contains an artificial protein and is shrinkable when being brought into contact with water; and a second fiber that has a shrinkage rate lower than a shrinkage rate of the first fiber when being brought into contact with water, in which the lofty blended yarn has a loftiness of 10 cm^3/g or more.

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Description

Technical Field

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

Background Art

[0002] Patent Literature 1 discloses a bulky treatment device for acrylic fibers that performs a bulky treatment (lofty treatment) on acrylic fibers and a method for producing the same. Patent Literature 2 discloses a knitted fabric including a highly shrinkable acrylic fiber having a boiling water shrinkage rate of 15% or more and a single fiber fineness of 0.7 to 2.2 dtex and a low shrinkage fiber having a boiling water shrinkage rate of 10% or less, in which the knitted fabric has a specific volume of 6 to 12 cm^3/g and a heat retention rate of 28 to 60%. Patent Literature 2 describes that the knitted fabric has an excellent texture, has a soft surface touch, is excellent in dimensional stability, is lightweight, is bulky, and is excellent in heat retaining property.

Citation List

Patent Literature

[0003]

Patent Literature 1: JP 2003-328241 A
Patent Literature 2: JP 2014-101601 A

Summary of Invention

Technical Problem

[0004] An object of the present invention is to provide a novel lofty blended yarn using a fiber containing an artificial protein, a method for producing the same, and a novel fabric using a lofty blended yarn containing an artificial protein fiber.

Solution to Problem

[0005] The present invention relates to, for example, the following inventions.

[1] A lofty blended yarn containing: a first fiber that contains an artificial protein and is shrinkable when being brought into contact with water; and a second fiber that has a shrinkage rate lower than a shrinkage rate of the first fiber when being brought into contact with water, in which the lofty blended yarn has a loftiness of 10 cm^3/g or more.
[2] The lofty blended yarn according to [1], in which the loftiness is 50 cm^3/g or less.
[3] The lofty blended yarn according to [1] or [2], in which the shrinkage rate of the first fiber when being brought into contact with water is 15% or more.
[4] The lofty blended yarn according to any one of [1] to [3], in which the number of crimps of the first fiber is 5 or more.
[5] The lofty blended yarn according to any one of [1] to [4], in which a content of the first fiber is 5 mass% or more based on a total mass of the lofty blended yarn.
[6] The lofty blended yarn according to [5], in which the content of the first fiber is 90 mass% or less based on the total mass of the lofty blended yarn.
[7] The lofty blended yarn according to any one of [1] to [6], in which an average length of the first fiber is 48 mm or more and 170 mm or less.
[8] The lofty blended yarn according to any one of [1] to [7], in which the first fiber and the second fiber are of different types.
[9] The lofty blended yarn according to any one of [1] to [7], in which the first fiber and the second fiber are of the same types.
[10] The lofty blended yarn according to [8], in which the second fiber is at least one of an animal hair fiber and silk.
[11] The lofty blended yarn according to [10], in which the second fiber is an animal hair fiber or silk.
[12] The lofty blended yarn according to any one of [1] to [11], the lofty blended yarn is spun by woolen spinning.
[13] A method for producing a lofty blended yarn, the method including: a step of obtaining a raw material blended yarn by blending a first sliver containing a first fiber that contains an artificial protein and is shrinkable when being brought

into contact with water, and a second sliver containing a second fiber that has a shrinkage rate lower than a shrinkage rate of the first fiber when being brought into contact with water; and a step of bringing the raw material blended yarn into contact with an aqueous medium and shrinking at least the first fiber to obtain a lofty blended yarn.

[14] The method according to [13], further including a step of obtaining the first sliver.

[15] The method according to [13] or [14], in which the step of obtaining the blended yarn is performed by worsted spinning.

[16] A fabric including the lofty blended yarn according to any one of [1] to [12].

Advantageous Effects of Invention

[0006] According to the present invention, a novel lofty blended yarn containing a fiber containing an artificial protein and a method for producing the same can be provided. In addition, a novel fabric using a lofty blended yarn containing an artificial protein fiber can be provided.

[0007] Since the lofty blended yarn of the present invention contains an artificial protein, the lofty blended yarn is excellent in water absorbency. In addition, since the lofty blended yarn of the present invention includes the first fiber containing an artificial protein capable of molecular design and the second fiber different from the first fiber, it is possible to secure a wide variety of characteristics in the lofty blended yarn of the present invention. In addition, even in the fabric of the present invention, since the lofty blended yarn as described above is included, excellent water absorbency and a wide variety of characteristics can be secured.

Brief Description of Drawings

[0008] Fig. 1 is an explanation diagram schematically illustrating an example of a spinning apparatus for producing a first fiber (artificial protein fiber).

Description of Embodiments

[0009] Hereinafter, modes for carrying out the present disclosure will be described in detail with reference to the drawings in some cases. However, the following embodiments are examples for describing the present disclosure, and are not intended to limit the present disclosure to the following contents.

[0010] The materials exemplified in the present specification can be used alone or in combination of two or more thereof unless otherwise specified. Contents of the respective components in a composition mean the total amount of a plurality of substances present in the composition, unless otherwise specified, when a plurality of substances corresponding to the respective components in the composition are present.

[Lofty blended yarn]

[0011] A lofty blended yarn according to the present embodiment contains a first fiber that contains an artificial protein and is shrinkable when being brought into contact with water, and a second fiber that has a shrinkage rate lower than a shrinkage rate of the first fiber when being brought into contact with water.

[0012] A loftiness of the lofty blended yarn is 10 cm^3/g or more. The loftiness of the lofty blended yarn may be 15 cm^3/g or more, 20 cm^3/g or more, 25 cm^3/g or more, 30 cm^3/g or more, 35 cm^3/g or more, 40 cm^3/g or more, 45 cm^3/g or more, 50 cm^3/g or more, or 55 cm^3/g or more. The loftiness of the lofty blended yarn may be 70 cm^3/g or less, 65 cm^3/g or less, 60 cm^3/g or less, 55 cm^3/g or less, 50 cm^3/g or less, 45 cm^3/g or less, or 40 cm^3/g or less. As the loftiness is higher, the softness, heat retaining property, water absorbency, anti-pilling property, and the like of the lofty blended yarn are improved.

[0013] The loftiness of the lofty blended yarn is measured in accordance with JIS L 1095A method.

[0014] The loftiness of the lofty blended yarn can be adjusted, for example, by controlling the shrinkage rate of the first fiber when being brought into contact with water and the shrinkage rate of the second fiber when being brought into contact with water. The loftiness tends to increase, for example, by increasing a difference between the shrinkage rate of the first fiber when being brought into contact with water and the shrinkage rate of the second fiber when being brought into contact with water.

<First fiber>

[0015] The first fiber is a fiber containing an artificial protein (artificial protein fiber). The fiber containing an artificial protein mentioned here includes a fiber containing only an artificial protein, a fiber containing a component not physically or chemically bonded to an artificial protein other than an artificial protein, a fiber containing a component physically or

chemically bonded to an artificial protein, and the like. In addition, the artificial protein includes a chemically modified artificial protein, an artificial protein derivative, and the like.

(Artificial protein)

[0016] In the present specification, the "artificial protein" means a protein artificially produced. The artificial protein includes a recombinant protein and a synthetic protein. The artificial protein may be a protein having a domain sequence different from an amino acid sequence of a naturally derived protein, or may be a protein having a domain sequence identical to an amino acid sequence of a naturally derived protein. The "artificial protein" may be a protein obtained by using an amino acid sequence of a naturally derived protein as it is, a protein in which an amino acid sequence is modified based on an amino acid sequence of a naturally derived protein (for example, a protein in which an amino acid sequence is modified by modifying a cloned gene sequence of a naturally derived protein), or a protein artificially designed and synthesized independently of a naturally derived protein (for example, a protein having a desired amino acid sequence by chemically synthesizing a nucleic acid encoding a designed amino acid sequence).

[0017] Since an artificial protein can freely design an amino acid sequence unlike a natural protein, a first fiber containing the artificial protein and a lofty blended yarn containing the first fiber can arbitrarily control functions, characteristics, physical properties, and the like by appropriately designing the amino acid sequence of the artificial protein. Since a uniform molecular design of the artificial protein is always possible, an artificial protein that has high homology with a target protein and is suitable for a purpose can be stably obtained. Thus, the quality of the first fiber containing the artificial protein and the lofty blended yarn containing the first fiber can be advantageously stabilized. From this point of view, an artificial structural protein is advantageously used as the artificial protein.

[0018] The number of amino acid residues of the artificial protein is not particularly limited, and may be, for example, 50 or more. The number of amino acid residues may be, for example, 100 or more, 150 or more, 200 or more, 250 or more, 300 or more, 350 or more, 400 or more, 450 or more, or 500 or more. The number of amino acid residues may be, for example, 5,000 or less, 4,500 or less, 4,000 or lee, 3,500 or less, 3,000 or less, 2,500 or less, 2,000 or less, 1,500 or less, or 1,000 or less. As the number of amino acid residues is smaller, the solubility in the solvent tends to increase.

