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(54) **ACRYLIC FIBER AND METHOD FOR
MANUFACTURING SAME**

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ABSTRACT

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An acrylic fiber is composed of an acrylic polymer. The acrylic polymer includes acrylonitrile, wherein the acrylic fiber has a deformation degree of 0.13 or less and a surface roughness of 6000 μm^2 or less. A method for producing an acrylic fiber by wet spinning or dry-wet spinning includes: dissolving an acrylic polymer in an organic solvent to form a spinning solution, the acrylic polymer including acrylonitrile; discharging the spinning solution into a coagulation bath to form an acrylic fiber; water washing the acrylic fiber; and drying the acrylic fiber, wherein, before drying the acrylic fiber, the acrylic fiber is pressed with a nip roll and subjected to pre-drying using a dryer into which steam is fed.



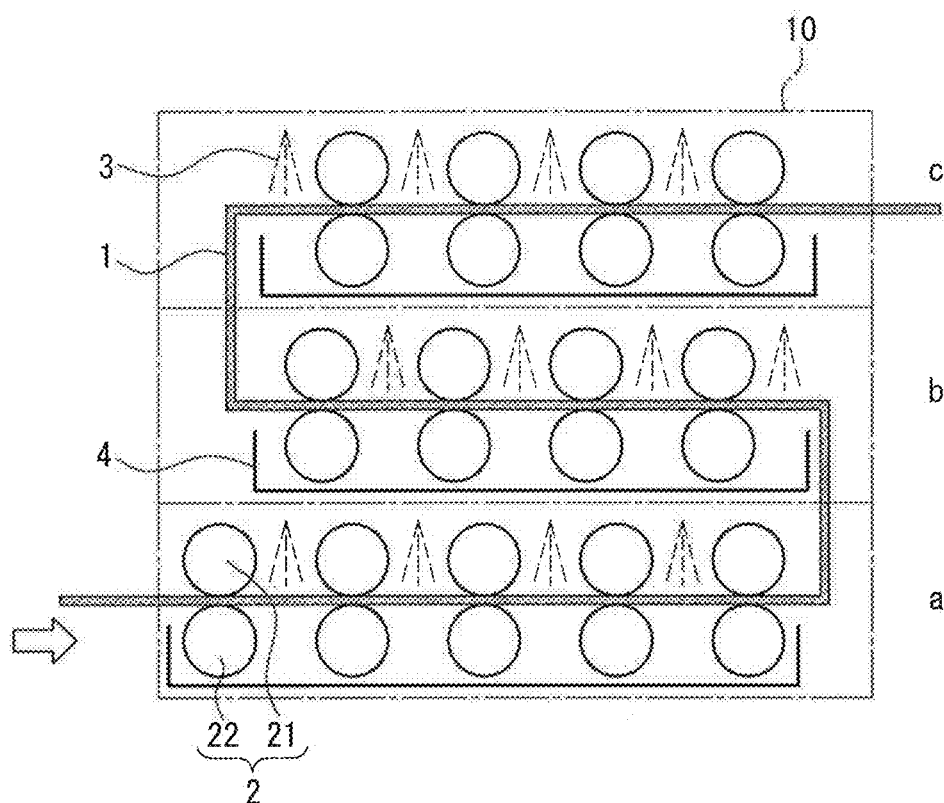


FIG. 1

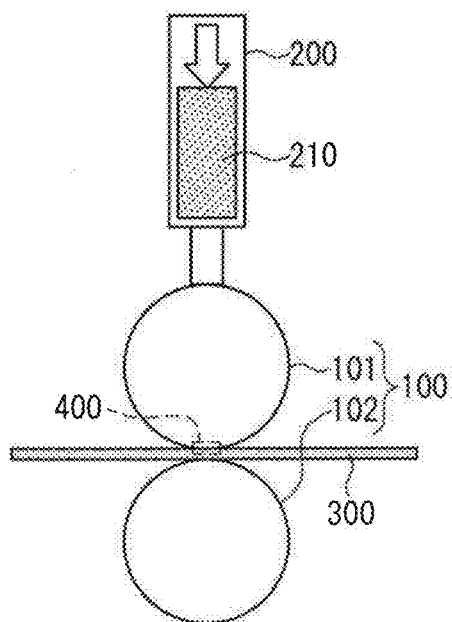


FIG. 2A

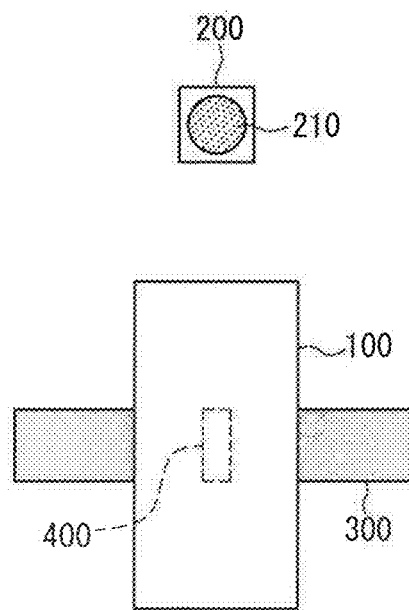


FIG. 2B

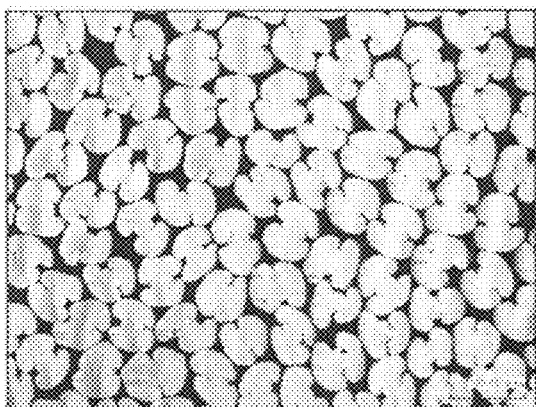


FIG. 3A

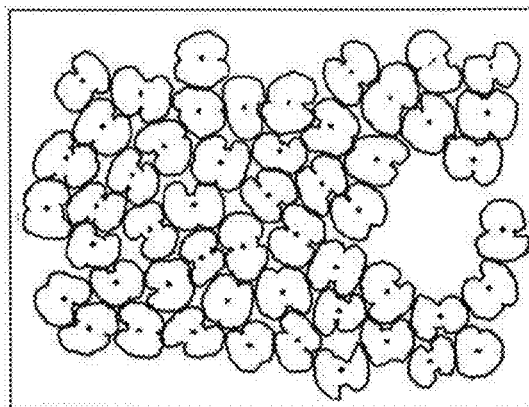


FIG. 3B

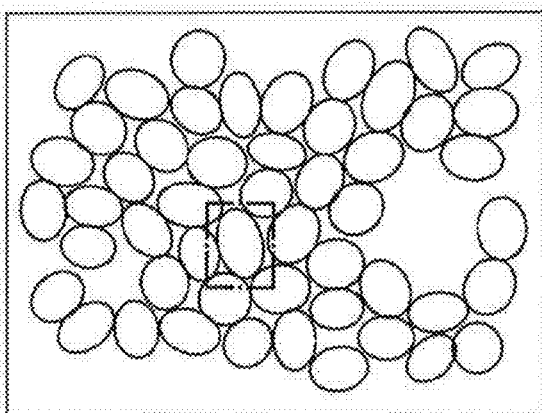


FIG. 3C