[0019] A molecular weight of the artificial protein is not particularly limited, and may be, for example, 2 kDa or more and 500 kDa or less. The molecular weight of the artificial protein may be, for example, 2 kDa or more, 3 kDa or more, 4 kDa or more, 5 kDa or more, 6 kDa or more, 7 kDa or more, 8 kDa or more, 9 kDa or more, 10 kDa or more, 20 kDa or more, 30 kDa or more, 40 kDa or more, 50 kDa or more, 60 kDa or more, 70 kDa or more, 80 kDa or more, 90 kDa or more, or 100 kDa or more, and may be 500 kDa or less, 400 kDa or less, less than 360 kDa, 300 kDa or less, or 200 kDa or less.

[0020] As the artificial protein, for example, an artificial protein having physical properties close to physical properties required for a desired application can be adopted. Examples of the artificial protein include artificial proteins that can be used industrially. The phrase "can be used for industrial purposes" means, for example, that it can be used for various general-purpose materials used indoors and/or outdoors. Examples of the artificial protein that can be used for industrial purposes include artificial structural proteins.

<Artificial structural protein>

[0021] The artificial protein may be, for example, an artificial structural protein. In the present specification, the "artificial structural protein" means a structural protein artificially produced. The structural protein is a type of artificial protein that can be used for industrial purposes, and means a protein related to a structure of a living body, a protein included in a structure created by a living body, or a protein derived from these proteins. The structural protein also refers to a protein that self-aggregates under predetermined conditions to form a structure such as a fiber, a film, a resin, a gel, a micelle, or a nanoparticle. Furthermore, the structural protein can also be said to be a protein in which a motif consisting of a characteristic amino acid sequence or the number of amino acid residue is repeatedly present to form a skeleton of an organism or material.

[0022] The artificial structural protein may be a structural protein produced from a microorganism by a genetic recombination technology, may have the same amino acid sequence as that of a natural structural protein, or may have an amino acid sequence improved from the viewpoint of productivity, moldability, or the like.

[0023] Specific examples of the artificial structural protein include spider silk, silkworm silk, keratin, collagen, elastin, resilin, and proteins derived from them.

[0024] The artificial structural protein according to the present embodiment may have 150 or more amino acid residues. The number of amino acid residues may be, for example, 200 or more or 250 or more and is preferably 300 or more, 350 or more, 400 or more, 450 or more, or 500 or more.

[0025] When an artificial structural protein is molded, an amino acid having a relatively small side chain is more likely to form a hydrogen bond and is more likely to have higher strength. An alanine residue content may be, for example, 10 to 40%, 12 to 40%, 15 to 40%, 18 to 40%, 20 to 40%, or 22 to 40% in terms of more excellent strength. A glycine residue

content may be, for example, 10 to 55%, 11 to 55%, 13 to 55%, 15 to 55%, 18 to 55%, 20 to 55%, 22 to 55%, or 25 to 55% in terms of more excellent strength.

[0026] In the present specification, the "content of alanine residues" means the number of alanine residues with respect to the total number of amino acid residues constituting a protein, and is a value represented by the following formula.

Content of alanine residues = (number of alanine residues contained in protein/number of all amino acid residues of protein) × 100 (%)

[0027] The glycine residue content, and a serine residue content, threonine residue content, proline residue content, and tyrosine residue content described below have the same meanings as those obtained by replacing the alanine residue with the glycine residue, the serine residue, the threonine residue, the proline residue, and the tyrosine residue, respectively, in the above formula.

[0028] In the artificial structural protein, the total content of the content of at least one type of amino acid residue selected from the group consisting of serine, threonine, and tyrosine (that is, any one of the serine residue content, the threonine residue content, the tyrosine residue content, the total of the serine residue content and the threonine residue content, the total of the serine residue content and the tyrosine residue content, the total of the threonine residue content and the tyrosine residue content, and the total of the serine residue content, the threonine residue content, and the tyrosine residue content), the alanine residue content, and the glycine residue content may be 40% or more based on the number of amino acid residues. The total content may be, for example, 45% or more, 50% or more, 55% or more, or 60% or more. The upper limit of the total content is not particularly limited, and may be, for example, 90% or less, 85% or less, or 80% or less.

[0029] In one embodiment, the artificial structural protein may have a total of the serine residue content, the threonine residue content, and the tyrosine residue content of 4% or more, 4.5% or more, 5% or more, 5.5% or more, 6% or more, 6.5% or more, or 7% or more, based on the number of amino acid residues. The total of the serine residue content, the threonine residue content, and the tyrosine residue content may be, for example, 35% or less, 33% or less, 30% or less, 25% or less, or 20% or less.

[0030] In the artificial structural protein according to the present embodiment, the distribution of serine residues, threonine residues, or tyrosine residues is mean, and the total content of the serine residue, threonine residue, and tyrosine residue among optional 20 continuous amino acid residues may be 4% or more, 5% or more, 10% or more, or 15% or more, and may be 50% or less, 40% or less, 30% or less, or 20% or less.

[0031] In addition, in the artificial structural protein, it is preferable that an amino acid having a relatively large side chain or an amino acid having flexibility is uniformly included in the entire sequence to a certain extent. Specifically, the artificial structural protein may include a motif containing a tyrosine residue, a threonine residue, and a proline residue repeatedly in a cycle. When such an artificial structural protein is used, the formation of strong intermolecular hydrogen bonds is easily inhibited during post-molding processing, and processability is easily improved. For example, a total content of the proline residues, the threonine residues, and the tyrosine residues in arbitrary 20 consecutive amino acid residues may be 5% or more, more than 5.5%, 6.0% or more, more than 6.5%, 7.0% or more, more than 7.5%, 8.0% or more, more than 8.5%, 9.0% or more, 10.0% or more, or 15.0% or more. For example, the total content of the proline residues, the threonine residues, and the tyrosine residues in arbitrary 20 consecutive amino acid residues may be 50% or less, 40% or less, 30% or less, or 20% or less.

[0032] The artificial structural protein may have a repetitive sequence. That is, the artificial structural protein may have a plurality of amino acid sequences (repetitive sequence units) having a high sequence identity in the artificial structural protein. The number of amino acid residues of the repetitive sequence units is preferably 6 to 200. The total number of glycine residues, serine residues, glutamine residues and alanine residues may be 40% or more, 45% or more, 50% or more, 55% or more, 60% or more, 65% or more, or 70% or more with respect to the total number of amino acid residues in the repetitive sequence unit. In addition, a sequence identity between the repetitive sequence units may be, for example, 85% or higher, 90% or higher, 95% or higher, 96% or higher, 97% or higher, 98% or higher, or 99% or higher.

[0033] A hydrophobic degree (hydropathy index) of the repetitive sequence unit may be, for example, -0.80 or more, -0.70 or more, -0.60 or more, -0.50 or more, -0.40 or more, -0.30 or more, -0.20 or more, -0.10 or more, 0.00 or more, 0.22 or more, 0.25 or more, 0.30 or more, 0.35 or more, 0.40 or more, 0.45 or more, 0.50 or more, 0.55 or more, 0.60 or more, 0.65 or more, or 0.70 or more. An upper limit value of the hydrophobic degree of the repetitive sequence unit is not particularly limited, and may be, for example, 1.0 or less or 0.7 or less.

[0034] The hydropathy index is determined according to a known method using a known hydrophobicity index of an amino acid residue. The known hydrophobicity indices of amino acid residues are shown in Table 1. For example, the hydrophobicity may be calculated according to the method described in Kyte J, Doolittle R (1982) "A simple method for displaying the hydropathic character of a protein", J. Mol. Biol., 157, pp. 105-132.

[Table 1]

Amino acid	HI	Amino acid	HI
Isoleucine (Ile)	4.5	Tryptophan (Trp)	-0.9
Valine (Val)	4.2	Tyrosine (Tyr)	-1.3
Leucine (Leu)	3.8	Proline (Pro)	-1.6
Phenylalanine (Phe)	2.8	Histidine (His)	-3.2
Cysteine (Cys)	2.5	Asparagine (Asn)	-3.5
Methionine (Met)	1.9	Asparaginic acid (Asp)	-3.5
Alanine (Ala)	1.8	Glutamine (Gln)	-3.5
Glycine (Gly)	-0.4	Glutamic acid (Glu)	-3.5
Threonine (Thr)	-0.7	Lysine (Lys)	-3.9
Serine (Ser)	-0.8	Arginine (Arg)	-4.5

[0035] The artificial structural protein may contain an $(A)_n$ motif. In the present specification, the $(A)_n$ motif means an amino acid sequence mainly containing an alanine residue. The number of amino acid residues in the $(A)_n$ motif may be 2 to 27 and may be an integer of 2 to 20, 2 to 16, or 2 to 12. A proportion of the number of alanine residues to the number of all amino acid residues in the $(A)_n$ motif may be 40% or more and may also be 60% or more, 70% or more, 80% or more, 83% or more, 85% or more, 86% or more, 90% or more, 95% or more, or 100%. The fact that the proportion of the number of alanine residues to the total number of amino acid residues in the $(A)_n$ motif is 100% means that the $(A)_n$ motif is composed only of alanine residues.

[0036] In the $(A)_n$ motif, the total number of alanine residues, serine residues, threonine residues, and valine residues may be 80% or more, preferably 85% or more, more preferably 90% or more, still more preferably 95% or more, and still more preferably 100% (it is meant to be composed of only one or more amino acid residues selected from an alanine residue, a serine residue, a threonine residue, and a valine residue) with respect to the total number of amino acid residues in the $(A)_n$ motif. A plurality of $(A)_n$ motifs present in the recombinant structural protein according to the present embodiment may be the same amino acid sequence or different amino acid sequences. The $(A)_n$ motif mainly contains alanine residues and tends to have α-helix structure or β-sheet structure. When the $(A)_n$ motif is contained in the repetitive sequence unit, the artificial structural protein according to the present embodiment has these repetitive secondary structures. Therefore, as described below, when the artificial structural protein is in the form of a fiber, the artificial structural protein is expected to exhibit high strength due to these secondary structures.

[0037] The artificial structural protein may be artificial fibroin. The "artificial fibroin" in the present specification means artificially produced fibroin (artificial fibroin). The artificial fibroin may be fibroin having an amino acid sequence different from or identical to an amino acid sequence of naturally derived fibroin.

[0038] Examples of the naturally derived fibroin include fibroin produced by insects or spiders. Natural fibroin is a fibrous protein, has a molecular weight of about 370,000, consists of two subunits, and has high contents of glycine residues, alanine residues, serine residues, and tyrosine residues, and these amino acid residues account for nearly 90% of the total number of amino acid residues. Natural fibroin has a crystalline region rich in amino acid residues having relatively small side chains such as glycine, alanine, and serine, and an amorphous region having amino acid residues having relatively large side chains such as tyrosine.

[0039] More specific examples of the naturally derived fibroin include fibroin having sequence information registered in NCBI GenBank. For example, it can be confirmed by extracting a sequence in which spidroin, ampullate, fibroin, "silk and polypeptide", or "silk and protein" is described as a keyword in DEFINITION from sequences including INV as DIVISION among pieces of sequence information registered in NCBI GenBank, a sequence in which a specific character string of product is described from CDS, or a sequence in which a character string specific to TISSUE TYPE is described from SOURCE.

[0040] Artificial fibroin can be produced by a known method, for example, a method described in WO 2019/194263 A.

[0041] The artificial fibroin may be a fibrous protein having a structure similar to that of naturally derived fibroin, or may be fibroin having a sequence similar to a repetitive sequence of naturally derived fibroin. The "sequence similar to a repetitive sequence of fibroin" may actually be a sequence of naturally derived fibroin, or may be a sequence similar thereto.

[0042] The artificial fibroin may be fibroin whose amino acid sequence is modified based on naturally derived fibroin (for example, fibroin whose amino acid sequence is modified by altering a cloned gene sequence of naturally derived fibroin) or fibroin obtained by artificially designing an amino acid sequence independently of naturally derived fibroin (for example, fibroin having a desired amino acid sequence by chemically synthesizing a nucleic acid encoding the designed amino acid

sequence), as long as it has the amino acid sequence specified in the present disclosure. Fibroin obtained by modifying an amino acid sequence of artificial fibroin is also included in artificial fibroin as long as the amino acid sequence thereof is different from the amino acid sequence of naturally derived fibroin.

[0043] Examples of the artificial fibroin include artificial silk fibroin (fibroin obtained by modifying an amino acid sequence of a silk protein produced by silkworms) and artificial spider silk fibroin (fibroin obtained by modifying an amino acid sequence of a spider silk protein produced by spiders). The artificial fibroin preferably contains artificial spider silk fibroin, and more preferably consists of artificial spider silk fibroin because it is relatively easily fibrillated and has a high fiber forming ability.

[0044] The artificial fibroin may be a protein having a domain sequence represented by Formula 1: $[(A)_n \text{ motif-REP}]_m$ or Formula 2: $[(A)_n \text{ motif-REP}]_m$- $(A)_n$ motif. An amino acid sequence (N-terminal sequence or C-terminal sequence) may be further added to any one or both of the N-terminal side and the C-terminal side of the domain sequence of the artificial fibroin. The N-terminal sequence and the **C-**terminal sequence are typically regions not containing repeats of amino acid motifs that are characteristic of fibroin and each consist of about 100 residues of amino acids, but are not limited thereto.

[0045] In the present specification, the "domain sequence" means an amino acid sequence represented by Formula 1: $[(A)_n \text{ motif-REP}]_m$ or Formula 2: $[(A)_n \text{ motif-REP}]_m$- $(A)_n$ motif. Here, the $(A)_n$ motif represents an amino acid sequence mainly consisting of alanine residues, and the number of amino acid residues is 2 to 27. The number of amino acid residues in the $(A)_n$ motif may be an integer of 2 to 20, 4 to 27, 4 to 20, 8 to 20, 10 to 20, 4 to 16, 8 to 16, or 10 to 16. A proportion of the number of alanine residues to the total number of amino acid residues in the $(A)_n$ motif only needs to be 40% or more, and may be 60% or more, 70% or more, 80% or more, 83% or more, 85% or more, 86% or more, 90% or more, 95% or more, or 100% (which means that the $(A)_n$ motif consists only of alanine residues). At least seven of a plurality of $(A)_n$ motifs in the domain sequence may consist only of alanine residues. The "REP" is an amino acid sequence consisting of 2 to 200 amino acid residues. The "REP" may also be an amino acid sequence consisting of 10 to 200 amino acid residues. The symbol "m" represents an integer from 2 to 300 and may be an integer from 10 to 300. The plurality of $(A)_n$ motifs may be identical or different amino acid sequences. The plurality of REPs may be the same amino acid sequence or different amino acid sequences.

[0046] Specific examples of the artificial fibroin include artificial fibroin derived from a major dragline silk protein produced in a major ampullate gland of a spider (first artificial fibroin), artificial fibroin containing a domain sequence in which the content of glycine residues is reduced (second artificial fibroin), artificial fibroin containing a domain sequence in which the content of an $(A)_n$ motif is reduced (third artificial fibroin), artificial fibroin in which the content of glycine residues and the content of an $(A)_n$ motif are reduced (fourth artificial fibroin), artificial fibroin containing a domain sequence including a region locally having a high hydrophobicity index (fifth artificial fibroin), and artificial fibroin containing a domain sequence in which the content of glutamine residues is reduced (sixth artificial fibroin) as described in WO 2021/187502 A. The definition of each of the first to sixth artificial fibroins is incorporated herein by reference with the content described in WO 2021/187502 A.

[0047] The artificial fibroin may have a tag sequence at one or both of the N-terminal and the C-terminal thereof. This makes it possible to isolate, immobilize, detect, and visualize the artificial fibroin. PRT966 is a sixth artificial fibroin having a tag sequence.

[0048] The tag sequence may be, for example, an affinity tag utilizing specific affinity (binding property, affinity) with another molecule. A specific example of the affinity tag includes a histidine tag (His-tag). The His-tag is a short peptide in which about 4 to 10 histidine residues are lined up and can be used for isolating artificial fibroin by chelating metal chromatography, since it has a property of specifically binding to metal ions such as nickel. Specific examples of the tag sequence include an amino acid sequence set forth in SEQ ID NO: 8 (an amino acid sequence including a His-tag sequence and a hinge sequence).

[0049] Also, a tag sequence such as glutathione-S-transferase (GST) that specifically binds to glutathione, and a maltose binding protein (MBP) that specifically binds to maltose can also be utilized.

[0050] Further, an "epitope tag" utilizing an antigen-antibody reaction can also be utilized. Adding a peptide (epitope) exhibiting antigenicity as a tag sequence allows binding of an antibody to the epitope. Examples of the epitope tag include an HA (a peptide sequence of influenza virus hemagglutinin) tag, a myc tag, and a FLAG tag. The use of the epitope tag allows purification of the artificial fibroin to be easily performed with high specificity.

[0051] Furthermore, it is possible to use a tag sequence which is cleaved with a specific protease. By treating a protein adsorbed via the tag sequence with a protease, the artificial fibroin from which the tag sequence is cleaved can be recovered.

[0052] Specific examples of the artificial fibroin include artificial fibroins set forth in SEQ ID NOs: 1 to 7. The artificial fibroin may be artificial fibroins set forth in SEQ ID NOs: 1 to 7 or artificial fibroin containing an amino acid sequence having 90% or more of sequence identity to an amino acid sequence thereof. Contents of alanine residues, glycine residues, serine residues, threonine residues, proline residues, and tyrosine residues of the artificial fibroins set forth in SEQ ID NOs: 1 to 7 are shown in Table 2 below.