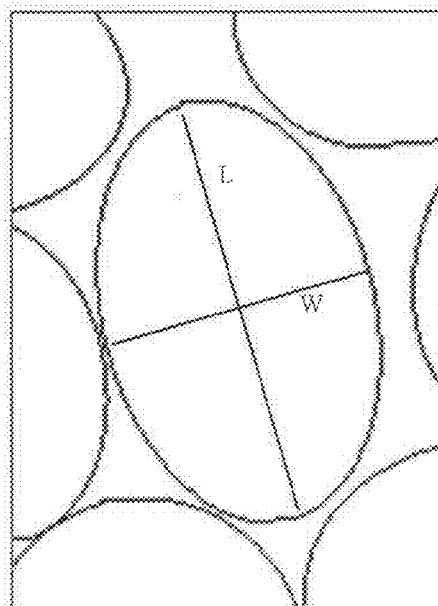


FIG. 3D

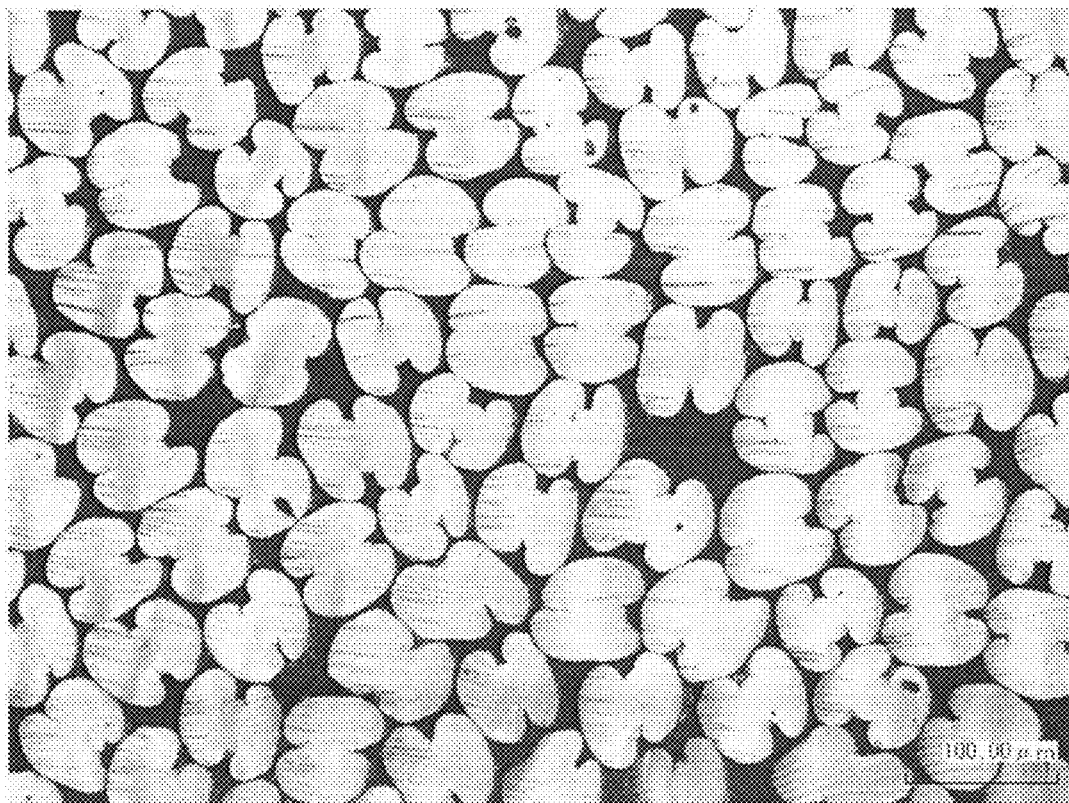


FIG. 4

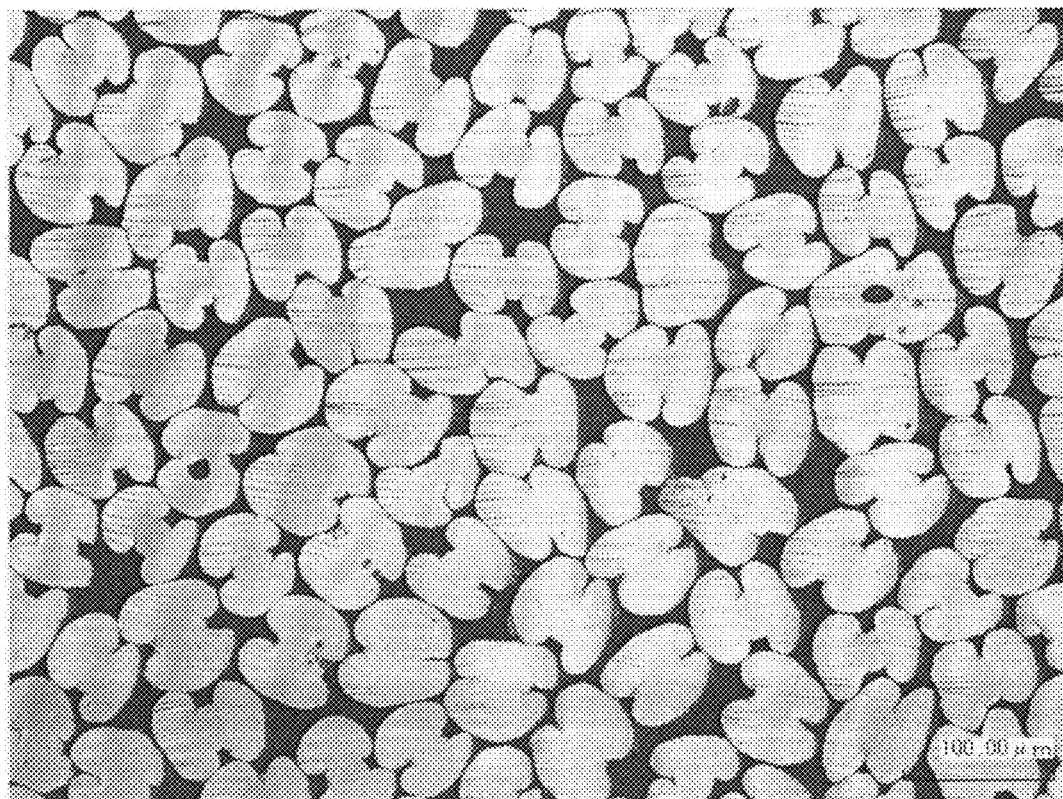


FIG. 5

ACRYLIC FIBER AND METHOD FOR MANUFACTURING SAME

TECHNICAL FIELD

[0001] One or more embodiments of the present invention relate to acrylic fibers composed of acrylic polymers, and a method for producing the same.

BACKGROUND

[0002] Acrylic fibers are generally produced by wet spinning or dry-wet spinning in which a spinning solution that is obtained by dissolving an acrylic polymer in an organic solvent is discharged from a spinning nozzle into a coagulation bath to form fibers. In the production of acrylic fibers by wet spinning or dry-wet spinning, after the spinning solution has been discharged from the spinning nozzle and coagulated in the coagulation bath, if coagulated yarns (fibers) in a wet state due to the organic solvent, etc., in the spinning solution are directly and immediately dried, the fibers adhere to one another. To cope with this, a washing step is generally performed in a water bath before drying to remove the organic solvent in the fibers. For example, Patent Document 1 discloses that wet spun acrylic fibers are washed in a water bath at high temperature before drying to remove the organic solvent.

[0003] On the other hand, in the production of fibers by wet spinning or dry-wet spinning, pressing of fibers with nip rolls is commonly performed before sending the fibers from a bath liquid of a coagulation bath, water bath, or the like, to the next step, so as to reduce an amount of the bath liquid to be sent to the next step.

Patent Document

[0004] Patent Document 1: JP 2004-346447A

[0005] However, pressing wet fibers before drying with nip rolls causes easy collapse of fiber cross sections. Such cross-sectional collapse is especially observed in the production of thick fibers having a single fiber fineness of 10 dtex or more.

SUMMARY

[0006] In one or more embodiments, the present invention provides acrylic fibers with less cross-sectional collapse and high surface smoothness, and a production method of acrylic fibers that can improve the surface smoothness of acrylic fibers while reducing the cross-sectional collapse of acrylic fibers in the production of acrylic fibers by wet spinning or dry-wet spinning.

[0007] One or more embodiments of the present invention relate to an acrylic fiber composed of an acrylic polymer containing acrylonitrile. The acrylic fiber has a deformation degree of 0.13 or less and a surface roughness of $6000 \mu\text{m}^2$ or less.

[0008] One or more embodiments of the present invention also relate to a method for producing an acrylic fiber by wet spinning or dry-wet spinning using a spinning solution in which an acrylic polymer containing acrylonitrile is dissolved in an organic solvent. The method includes at least a coagulation step, a water washing step, and a drying step. The acrylic fiber that has been pressed with a nip roll is subjected to predrying before the drying step, using a dryer into which steam is fed.

[0009] In one or more embodiments, the method for producing an acrylic fiber further includes a bath drawing step of drawing the acrylic fiber in a drawing bath before or after the water washing step. In one or more embodiments, the water washing step is performed by spraying water on the acrylic fiber and pressing with the nip roll the acrylic fiber on which water has been sprayed. In one or more embodiments, the predrying is performed at a dry-bulb temperature of 100 to 160° C. and a wet-bulb temperature of 60 to 100° C.

[0010] In one or more embodiments, the organic solvent in the spinning solution is at least one selected from the group consisting of dimethyl sulfoxide, dimethylacetamide, and N,N-dimethylformamide. In one or more embodiments, the coagulation step is performed using a coagulation bath including at least one organic solvent selected from the group consisting of dimethyl sulfoxide, dimethylacetamide, and N,N-dimethylformamide.

[0011] In one or more embodiments, the acrylic polymer includes acrylonitrile in an amount of 20 to 85 mass %, halogen-containing vinyl and/or halogen-containing vinylidene in an amount of 15 to 80 mass %, and a sulfonic acid group-containing monomer in an amount of 0 to 10 mass % with respect to the total mass of the acrylic polymer. In one or more embodiments, the acrylic polymer has a specific viscosity of 0.1 to 0.3.

[0012] In one or more embodiments, acrylic fiber has a single fiber fineness of 10 to 100 dtex.

[0013] One or more embodiments of the present invention provide acrylic fibers that are composed of acrylic polymers containing acrylonitrile, and that have less cross-sectional collapse and high surface smoothness. One or more embodiments of the production method of acrylic fibers of the present invention can improve the surface smoothness of acrylic fibers while reducing the cross-sectional collapse of acrylic fibers in the production of acrylic fibers by wet spinning or dry-wet spinning.

BRIEF DESCRIPTION OF DRAWINGS

[0014] FIG. 1 is a schematic cross-sectional view of a washing device used in examples of the present invention.

[0015] FIG. 2A is a schematic cross-sectional view for explaining a nip pressure applied by nip rolls, and FIG. 2B is a schematic surface view for explaining the same.

[0016] FIGS. 3A to 3D are schematic views for explaining a method for measuring the deformation degree of fibers.

[0017] FIG. 4 is a photograph showing the cross sections of acrylic fibers of Example 1 (400× magnification).

[0018] FIG. 5 is a photograph showing the cross sections of acrylic fibers of Comparative Example 1 (400× magnification).

DETAILED DESCRIPTION OF EMBODIMENTS

[0019] The present inventors repeatedly examined ways to reduce the cross-sectional collapse of acrylic fibers occurring when acrylic fibers in a wet state before drying are pressed with nip rolls in wet spinning or dry-wet spinning. As the result of the examinations, it was surprisingly found that the cross-sectional collapse can be reduced by subjecting acrylic fibers that have been pressed with nip rolls in any of the stages before a drying step to predrying in a dryer into which steam is fed and thereafter drying the predried fibers. The reason for this is considered as follows. By subjecting

acrylic fibers in a wet state whose cross sections collapse due to pressing with nip rolls to predrying in a dryer into which steam is fed, the cross-sectional collapse recovers. It was also found that there is a tendency for the fiber surfaces to smoothen by subjecting the acrylic fibers to predrying using a dryer into which steam is fed and then proceeding to a drying step.

[0020] The acrylic fibers of one or more embodiments of the present invention have a deformation degree of 0.13 or less and a surface roughness of $6000\ \mu\text{m}^2$ or less. Within these ranges, the cross-sectional collapse is reduced and the surface smoothness is improved.

[0021] In one or more embodiments of the present invention, the deformation degree of the fibers can be measured and calculated in the manner described below. The deformation degree is an index indicating the degree of the cross-sectional collapse. As the deformation degree increases, the number of fibers with different cross-sectional shapes increases, and the fiber bundle includes more fibers with cross-sectional collapse. As the deformation degree of the fiber cross section decreases, the fiber bundle includes fewer fibers with cross-sectional collapse. The present inventors found that, in the case of using the acrylic fibers as artificial hair, a hackling loss rate decreases in keeping with the deformation degree. Specifically, the hackling loss rate can be reduced to 5% or less by controlling the deformation degree to be 0.13 or less. In one or more embodiments of the present invention, the deformation degree of the acrylic fibers is 0.13 or less, or 0.12 or less, or 0.115 or less, from the viewpoint of improving hackling properties. Moreover, if the cross-sectional shapes of the fibers are excessively uniform, the acrylic fibers are unnatural as artificial hair. From this viewpoint, it may be preferred that the deformation degree be in a range from 0.05 to 0.13 in products that are important to have good appearance.