[Table 2]

	Alanine residue content (%)	Glycine residue content (%)	Serine residue content (%)	Threonine residue content (%)	Tyrosine residue content (%)	Glutamine residue content (%)	Lysine residue content (%)
PRT799 (SEQ ID NO: 1)	19.8	31.0	9.3	0	7.0	17.3	0.1
PRT966 (SEQ ID NO: 2)	19.7	31.2	9.4	0	7.1	0	0
PRT918 (SEQ ID NO: 3)	19.5	30.9	9.7	0	7.0	0	0
PRT313 (SEQ ID NO: 4)	25.7	36.0	8.9	0	6.4	8.2	0
PRT1000 (SEQ ID NO: 5)	19.4	30.8	9.6	0	7.0	0	0
PRT1001 (SEQ ID NO: 6)	19.3	30.7	9.6	0	6.9	0	0
PRT587 (SEQ ID NO: 7)	19.7	31.1	9.4	0	7.1	17.3	0

[0053] The artificial fibroin may be artificial fibroin having at least two characteristics among the characteristics of the first artificial fibroin, the second artificial fibroin, the third artificial fibroin, the fourth artificial fibroin, the fifth artificial fibroin, and the sixth artificial fibroin.

[0054] A molecular weight of the artificial fibroin according to the present embodiment is not particularly limited, and may be, for example, 2 kDa or more and 700 kDa or less. The molecular weight of the artificial fibroin may be, for example, 2 kDa or more, 3 kDa or more, 4 kDa or more, 5 kDa or more, 6 kDa or more, 7 kDa or more, 8 kDa or more, 9 kDa or more, 10 kDa or more, 20 kDa or more, 30 kDa or more, 40 kDa or more, 50 kDa or more, 60 kDa or more, 70 kDa or more, 80 kDa or more, 90 kDa or more, or 100 kDa or more, and may be 700 kDa or less, 600 kDa or less, 500 kDa or less, 400 kDa or less, less than 360 kDa, 300 kDa or less, or 200 kDa or less.

(Content of artificial protein)

[0055] The content of the artificial protein may be 30 mass% or more, 40 mass% or more, or 50 mass% or more, 60 mass% or more, 70 mass% or more, or 80 mass% or more, and 100 mass% or less, 95 mass% or less, or 90 mass% or less, based on the total mass of the first fiber. As the content of the protein increases, a shrinkage rate of the first fiber when being brought into contact with water tends to increase. The range of the content of the artificial protein obtained by combining the upper limit value and the lower limit value includes any range determined by arbitrarily selecting each of the upper limit value and the lower limit value (for example, 30 to 100 mass%, 40 to 95 mass%, and the like)

(Shrinkage rate when being brought into contact with water)

[0056] The first fiber is a fiber shrinkable when being brought into contact with water. The shrinkage rate of the first fiber when being brought into contact with water may be, for example, 10% or more, 15% or more, 20% or more, 25% or more, 30% or more, 35% or more, 40% or more, 45% or more, or 50% or more. The shrinkage rate of the first fiber when being brought into contact with water may be, for example, 80% or less, 75% or less, 70% or less, 65% or less, 60% or less, or 55% or less. As the shrinkage rate of the first fiber with water is higher, the loftiness of the blended yarn is improved, such that the softness, heat retaining property, pilling property, water absorbency, anti-pilling property and the like of the lofty blended yarn are improved. The range of the shrinkage rate of the first fiber when being brought into contact with water obtained by combining the upper limit value and the lower limit value includes any range determined by arbitrarily selecting each of the upper limit value and the lower limit value (for example, 10 to 80%, 15 to 80%, 20 to 75%, and the like).

[0057] The "shrinkage rate when being brought into contact with water" in the present specification can be measured by the following method. First, a plurality of fibers having the same length are bundled to obtain a fiber bundle, 0.8 **g** of a lead weight is attached to the fiber bundle, and the fiber bundle is immersed in water at 95°C for 10 minutes. Thereafter, the fiber bundle is taken out of water, the taken out fiber bundle is dried at room temperature for 2 hours with the 0.8 g lead weight still attached, and the length of the fiber bundle is measured after drying. Next, the "shrinkage rate (%) when being brought into contact with water" of the fiber is calculated according to the following Formula I. In Formula I, L0 represents the length of the fiber bundle before the fiber bundle is brought into contact with water, and Ld represents the length of the fiber bundle in a dry state after shrinking when being brought into contact with water.

$$\text{Formula I: Shrinkage rate} = \{1-(Ld/L0)\} \times 100\ (\%)$$

[0058] The "shrinkage rate when being brought into contact with water" in the present specification can be adjusted by controlling the amino acid sequence of the artificial protein and the production conditions of the fiber (for example, when a stretching treatment is performed in the production of fibers, stretching conditions and the like are used).

(Number of crimps)

[0059] The number of crimps of the first fiber may be, for example, 5 or more, 7 or more, 9 or more, 11 or more, 13 or more, 15 or more, or 16 or more. The number of crimps of the first fiber may be, for example, 20 or less, 19 or less, 18 or less, or 17 or less. As the first crimp number is higher, the loftiness of the blended yarn tends to be improved, and the softness, heat retaining property, pilling property, water absorbency, anti-pilling property, and the like of the lofty blended yarn tend to be enhanced. The range of the number of crimps of the first fiber obtained by combining the upper limit value and the lower limit value includes any range determined by arbitrarily selecting each of the upper limit value and the lower limit value (for example, 5 to 20 pieces, 7 to 18 pieces, and the like).

[0060] The number of crimps can be measured in accordance with JIS L 1015 method.

[0061] The crimp of the first fiber is mainly formed by shrinkage of the blended yarn described below when being brought into contact with water. Therefore, the number of crimps of the first fiber can also be adjusted by controlling the amino acid sequence of the artificial protein and the production conditions of the fiber (for example, when a stretching treatment is performed in the production of fibers, stretching conditions and the like are used), similarly to the "shrinkage rate when being brought into contact with water" of the first fiber.

(Average length of first fiber)

[0062] An average length of the first fiber may be, for example, 48 mm or more, 50 mm or more, 60 mm or more, 70 mm or more, 80 mm or more, 90 mm or more, 100 mm or more, 110 mm or more, 120 mm or more, 130 mm or more, 140 mm or more, or 150 mm or more, and may be 170 mm or less or 160 mm or less. As the first average length is higher, the loftiness of the blended yarn tends to be improved, and the softness, heat retaining property, pilling property, water absorbency, anti-pilling property, and the like of the lofty blended yarn tend to be enhanced. The range of the average length of the first fiber obtained by combining the upper limit value and the lower limit value includes any range determined by arbitrarily selecting each of the upper limit value and the lower limit value (for example, 48 to 170 mm, 70 to 160 mm, and the like).

[0063] The "average length of the fiber" in the present specification means a length of a short fiber randomly extracted from the lofty blended yarn. Specifically, the "average length of the fiber" is measured in accordance with JIS L 1015C method.

(Fineness of first fiber)

[0064] A fineness of the first fiber may be, for example, 0.5 denier or more, 0.7 denier or more, 1.0 denier or more, 1.5 denier or more, or 2.0 denier or more. In addition, the fineness of the first fiber may be, for example, 5 denier or less, 4.5 denier or less, 4.0 denier or less, or 3.5 denier or less. For example, it is possible to realize a fiber having excellent mechanical strength even with low fineness and a fiber having excellent flexibility even with high fineness by controlling the molecular design of the artificial protein contained in the first fiber. The range of the fineness of the first fiber obtained by combining the upper limit value and the lower limit value includes any range determined by arbitrarily selecting each of the upper limit value and the lower limit value (for example, 1.0 to 3.5 denier and the like).

(Content of first fiber)

[0065] The content of the first fiber may be, for example, 5 mass% or more, 10 mass% or more, 15 mass% or more, 20 mass% or more, 25 mass% or more, 30 mass% or more, 35 mass% or more, 40 mass% or more, 45 mass% or more, 50 mass% or more, 55 mass% or more, 60 mass% or more, 65 mass% or more, 70 mass% or more, 75 mass% or more, or 80 mass% or more, and 90 mass% or less or 85 mass% or less, based on the total mass of the lofty blended yarn. When the content of the first fiber is too low, the loftiness of the lofty blended yarn may be lowered. The range of the content of the first fiber obtained by combining the upper limit value and the lower limit value includes any range determined by arbitrarily selecting each of the upper limit value and the lower limit value (for example, 5 to 90%, 10 to 85%, and the like). In addition, the content of the first fiber can be appropriately determined according to a difference between a shrinkage rate of the first fiber when being brought into contact with water and a shrinkage rate of the second fiber when being brought into contact with water, and the like, or according to desired characteristics of the lofty blended yarn to be realized by a combination of the characteristics of the first fiber and the characteristics of the second fiber, and the like.