[0022] In one or more embodiments of the present invention, the surface roughness of the fibers can be measured and calculated in the manner described below. The surface roughness is an index indicating the degree of the smoothness of the fiber surfaces. The fiber surface is smoother as the surface roughness is lower. The present inventors found that, in the case of using the acrylic fibers as artificial hair, the hackling loss rate decreases in keeping with the surface roughness. Specifically, the hackling loss rate can be reduced to 5% or less by controlling the surface roughness to be $6000\ \mu\text{m}^2$ or less. In one or more embodiments of the present invention, the surface roughness of the acrylic fibers is $6000\ \mu\text{m}^2$ or less, or $5800\ \mu\text{m}^2$ or less, or $5500\ \mu\text{m}^2$ or less, from the viewpoint of improving hackling properties. Further, if the surface roughness is less than $3500\ \mu\text{m}^2$, the fiber surfaces are too smooth, and the grip feeling of the acrylic fibers as artificial hair products in the case of using the fibers as artificial hair products becomes too high. From this viewpoint, it may be preferred that the surface roughness be in a range from 3500 to $6000\ \mu\text{m}^2$ in products that are important to have natural touch.

[0023] Any polymer that contains acrylonitrile can be used as the acrylic polymer. The acrylic polymer may be a homopolymer of acrylonitrile, or may be a copolymer of acrylonitrile and another copolymerizable monomer. Any monomer that is copolymerizable with acrylonitrile can be used as the other copolymerizable monomer. However, for example, it is possible to use known vinyl compounds such as vinyl halides exemplified by vinyl chloride, vinyl bro-

mide, and the like; vinylidene halides exemplified by vinylidene chloride, vinylidene bromide, and the like; unsaturated carboxylic acids exemplified by acrylic acid and methacrylic acid as well as their salts; methacrylic acid esters exemplified by methyl methacrylate; unsaturated carboxylic acid esters exemplified by glycidyl methacrylate and the like; and vinyl esters exemplified by vinyl acetate and vinyl butyrate. A sulfonic acid group-containing monomer may also be used as the other copolymerizable monomer. Although there is no limitation on the sulfonic acid group-containing monomer, allyl sulfonic add, methallyl sulfonic add, styrene sulfonic acid, isoprene sulfonic acid, 2-acrylamide-2-methylpropane sulfonic acid, as well as metallic salts, such as sodium salts, and amine salts thereof can be used. These other copolymerizable monomers can be used alone or in combination of two or more.

[0024] In one or more embodiments, the acrylic polymer contains acrylonitrile in an amount of 20 to 85 mass %, halogen-containing vinyl and/or halogen-containing vinylidene in an amount of 15 to 80 mass %, and a sulfonic acid group-containing monomer in an amount of 0 to 10 mass % with respect to the total mass of the acrylic polymer. When the content of the acrylonitrile in the acrylic polymer is 20 to 85 mass %, heat resistance improves, and the processing temperature for curling of the acrylic fibers can be set appropriately in the case of using the fibers as artificial hair. When the content of the halogen-containing vinyl and/or halogen-containing vinylidene in the acrylic polymer is 15 to 80 mass %, flame resistance improves. In one or more embodiments, the acrylic polymer contains acrylonitrile in an amount of 30 to 70 mass %, halogen-containing vinyl and/or halogen-containing vinylidene in an amount of 30 to 70 mass %, and a sulfonic acid group-containing monomer in an amount of 0 to 10 mass %. In one or more embodiments, in terms of hydrophilicity, the acrylic polymer contains acrylonitrile in an amount of 20 to 85 mass %, halogen-containing vinyl and/or halogen-containing vinylidene in an amount of 14.5 to 79.5 mass %, and a sulfonic acid group-containing monomer in an amount of 0.5 to 10 mass %, or contains acrylonitrile in an amount of 20 to 80 mass %, halogen-containing vinyl and/or halogen-containing vinylidene in an amount of 19.5 to 79.5 mass %, and a sulfonic acid group-containing monomer in an amount of 0.5 to 5 mass %, or contains acrylonitrile in an amount of 20 to 75 mass %, halogen-containing vinyl and/or halogen-containing vinylidene in an amount of 24.5 to 79.5 mass %, and a sulfonic acid group-containing monomer in an amount of 0.5 to 5 mass %, with respect to the total mass of the acrylic polymer.

[0025] In one or more embodiments, the acrylic polymer has a specific viscosity of 0.1 to 0.3, or 0.15 to 0.25, from the viewpoint of easy dissolution in organic solvents. In one or more embodiments of the present invention, 2 g of an acrylic polymer is dissolved in 1 L of dimethylformamide, and the specific viscosity of the obtained polymer solution is measured at 30° C. with an Ostwald viscometer to determine the specific viscosity of the acrylic polymer.

[0026] In one or more embodiments, the acrylic fibers have a single fiber fineness of 10 to 100 dtex, or 20 to 90 dtex, or 30 to 85 dtex, or 40 to 80 dtex, or 45 to 70 dtex, from the viewpoint of suitable use as artificial hair.

[0027] The acrylic fibers can be produced by wet spinning or dry-wet spinning using the above-described spinning solution in which an acrylic polymer is dissolved in an organic solvent.

[0028] In one or more embodiments, the spinning solution contains the acrylic polymer in an amount of 15 to 40 mass %, the organic solvent in an amount of 60 to 85 mass %, and water in an amount of 0 to 10 mass %, or contains the acrylic polymer in an amount of 20 to 35 mass %, the organic solvent in an amount of 65 to 80 mass %, and water in an amount of 0 to 10 mass % with respect to the total mass of the spinning solution, from the viewpoint of spinning stability.

[0029] In one or more embodiments, although the composition of the spinning solution varies depending on the composition of the acrylic polymer, the spinning solution contains the acrylic polymer in an amount of 20 to 30 mass %, the organic solvent (e.g., dimethyl sulfoxide) in an amount of 65.2 to 78.5 mass %, and water in an amount of 1.5 to 4.8 mass %, or contains the acrylic polymer in an amount of 22 to 30 mass %, the organic solvent in an amount of 66 to 76 mass %, and water in an amount of 2 to 4 mass %, or contains the acrylic polymer in an amount of 25 to 30 mass %, the organic solvent in an amount of 66.5 to 72.5 mass %, and water in an amount of 2.5 to 3.5 mass % with respect to the total mass of the spinning solution, from the viewpoint of improving hackling properties in the case of using the acrylic fibers as artificial hair.

[0030] The spinning solution may contain other additives for improving fiber properties as needed. Examples of the additives include gloss adjusting agents such as titanium dioxide, silicon dioxide, esters and ethers of cellulose derivatives including cellulose acetate, coloring agents such as organic pigments, inorganic pigments, and dyes, and stabilizers for improving light resistance and heat resistance.

[0031] The acrylic fibers can be produced in the same procedure as that of general wet spinning or dry-wet spinning, except that acrylic fibers that have been pressed with nip rolls are subjected to predrying before the drying step, using a dryer into which steam is fed. The production method of the acrylic fibers includes at least a coagulation step, a water washing step, and a drying step. In one or more embodiments, the method includes a bath drawing step before or after the water washing step. Moreover, the method may include a finishing oil application step before the drying step, and a drawing step and a thermal relaxation treatment step after the drying step.

[0032] <Coagulation Step>

[0033] For example, first, the spinning solution is discharged into a coagulation bath containing an aqueous solution of an organic solvent directly or via a spinning nozzle to coagulate the spinning solution, and thus fibers are formed. In one or more embodiments, the coagulation bath is preferably a mixed solution of water and an organic solvent, from the viewpoint of easy control of the coagulation state. For example, in one or more embodiments, the coagulation bath is an aqueous solution of an organic solvent that contains an organic solvent in an amount of 20 to 75 mass % and water in an amount of 25 to 80 mass %, or an aqueous solution of an organic solvent that contains an organic solvent in an amount of 30 to 70 mass % and water in an amount of 30 to 70 mass %, or an aqueous solution of an organic solvent that contains an organic solvent in an amount of 40 to 70 mass % and water in an amount of 30 to

60 mass %, with respect to the total mass of the coagulation bath. The temperature of the coagulation bath may be, e.g., 5 to 40° C. If the concentration of the solvent in the coagulation bath is excessively low, coagulation proceeds fast, which tends to create a rough coagulation structure and form voids inside fibers.

[0034] Any good solvents for the acrylic polymer can be used as the organic solvent in the spinning solution and the organic solvent in the coagulation bath. However, in one or more embodiments, the organic solvents are at least one selected from the group consisting of dimethyl sulfoxide (DMSO), dimethylacetamide (DMAc), and N,N-dimethylformamide (DMF) for the viewpoint of productivity, and may be dimethyl sulfoxide from the viewpoint of safety. In one or more embodiments, the organic solvent in the spinning solution and the organic solvent in the coagulation bath are the same, from the viewpoints of the quality of the acrylic fibers and the ease of process control.

[0035] <Bath Drawing Step>

[0036] Next, in one or more embodiments, the acrylic fibers (coagulated yarns) are drawn in a drawing bath. The drawing bath may be a water bath or an aqueous solution of an organic solvent having a lower organic solvent concentration than the coagulation bath. In one or more embodiments, the temperature of the drawing bath is 30° C. or more, or 40° C. or more, or 50° C. or more. In one or more embodiments, the organic solvent in the drawing bath is the same as the organic solvent in the coagulation bath. In one or more embodiments, the drawing ratio is not particularly limited, but the drawing ratio may be 2 to 8 times, or 2 to 7 times, or 2 to 6 times, from the viewpoint of enhancing the fiber strength and productivity.

[0037] <Water Washing Step>

[0038] Next, the acrylic fibers (coagulated yarns or drawn yarns) are washed with water to remove the organic solvent. The water washing step can be performed by soaking the acrylic fibers in a water bath and then pressing the fibers with nip rolls, or spraying water on the acrylic fibers and pressing with nip rolls the acrylic fibers on which water has been sprayed. In one or more embodiments, the water washing step is performed by spraying water on the acrylic fibers and pressing with nip rolls the acrylic fibers on which water has been sprayed, from the viewpoint of removing the organic solvent in the acrylic fibers in a short time without using a water bath.

[0039] In one or more embodiments of the present invention, “nip rolls” can be any rolls that are commonly used in the production of fibers through wet spinning. The “pressing with nip rolls” refers to application of a pressure to acrylic fibers by passing the fibers between a pair of upper and lower nip rolls, or a pressure applied to the acrylic fibers at the time of winding the fibers on nip rolls. The method for applying a pressure is not particularly limited as long as a pressure can be applied to the acrylic fibers with nip rolls. Examples of the method include a method in which a pressure is applied to the upper nip roll by a cylinder, a method in which a weight is placed on the upper nip roll, and a method in which the upper nip roll is pulled down.