(Method for producing first fiber)

[0066] The first fiber can be produced by a normal spinning method. The first fiber can be produced by a method including a step of obtaining a dope solution containing an artificial protein, and a step of performing spinning using the dope solution to obtain a first fiber containing an artificial protein.

[0067] The dope solution can be obtained by dissolving an artificial protein in a solvent. Examples of the solvent include dimethyl sulfoxide (DMSO), N,N-dimethylformamide (DMF), and hexafluoroisopropanol (HFIP). In order to dissolve the artificial protein, a dissolution accelerator may be used, if necessary. Examples of the dissolution accelerator include an inorganic salt.

[0068] Examples of the spinning method include wet spinning, dry spinning, dry-wet spinning, and melt spinning. Preferred examples of the spinning method include wet spinning and dry-wet spinning.

[0069] Fig. 1 is an explanation diagram schematically illustrating an example of a spinning apparatus for producing a first fiber. A spinning apparatus 10 illustrated in Fig. 1 is an example of a spinning apparatus for dry-wet spinning and includes an extruder 1, an undrawn yarn-producing device 2, a wet heat drawing device 3, and a drying device 4.

[0070] A spinning method using the spinning apparatus 10 will be described. First, a dope solution 6 stored in a reservoir 7 is extruded from a spinneret 9 by a gear pump 8. On a laboratory scale, a cylinder may be filled with the dope solution, and the dope solution may be extruded from a nozzle using a syringe pump. Next, the extruded dope solution 6 is fed into a coagulation liquid 11 in a coagulation liquid tank 20 through an air gap 19, a solvent is removed, and the artificial protein is coagulated, thereby forming a fibrous coagulated body. Next, the fibrous coagulated body is fed into hot water 12 in a drawing bath 21 and drawn. A draw ratio is determined by a speed ratio between a feed nip roller 13 and a take-up nip roller 14. Thereafter, the drawn fibrous coagulated body is fed to the drying device 4 and dried in a yarn path 22, and an artificial protein fiber 36 is obtained as a yarn package 5. Reference numerals 18a to 18g represent yarn guides.

[0071] The coagulation liquid 11 may be any solvent that can be desolvated, and examples thereof include a lower alcohol having 1 to 5 carbon atoms such as methanol, ethanol, or 2-propanol, and acetone. The coagulation liquid 11 may suitably contain water. The coagulation liquid 11 preferably has a temperature of 0°C to 30°C. In a case where a syringe pump having a nozzle with a diameter of 0.1 to 0.6 mm is used as the spinneret 9, an extrusion speed is preferably 0.2 to 6.0 ml/hour and more preferably 1.4 to 4.0 ml/hour per hole. A distance that the coagulated protein passes in the coagulation liquid 11 (substantially a distance from the yarn guide 18a to the yarn guide 18b) may be any length that allows desolvation to be efficiently performed, and is, for example, 200 to 500 mm. A take-up speed of the undrawn yarn may be, for example, 1 to 20 m/min and is preferably 1 to 3 m/min. A residence time in the coagulation liquid 11 may be, for example, 0.01 to 3 minutes and is preferably 0.05 to 0.15 minutes. Furthermore, the drawing (pre-drawing) may be performed in the coagulation liquid 11. The coagulation liquid tank 20 may be provided with multiple stages, and the drawing may be performed in each stage or in a specific stage, if necessary.

[0072] In addition to pre-drawing in the coagulation liquid tank 20 and wet heat drawing in the drawing bath 21, for example, dry heat drawing is also employed to obtain a first fiber.

[0073] The wet heat drawing is performed in hot water, in a solution obtained by adding an organic solvent or the like to hot water, or with heated steam. The temperature may be, for example, 50 to 90°C and preferably 75 to 85°C. In the wet heat drawing, the undrawn yarn (or pre-drawn yarn) is drawn to, for example, 1 to 10 times and preferably 2 to 8 times its original size.

[0074] The dry heat drawing is performed using, for example, an electric tubular furnace or a dry heat plate. The temperature may be, for example, 140°C to 270°C and is preferably 160°C to 230°C. In the dry heat drawing, the undrawn yarn (or pre-drawn yarn) is drawn to, for example, 0.5 to 8 times and preferably 1 to 4 times its original size.

[0075] The wet heat drawing and the dry heat drawing may be performed independently, or performed through multiple stages, or in combination. In other words, the wet heat drawing and the dry heat drawing may be appropriately combined: for example, the wet heat drawing is performed in the first stage and the dry heat drawing in the second stage, or the wet heat drawing is performed in the first and second stages and the dry wet drawing in the third stage.

[0076] A lower limit of the final draw ratio is preferably more than 1 time, 2 times or more, 3 times or more, 4 times or more, 5 times or more, 6 times or more, 7 times or more, 8 times or more, or 9 times or more with respect to an unstretched yarn (or pre-stretched yarn), and an upper limit thereof is preferably 40 times or less, 30 times or less, 20 times or less, 15 times or less, 14 times or less, 13 times, 12 times or less, 11 times or less, or 10 times or less with respect to the unstretched yarn (or the pre-stretched yarn). When the first fiber is a fiber spun at a draw ratio of 2 times or more, the shrinkage rate of the first fiber when being brought into contact with water tends to be higher.

<Second fiber>

[0077] The second fiber is a fiber having a shrinkage rate lower than that of the first fiber when being brought into contact with water. The second fiber may contain, for example, at least one selected from the group consisting of synthetic fibers (including chemical fibers and semisynthetic fibers), natural fibers, regenerated fibers, and artificial protein fibers.

Examples of the second fiber include animal hair fibers such as wool, cashmere, mohair, angora, and alpaca, natural cellulose fibers such as silk (including regenerated silk), cotton, and hemp, regenerated cellulose fibers such as lyocell and rayon, artificial protein fibers, and synthetic fibers such as nylon fibers, polyester fibers, and acrylic fibers. As the synthetic fibers, the natural fibers, the regenerated fibers, and the artificial protein fibers, fibers having a shrinkage rate lower than that of the first fiber when being brought into contact with water are selected. When the second fiber is an artificial protein fiber, an artificial protein fiber containing an artificial protein of the same type as the artificial protein contained in the first fiber but having a shrinkage rate lower than that of the first fiber when being brought into contact with water is selected as the second fiber, and an artificial protein fiber containing an artificial protein of a type different from the artificial protein contained in the first fiber is selected.

(Shrinkage rate when being brought into contact with water)

[0078] The shrinkage rate of the second fiber when being brought into contact with water may be, for example, 0% or more, 5% or more, 10% or more, 15% or more, 20% or more, 25% or more, or 30% or more. The shrinkage rate of the second fiber when being brought into contact with water may be, for example, 45% or less or 40% or less. The second fiber may be a fiber that does not shrink at all when being brought into contact with water. The range of the shrinkage rate of the second fiber when being brought into contact with water obtained by combining the upper limit value and the lower limit value includes any range determined by arbitrarily selecting each of the upper limit value and the lower limit value (for example, 0 to 45%, 5 to 40%, and the like).

[0079] A difference (X1-X2) between a shrinkage rate X1 of the first fiber when being brought into contact with water and a shrinkage rate X2 of the second fiber when being brought into contact with water may be, for example, 5% or more, 10% or more, 15% or more, 20% or more, 25% or more, 30% or more, 35% or more, or 40% or more, and may be 50% or less or 45% or less. As the difference (X1-X2) between the shrinkage rate X1 and the shrinkage rate X2 is higher, the loftiness of the blended yarn tends to be improved, and the softness, heat retaining property, pilling property, water absorbency, anti-pilling property, and the like of the lofty blended yarn tend to be enhanced. The range of the difference (X1-X2) between the shrinkage rate X1 and the shrinkage rate X2 obtained by combining the upper limit value and the lower limit value includes any range determined by arbitrarily selecting each of the upper limit value and the lower limit value (for example, 5 to 50%, 10 to 45%, and the like).

(Number of crimps)

[0080] The number of crimps of the second fiber may be, for example, 5 or more, 7 or more, 9 or more, 11 or more, 13 or more, 15 or more, 17 or more, 19 or more, or 20 or more. The number of crimps of the second fiber may be, for example, 25 or less, 23 or less, or 21 or less. The range of the number of crimps of the second fiber obtained by combining the upper limit value and the lower limit value includes any range determined by arbitrarily selecting each of the upper limit value and the lower limit value (for example, 5 to 25 pieces, 7 to 23 pieces, and the like).

(Average length of second fiber)

[0081] An average length of the second fiber may be, for example, 48 mm or more, 50 mm or more, 60 mm or more, 70 mm or more, 80 mm or more, 90 mm or more, 100 mm or more, 110 mm or more, 120 mm or more, 130 mm or more, 140 mm or more, 150 mm or more, or 160 mm or more, and may be 200 mm or less, 190 mm or less, 180 mm or less, or 170 mm or less. The range of the average length of the second fiber obtained by combining the upper limit value and the lower limit value includes any range determined by arbitrarily selecting each of the upper limit value and the lower limit value (for example, 48 to 200 mm, 60 to 190 mm, and the like).

(Content of second fiber)

[0082] The content of the second fiber may be 10 mass% or more, 20 mass% or more, 30 mass% or more, 40 mass% or more, or 50 mass% or more, and may be 95 mass% or less, 90 mass% or less, 80 mass% or less, 70 mass% or less, or 60 mass% or less, based on the total mass of the lofty blended yarn. The range of the content of the second fiber obtained by combining the upper limit value and the lower limit value includes any range determined by arbitrarily selecting each of the upper limit value and the lower limit value (for example, 5 to 50%, 10 to 45%, and the like).

(Method for obtaining second fiber)

[0083] As the second fiber, a commercially available product can be used as it is, or the second fiber may be produced using a known general method, or may be produced by spinning using the same method as the first fiber.

<Application>

[0084] The lofty blended yarn can be used for, for example, clothing fabrics, bedding, and the like.

[Method for producing lofty blended yarn]

[0085] A method for producing a lofty blended yarn according to the present embodiment includes a step of obtaining a raw material blended yarn by blending a first sliver containing a first fiber that contains an artificial protein and is shrinkable when being brought into contact with water, and a second sliver containing a second fiber that has a shrinkage rate lower than a shrinkage rate of the first fiber when being brought into contact with water (blending step); and a step of bringing the raw material blended yarn into contact with an aqueous medium and shrinking at least the first fiber to obtain a lofty blended yarn (shrinking step). This method can suitably produce the lofty blended yarn described above. The details of the artificial protein, the first fiber, and the second fiber may be as described above. According to the production method, a lofty blended yarn having the loftiness described above can be produced. As a spinning method used when obtaining the raw material blended yarn, for example, known spinning methods such as worsted spinning (including 2-inch spinning), woolen spinning, cotton spinning, and silk spinning can be adopted. From the viewpoint of obtaining a lofty blended yarn having higher loftiness, among these spinning methods, for example, worsted spinning can be advantageously adopted. The reason why a lofty blended yarn having higher loftiness can be obtained by using a raw material spun yarn obtained by worsted spinning is considered as follows. Since the number of twists of the blended yarn obtained by the worsted spinning is smaller than that of the blended yarn obtained by other spinning methods, the entire blended yarn becomes soft. This is considered that the lofting effect obtained by the first water shrinking. Furthermore, in the worsted spinning, since the fiber length of the staple to be used is larger than the fiber length of the staple to be used in the woolen spinning or the cotton spinning (in the worsted spinning, for example, fibers having a length of 50 to 170 mm are used), the force required for drafting when aligning the sliver increases. Therefore, in the worsted spinning, a larger residual stress is generated in the first fiber, and the shrinkage rate when being brought into contact with water increases. As a result, it is considered that higher loftiness can be obtained in the lofty blended yarn. In addition, in the worsted spinning, a step of combing the slivers into a comb-like body is performed when aligning the sliver, and at this time, a large resistance is applied to the fiber. This also results in a larger residual stress in the first fiber, and thus it is estimated that higher loftiness can be obtained in the finally obtained lofty blended yarn.

[0086] As the first sliver, a sliver prepared in advance (already produced) may be used, or a sliver obtained in the step of producing a sliver using a tow containing the first fiber (first sliver obtaining step) may be used. In addition, as the second sliver, a sliver prepared in advance (already produced) may be used, or a sliver obtained in the step of producing a sliver using the second fiber by a known method (second sliver obtaining step) may be used.

[0087] In the first sliver obtaining step, for example, the tow of the first fiber is supplied between two sets of front and rear rollers, a surface speed of the subsequent roller is set to be larger than a surface speed of the preceding roller, and the tow is draft-cut (stretch cut), that is, the tow is tensioned, such that the first sliver can be obtained using a normal method.

[0088] In the first sliver obtaining step, the first sliver can be obtained in a state where the first fiber is unshrunk and uncrimped by adopting the method of draft cutting the tow containing the first fiber. This makes it easier to obtain a lofty blended yarn having a loftiness within the range described above. In addition, when the tow is draft cut, the residual stress is further increased by pulling the first fiber. Therefore, it is considered that a water shrinkage rate (shrinkage rate when brought into contact with water) of the first fiber is further increased. Accordingly, a lofty blended yarn having more sufficient loftiness is expected to be obtained.

[0089] In the blending step, the first sliver and the second sliver are blended to obtain a raw material blended yarn. The second sliver contains a second fiber. As the second sliver, a commercially available product can be used as it is, or a second fiber having a shrinkage rate lower than that of the first fiber when being brought into contact with water may be used. As a method for obtaining the second sliver using the second fiber, any known method can be adopted.

[0090] The method of blending the first sliver and the second sliver can be performed using a normal method of blending the slivers. The blending can be performed by a method including a step of forming a roving yarn from the first sliver and the second sliver, and a step of applying twists to the roving yarn while applying a draft, for the purpose of, for example, increasing the parallelism of the fibers and uniformly mixing the fibers. The drafting in the twisting step also further increases the residual stress of the first fiber, and the water shrinkage rate is further improved. As a result, a lofty blended yarn having more sufficient loftiness is expected to be obtained.

[0091] By adopting the blending step described above, the stretching, heat retaining property, water absorbency, and anti-pilling property tend to be improved in addition to the loftiness.

[0092] In the shrinking step, the raw material blended yarn is brought into contact with an aqueous medium to shrink at least the first fiber to obtain a lofty blended yarn.

[0093] The aqueous medium is a liquid or gas (steam) medium containing water (including water vapor). The aqueous medium may be water or a liquid mixture of water and a hydrophilic medium. As the hydrophilic medium, for example, a

volatile solvent such as ethanol or methanol or a vapor thereof can be used. The aqueous medium may be a liquid mixture of water and a volatile solvent such as ethanol and methanol, and is preferably water or a liquid mixture of water and ethanol. A ratio between water and the volatile solvent or a vapor thereof is not particularly limited, and for example, a mass ratio of water : volatile solvent or vapor thereof may be 10 : 90 to 90 : 10. A proportion of water is preferably 30 mass% or higher and may be 40 mass% or 50 mass% or higher.

[0094] The aqueous medium is preferably a liquid or a gas which is at a temperature of 10°C to 230°C and contains water (including water vapor). A temperature of the aqueous medium may be 10°C or higher, 25°C or higher, 40°C or higher, 60°C or higher, or 100°C or higher, and may be 230°C or lower, 120°C or lower, 100°C or lower, or 90°C or lower. More specifically, in a case where the aqueous medium is a gas (steam), the temperature of the aqueous medium is preferably 100°C to 230°C and more preferably 100°C to 120°C.

[0095] Examples of the method of bringing the raw material blended yarn into contact with the aqueous medium include a method of spraying an aqueous medium onto a raw material blended yarn, a method of immersing a raw material blended yarn in an aqueous medium, and a method of exposing a raw material blended yarn to an environment filled with steam of an aqueous medium.

[0096] A contact time with the aqueous medium is appropriately adjusted according to the type of the raw material blended yarn, the temperature of the aqueous medium, the method of contacting with the aqueous medium, and the like. The contact time with the aqueous medium may be, for example, 1 minute or longer, 5 minutes or longer, 10 minutes or longer, or 15 minutes or longer, and may be 30 minutes or shorter, 20 minutes or shorter, or 15 minutes or shorter. The contact with the aqueous medium may be performed under normal pressure or under reduced pressure (for example, in vacuum).

[0097] The raw material blended yarn brought into contact with the aqueous medium may be washed, if necessary. Washing can be performed using, for example, the aqueous medium described above. A temperature of the aqueous medium at the time of washing may be, for example, 10°C or higher, 20°C or higher, or 30°C or higher, and may be 50°C or lower, 45°C or lower, or 40°C or lower.

[0098] The raw material blended yarn brought into contact with the aqueous medium may be dried. A drying method is not particularly limited, and the drying may be natural drying or drying by hot wind or a hot roller. A drying temperature is not particularly limited, and may be, for example, 20°C to 150°C. The drying temperature is preferably 40°C to 120°C and more preferably 60°C to 100°C. A drying time may be, for example, 5 minutes or longer, or 10 minutes or longer, and may be 30 minutes or shorter or 20 minutes or shorter.

[0099] A fabric including the lofty blended yarn according to the present embodiment may be formed of only the lofty blended yarn, or may include other yarns (for example, spun yarn, twisted yarn, and the like). The fabric may be either a knitted fabric or a woven fabric, or a combination thereof. Any known method can be adopted as a method for producing the knitted fabric and the woven fabric constituting the fabric (knitting method and weaving method).