[0040] The nip rolls may be, e.g., rubber nip rolls and metallic nip rolls. In one or more embodiments, the upper nip roll is a rubber nip roll (also referred to as a rubber roll), and the lower nip roll is a metallic nip roll (also referred to as a metal roll). Examples of the material for the rubber nip rolls include natural rubber, styrene-butadiene rubber, nitrile

rubber, chloroprene rubber, butyl rubber, ethylene-propylene rubber, chlorosulfonated polyethylene rubber, silicone rubber, fluororubber, and urethane rubber. The rubber nip rolls may be obtained by wrapping a metallic roll with rubber. In one or more embodiments, the thickness of the rubber is 3 mm or more, or 5 mm or more, or 8 mm or more, from the viewpoint of maintaining the cross-sectional shape of the fibers. An exemplary material for the metallic nip rolls is stainless. In one or more embodiments, the hardness of the nip rolls is 40 to 100, or 50 to 85, or 55 to 80, as measured by a type A durometer in accordance with JIS K 6253.

[0041] In one or more embodiments of the present invention, spraying of water and pressing with the nip rolls may be alternately performed several times, or spraying of water may be performed at least twice and thereafter pressing with the nip rolls may be performed at least once. In one or more embodiments, from the viewpoint of improving the efficiency of removing the organic solvent in the acrylic fibers, the spraying of water and pressing with the nip rolls are alternately performed six times or more, or eight times or more, or ten times or more.

[0042] The water washing step can be performed by nip rolls and a means for spraying water that are alternately arranged. In the case where pressing with the nip rolls and spraying of water are alternately performed two times or more, a washing device including two or more sets of nip rolls and means for spraying water that are alternately arranged can be used. The plurality of nip rolls and means for spraying water may be alternately arranged in series, or may be alternately arranged in two or more rows. For example, as shown in FIG. 1, in a washing device 10 constituted by thirteen pairs of nip rolls 2, each pair including an upper nip roll 21 and a lower nip roll 22, and twelve water spraying means 3 (shower nozzles), the nip rolls 2 and the water spraying means 3 (shower nozzles) are arranged in three rows, i.e., a group "a", a group "b", and a group "c". Water receiving members 4 are disposed for the respective groups, and washing water that has been sprayed once is collected and drained by corresponding one of the water receiving members 4. The acrylic fibers move through the washing device 10 in the order of the group "a", the group "b", and the group "c". The group "a" is constituted by five pairs of nip rolls 2 and four water spraying means 3 (shower nozzles) that are alternately arranged, the group "b" is constituted by four pairs of nip rolls 2 and four water spraying means 3 (shower nozzles) that are alternately arranged, and the group "c" is constituted by four pairs of nip rolls 2 and four water spraying means 3 (shower nozzles) that are alternately arranged.

[0043] In one or more embodiments of the water washing step, the means for spraying water is not limited particularly, but a nozzle may be preferred from the viewpoint of the ease of spraying. Any nozzle that can spray water can be used as the nozzle, and the shape and the like of the nozzle are not limited particularly. For example, a slit-like nozzle or a hole-shaped nozzle can be used. The direction in which water is sprayed is not limited particularly, and water may be sprayed from the side or from below. In one or more embodiments, from the viewpoint of uniformly spraying water, it may be preferable to use a shower nozzle having a plurality of holes. The temperature of water used for spraying of water is not limited particularly, but, for example, water within a temperature range of 20 to 95° C. can be used. In one or more embodiments, from the viewpoint of improv-

ing the desolvation effect of removing the organic solvent, the temperature of water is 40° C. or more, or 50° C. or more, or 60° C. or more.

[0044] In one or more embodiments, the amount of water (amount of water sprayed) coming out from each nozzle used for the spraying of water per unit time is, from the viewpoint of improving the desolvation effect, two times or more, or three times or more, or four times or more the dry mass of a resin constituting the acrylic fibers passing through the nip rolls per unit time. Moreover, in one or more embodiments, from the viewpoint of reducing the amount of water while improving the desolvation effect, the above-described amount of water is eight times or less, or seven times or less, or six times or less the dry mass of the resin constituting the acrylic fibers. The amounts of water sprayed from respective nozzles may be uniform or may be different from nozzle to nozzle. Hereinafter, the ratio of the amount of water coming out from each nozzle per unit time to the dry mass of the resin constituting the acrylic fibers passing through the nip rolls per unit time is also referred to as the washing ratio.

[0045] The above-described dry mass of the resin constituting the acrylic fibers passing through the nip rolls per unit time is calculated in the following manner. Hereinafter, the solid concentration (mass %) in the spinning solution refers to the concentration of the acrylic polymer in the spinning solution.

$$\text{Dry mass of resin constituting acrylic fibers passing through nip rolls per unit time (g)} = (\text{amount of spinning solution discharged (L/hr)} \times \text{specific gravity of spinning solution (g/L)} \times \text{solid concentration in spinning solution (mass \%)}) / 100$$

[0046] Moreover, the amount of water coming out from each nozzle per unit time is calculated as follows.

$$\text{Amount of water coming out from each nozzle per unit time (g)} = \text{dry mass of resin constituting acrylic fibers passing through nip rolls per unit time (g)} \times \text{washing ratio (times)}$$

[0047] In one or more embodiments, in the water washing step, from the viewpoint of improving the efficiency of removing the organic solvent in the acrylic fibers, the nip pressure applied by the nip rolls is 0.2 MPa or higher, or 0.4 MPa or higher, or 0.6 MPa or higher. Moreover, a plurality of nip rolls may apply the same nip pressure or may apply different nip pressures. In one or more embodiments, from the viewpoint of easily reducing the cross-sectional collapse of the fibers, in the case where the organic solvent content in the acrylic fibers is 50 mass % or more, the nip pressure applied by the nip rolls is 2 MPa or lower, or 1.5 MPa or lower, or 1 MPa or lower.