Examples

[0100] Hereinafter, the present invention will be described more specifically based on Examples. Note that the present invention is not limited to the following Examples.

<Production of artificial protein>

(1) Preparation of plasmid expression strain

[0101] An artificial protein (artificial fibroin) having an amino acid sequence set forth in SEQ ID NO: 2 (PRT966) was designed.

[0102] Next, a nucleic acid encoding the designed artificial protein was synthesized. In the nucleic acid, an NdeI site was added to a 5'-terminal, and an EcoRI site was added downstream of the stop codon. The nucleic acid was cloned into a cloning vector (pUC118). Thereafter, the nucleic acid was enzymatically cleaved by treatment with NdeI and EcoRI, and then, recombined into the protein expression vector pET-22b(+), thereby obtaining an expression vector.

(2) Expression of protein

[0103] Escherichia coli BLR (DE3) was transformed with a pET22b(+) expression vector containing a nucleic acid encoding the designed artificial protein. The transformed Escherichia coli was cultured in 2 mL of an LB culture medium containing ampicillin for 15 hours. The culture solution was added to 100 mL of a seed culture medium containing ampicillin (Table 3) so that OD_{600} reached 0.005. The culture solution was maintained at a temperature of 30°C, and placed in a culture flask (for about 15 hours) until OD_{600} reached 5, thereby obtaining a seed culture solution.

[Table 3]

Seed culture medium	
Reagent	Concentration (g/L)
Glucose	5.0
KH_2PO_4	4.0
K_2HPO_4	
Yeast Extract	9.3 6.0
Ampicillin	0.1

[0104] The seed culture solution was added to a jar fermenter to which 500 mL of a production medium (Table 4) was added so that OD_{600} reached 0.05. Culture was performed while maintaining the culture solution at a temperature of 37°C and controlling the pH to be constant at 6.9. Furthermore, the culture solution was maintained to have a 20% dissolved oxygen concentration of the saturated dissolved oxygen concentration.

[Table 4]

Production medium	
Reagent	Concentration (g/L)
Glucose	12.0
KH_2PO_4	9.0
$MgSO_4 \cdot 7H_2O$	2.4
Yeast Extract	15
$FeSO_4 \cdot 7H_2O$	0.04
$MnSO_4 \cdot 5H_2O$	0.04
$CaCl_2 \cdot 2H_2O$	0.04
GD-113 (Antifoaming agent)	0.1 (mL/L)

[0105] Immediately after glucose in the production medium was completely consumed, a feed solution (455 g/1 L of glucose, 120 g/1 L of Yeast Extract) was added to the production medium at a speed of 1 mL/min. Culture was performed while maintaining the culture solution at a temperature of 37°C and controlling the pH to be constant at 6.9. The culture was performed for 20 hours while a dissolved oxygen concentration in the culture solution was maintained at 20% of the saturated dissolved oxygen concentration. Thereafter, 1 M isopropyl-β-thiogalactopyranoside (IPTG) was added to the culture solution so that the final concentration thereof was 1 mM, thus inducing the expression of the artificial protein. When 20 hours had elapsed after the addition of IPTG, the culture solution was centrifuged, and bacterial cells were collected. SDS-PAGE was performed using bacterial cells prepared from the culture solutions before and after the addition of IPTG, and expression of the target artificial protein was confirmed by appearance of a band of the size of the target artificial protein depending on the addition of IPTG.

(3) Purification of protein

[0106] Bacterial cells that were collected 2 hours after the addition of IPTG were washed with a 20 mM Tris-HCl buffer (pH 7.4). The washed bacterial cells were suspended in a 20 mM Tris-HCl buffer (pH 7.4) containing about 1 mM phenylmethylsulfonyl fluoride (PMSF), and the bacterial cells were disrupted using a high-pressure homogenizer (manufactured by GEA Niro Soavi Technologies). The disrupted cells were centrifuged to obtain a precipitate. The obtained precipitate was washed with a 20 mM Tris-HCl buffer (pH 7.4) until the purity was high. The washed precipitate was suspended in an 8 M guanidine buffer (8 M guanidine hydrochloride, 10 mM sodium dihydrogen phosphate, 20 mM NaCl, and 1 mM Tris-HCl, pH 7.0) such that a concentration thereof was 100 mg/mL, and the suspended precipitate was dissolved by performing stirring using a stirrer at 60°C for 30 minutes. After the precipitate was dissolved, the resulting solution was dialyzed with water using a dialysis tube (cellulose tube 36/32 manufactured by Sanko Junyaku Co., Ltd.). A white aggregate protein obtained after the dialysis was collected by centrifugation, and moisture was removed with a lyophilizer so as to collect lyophilized powder containing PRT966 as an artificial protein.

<Production of first fiber (artificial protein fiber)>

(1) Preparation of dope solution

[0107] The lyophilized powder of the artificial protein was added to dimethyl sulfoxide (DMSO) so as to have a concentration of 24 mass%, and then LiCl was added thereto as a dissolution accelerator so as to have a concentration of 4.0 mass%. Thereafter, the lyophilized powder of the artificial protein was dissolved for 3 hours using a shaker to obtain a DMSO solution of the artificial protein. Insolubles and bubbles in the obtained DMSO solution were removed to prepare a dope solution. The dope solution had a solution viscosity of 5,000 cP (centipoise) at 90°C.

(2) Spinning

[0108] Known dry-wet spinning was performed using the dope solution obtained as described above and the spinning apparatus 10 illustrated in Fig. 1 to obtain artificial protein fibers. The obtained artificial protein fiber was wound around a bobbin. Dry-wet spinning was performed under the following conditions.

Temperature of coagulation liquid (methanol): 5 to 10°C
Draw ratio: 4.52 times
Drying temperature: 80°C

<Production of blended yarn>

[0109] The artificial protein fiber was tow cut to produce a first sliver containing the artificial protein fiber. A cut length of the artificial protein fiber cut at this time was about 150 mm to 250 mm. A worsted spinning method was used to produce a blended yarn.

<Example 1>

[0110] A pre-spinning step was performed using a first sliver and a second sliver. The step is a step of forming the first sliver and the second sliver into a roving yarn for post-spinning. The purpose of the step is to increase the parallelism of the fibers, uniformly mix the fibers, and the like. As the second sliver, a wool sliver was used. A commercially available product was used as the wool sliver, and the fiber length was about 75 mm. In the pre-spinning step, for example, 6 to 8 wool and 2 to 4 artificial protein fibers of 10 slivers are aligned at a draft ratio of 2 to 6. This is repeated, for example, five times.

[0111] The post-spinning step was performed using the roving yarn. Specifically, the step is a step of applying twists to the roving yarn while applying draft. In this step, the number of twists was about 300 times/m, and the draft ratio was 25 to 30. As a twisting direction, twisting is applied in a Z direction. When two yarns are used, the number of twists is about 230 times/m, and twists are applied in an S direction.

[0112] A reel of the raw material blended yarn obtained by the above method was prepared (2 m and 40 cm). The reel was set in a reel dyeing machine. Water at 100°C was sprayed into the reel in a reel dyeing machine for 15 to 20 minutes. The obtained reel was washed with water at 30 to 40°C, dehydrated, and then dried with hot air at around 90°C for 15 minutes. Thus, a lofty blended yarn using artificial protein fibers and wool was obtained.

<Content of first fiber>

[0113] A content of the first fiber was 30 mass% based on the total mass of the blended yarn.

<Average length of fiber>

[0114] An average length of the first fiber was 72.4 mm. An average length of the second fiber was 74.2 mm. An average length of the fibers is an average length measured according to JIS L 1015C.

<Shrinkage rate when being brought into contact with water>

[0115] A shrinkage rate of the first fiber when being brought into contact with water was 45%. A shrinkage rate of the second fiber when being brought into contact with water was 10%. The "shrinkage rate when being brought into contact with water" of each of the first fiber and the second fiber was measured in the same manner according to the following method. First, a plurality of fibers having the same length were bundled to obtain a fiber bundle. 0.8 g of a lead weight was attached to the obtained fiber bundle, and the fiber bundle was immersed in water at 95°C for 10 minutes. Thereafter, the

fiber bundle was taken out of water, the taken out fiber bundle was dried at room temperature for 2 hours with the 0.8 g lead weight still attached, and the length of the fiber bundle was measured after drying. Next, the "shrinkage rate (%) when being brought into contact with water" of the fiber was calculated according to the following Formula I. In Formula I, L0 represents the length of the fiber bundle before the fiber bundle is brought into contact with water, and Ld represents the length of the fiber bundle in a dry state after shrinking when being brought into contact with water.

$$\text{Formula I: Shrinkage rate} = \{1-(Ld/L0)\} \times 100\ (\%)$$

<Number of crimps>

[0116] The number of crimps of the first fiber was 8.0. The number of crimps of the second fiber was 11.8. The number of crimps was measured according to JIS L 1015 method.

<Loftiness>

[0117] A loftiness of the blended yarn obtained by the method described above was 36.1 cm^3/g. The loftiness was measured according to JIS L 1095A method.

<Example 2>

[0118] A lofty blended yarn using an artificial protein fiber and silk was obtained in the same manner as in Example 1, except that a silk sliver was used as the second sliver. A worsted spinning method was used to produce a raw material blended yarn.

<Content of first fiber>

[0119] A content of the first fiber was 30 mass% based on the total mass of the blended yarn.

<Average length of fiber>

[0120] An average length of the first fiber was 68.0 mm. An average length of the second fiber was 86.2 mm.

<Shrinkage rate when being brought into contact with water>

[0121] A shrinkage rate of the first fiber when being brought into contact with water was 45%. A shrinkage rate of the second fiber when being brought into contact with water was 10%.

<Number of crimps when being brought into contact with water>

[0122] The number of crimps of the first fiber was 8.0. The number of crimps of the second fiber was 19.1. The average length, the shrinkage rate when being brought into contact with water, and the number of crimps of each of the first and second fibers were measured in the same manner as in Example 1.

<Loftiness>

[0123] A loftiness of the blended yarn obtained by the method described above was 22.0 cm^3/g. The loftiness was measured in the same manner as in Example 1.

Reference Signs List

[0124]

1 Extruder
2 Undrawn yarn-producing device
3 Wet heat drawing device
4 Drying device
6 Dope solution

10 Spinning apparatus
20 Coagulation liquid tank
21 Drawing bath
36 Artificial protein fiber

[Sequence Listing]

Claims

1. A lofty blended yarn comprising:

   a first fiber that contains an artificial protein and is shrinkable when being brought into contact with water; and
   a second fiber that has a shrinkage rate lower than a shrinkage rate of the first fiber when being brought into contact with water,
   wherein the lofty blended yarn has a loftiness of 10 cm^3/g or more.

2. The lofty blended yarn according to claim 1, wherein the loftiness is 50 cm^3/g or less.

3. The lofty blended yarn according to claim 1 or 2, wherein the shrinkage rate of the first fiber when being brought into contact with water is 15% or more.

4. The lofty blended yarn according to claim 1 or 2, wherein the number of crimps of the first fiber is 5 or more.

5. The lofty blended yarn according to claim 1 or 2, wherein a content of the first fiber is 5 mass% or more based on a total mass of the lofty blended yarn.

6. The lofty blended yarn according to claim 1 or 2, wherein an average length of the first fiber is 48 mm or more and 170 mm or less.

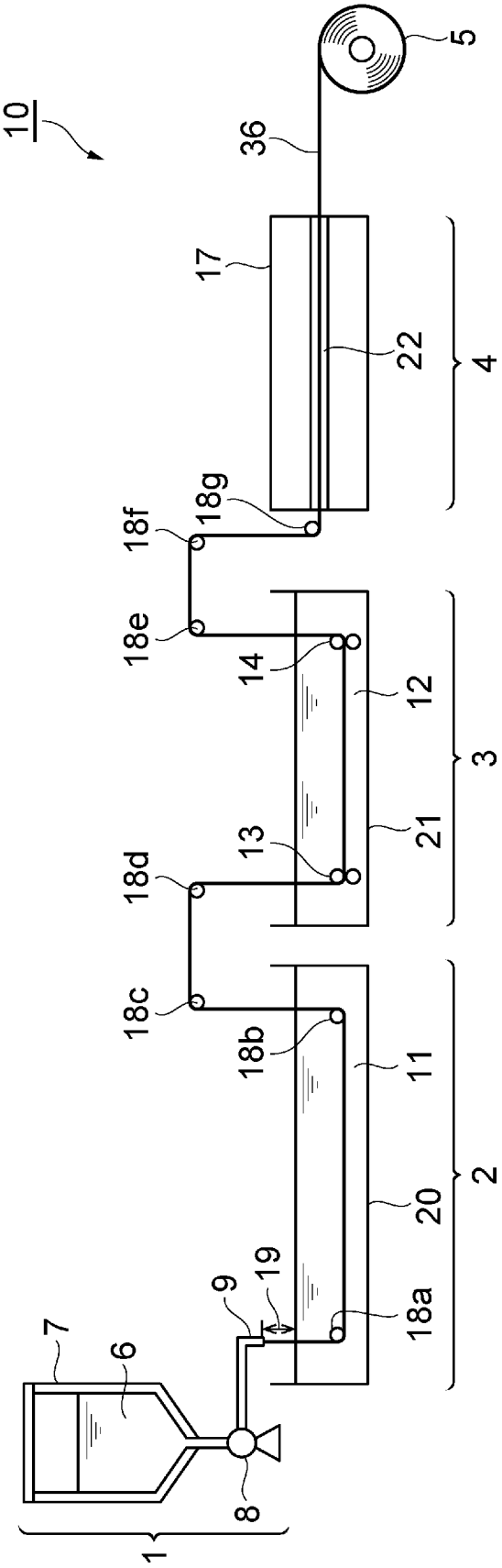
7. The lofty blended yarn according to claim 1 or 2, wherein the second fiber is at least one of an animal hair fiber and silk.

8. A method for producing a lofty blended yarn, the method comprising:

   a step of obtaining a raw material blended yarn by blending a first sliver containing a first fiber that contains an artificial protein and is shrinkable when being brought into contact with water, and a second sliver containing a second fiber that has a shrinkage rate lower than a shrinkage rate of the first fiber when being brought into contact with water; and
   a step of bringing the raw material blended yarn into contact with an aqueous medium and shrinking at least the first fiber to obtain a lofty blended yarn.

9. A fabric comprising the lofty blended yarn according to claim 1 or 2.

FIG. 1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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/038721

A. CLASSIFICATION OF SUBJECT MATTER

D02G 3/04(2006.01)i; ***D01F 4/00***(2006.01)i; ***D02G 3/24***(2006.01)i
FI: D02G3/04; D01F4/00 Z; D02G3/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

D02G1/00-3/48; D01F4/00-4/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2022-24192 A (SPIBER INC.) 09 February 2022 (2022-02-09) claims, paragraphs [0218]-[0221]	1-9
A	WO 2019/194258 A1 (HASETORA SPINNING CO., LTD.) 10 October 2019 (2019-10-10) claims, paragraphs [0219]-[0242]	1-9
A	JP 2018-521239 A (BOLT THREADS, INC.) 02 August 2018 (2018-08-02) claims, paragraphs [0133]-[0144]	1-9
A	JP 2007-321265 A (TORAY IND., INC.) 13 December 2007 (2007-12-13) paragraph [0071]	1-9
A	JP 2-53924 A (TOKYO TEORIKI KK) 22 February 1990 (1990-02-22) claims	1-9
A	JP 2-19527 A (KANEBO LTD.) 23 January 1990 (1990-01-23) claims	1-9

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 December 2023	**16 January 2024**
Name and mailing address of the ISA/JP **Japan Patent Office (ISA/JP)** **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/038721

Box No. I Nucleotide and/or amino acid sequence(s) (Continuation of item 1.c of the first sheet)

1. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, the international search was carried out on the basis of a sequence listing:
   a. ☑ forming part of the international application as filed:
      ☑ in the form of an Annex C/ST.25 text file.
      ☐ on paper or in the form of an image file.
   b. ☐ furnished together with the international application under PCT Rule 13*ter*.1(a) for the purposes of international search only in the form of an Annex C/ST.25 text file.
   c. ☐ furnished subsequent to the international filing date for the purposes of international search only:
      ☐ in the form of an Annex C/ST.25 text file (Rule 13*ter*.1(a)).
      ☐ on paper or in the form of an image file (Rule 13*ter*.1(b) and Administrative Instructions, Section 713).

2. ☐ In addition, in the case that more than one version or copy of a sequence listing has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that forming part of the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

3. Additional comments:

Form PCT/ISA/210 (continuation of first sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/038721

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2022-24192 A	09 February 2022	WO 2020/067546 A1	
WO 2019/194258 A1	10 October 2019	US 2021/0032782 A1 claims, paragraphs [0350]-[0377] EP 3808882 A1 CN 112074631 A	
JP 2018-521239 A	02 August 2018	US 2018/0216260 A1 claims, paragraphs [0136]-[0147] EP 3307765 A1	
JP 2007-321265 A	13 December 2007	(Family: none)	
JP 2-53924 A	22 February 1990	(Family: none)	
JP 2-19527 A	23 January 1990	KR 10-1991-0001113 A CN 1039271 A	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2003328241 A **[0003]**
- JP 2014101601 A **[0003]**
- WO 2019194263 A **[0040]**
- WO 2021187502 A **[0046]**

Non-patent literature cited in the description

- **KYTE J** ; **DOOLITTLE R**. A simple method for displaying the hydropathic character of a protein. *J. Mol. Biol.*, 1982, vol. 157, 105-132 **[0034]**