[0048] In one or more embodiments of the present invention, the nip pressure applied by a nip roll is expressed as the force applied to a contact portion between the nip roll and the fiber bundle/the area of the contact portion between the nip roll and the fiber bundle. Hereinafter, the nip pressure applied by a nip roll in the case where a pressure is applied to the nip roll by a cylinder will be described using the drawings. FIG. 2A is a schematic cross-sectional view for explaining the nip pressure applied by nip rolls, and FIG. 2B is a schematic surface view for explaining the same. A cylinder 200 to which an air pressure is applied in the direction indicated by an arrow applies a pressure to an upper nip roll 101, thereby pressing a fiber bundle 300 sandwiched by a pair of nip rolls 100 including the upper nip

roll **101** and a lower nip roll **102**. At this time, a portion indicated by reference numeral **400** is a contact portion between the nip rolls **100** and the fiber bundle **300**. When the horizontal cross-sectional area of an inner cylinder **210** of the cylinder is regarded as the area of the inner cylinder of the cylinder, the nip pressure applied by the nip roll is calculated as follows.

$$\text{Nip pressure} = (\text{air pressure applied to cylinder} \times \text{area of inner cylinder of cylinder}) / (\text{area of contact portion between nip roll and fiber bundle})$$

[0049] In one or more embodiments, in the water washing step, from the viewpoint of improving the desolvation effect, the ratio of the total fineness to the width of the acrylic fiber bundle is 300,000 dtex/cm or less, or 200,000 dtex/cm or less, or 100,000 dtex/cm or less.

[0050] <Finishing Oil Application Step>

[0051] After the water washing step, a finishing oil may be applied to the acrylic fibers before predrying. Any finishing oils that are commonly used for the purpose of preventing static electricity, adhesion between fibers, or improving texture in the spinning step may be used, and known finishing oils can be used.

[0052] <Predrying Step>

[0053] After the water washing step or the finishing oil application step, the acrylic fibers are subjected to predrying using a dryer into which steam is fed. In one or more embodiments, in the predrying step, a dry-bulb temperature inside the dryer is 100 to 160° C., and a wet-bulb temperature inside the dryer is 60 to 100° C., from the viewpoint of obtaining high effects of recovering the cross-sectional collapse. In one or more embodiments, the dry-bulb temperature is 110 to 150° C., and the wet-bulb temperature is 70 to 90° C. In one or more embodiments of the present invention, the term “temperature” indicates “dry-bulb temperature” unless otherwise specified. In one or more embodiments, the predrying time is not particularly limited, but may be 1 to 10 minutes or 1 to 6 minutes.

[0054] Any drier that can dry fibers may be used as the dryer. The dryer may be, e.g., a hot-air dryer that can directly blow hot air onto fibers. Specific examples of the dryer include a jet dryer, a hot-air convection dryer, and a suction drum drier. In one or more embodiments, the temperature of hot air is not particularly limited, but may be 80 to 170° C. or 100 to 160° C. In one or more embodiments, the temperature of the steam to be fed into the drier is not particularly limited, but may be 100° C. or more, or 100 to 150° C., or 110 to 140° C., from the viewpoint of maintaining high temperature inside the drier. The feeding amount of the steam is not particularly limited, and can be determined appropriately based on a desired wet-bulb temperature.

[0055] In one or more embodiments, the water content of the acrylic fibers after predrying is not particularly limited, but may be 10 to 80 mass % or 20 to 70 mass %, from the viewpoint of obtaining high effects of recovering the cross-sectional collapse.

[0056] <Drying Step>

[0057] The acrylic fibers after predrying are subjected to a drying step to remove water inside the fibers almost perfectly. Any drying method that can remove water inside fibers can be used. Examples of the method include hot-air drying, and drying using a heat roll by bringing fibers into contact with the heat roll. In one or more embodiments, the drying temperature is not particularly limited, but may be 110 to 190° C. or 110 to 170° C.

[0058] <Drawing Step>

[0059] The dried fibers may then be drawn further as needed. In one or more embodiments, the drawing temperature is not particularly limited, but may be 110 to 190° C. or 110 to 160° C. In one or more embodiments, the drawing ratio is not particularly limited, but may be 1 to 4 times. In one or more embodiments, the total drawing ratio including the bath drawing before drying is 2 to 12 times.

[0060] <Thermal Relaxation Treatment Step>

[0061] In one or more embodiments, the dried fibers or the fibers drawn further after drying are further subjected to a thermal relaxation treatment step for relaxation. In one or more embodiments, the relaxation rate is not particularly limited, but may be 5% or more or 10% or more. In one or more embodiments, the thermal relaxation treatment can be performed under a dry heat atmosphere or superheated steam atmosphere at a temperature of 130 to 200° C. or 140 to 190° C. In one or more embodiments, the thermal relaxation treatment can also be performed in a pressurized steam atmosphere or heated and pressurized steam atmosphere at 120 to 180° C. under 0.05 to 0.4 MPa or 0.1 to 0.4 MPa.

[0062] In the production method of one or more embodiments of the present invention, the cross-sectional collapse of the acrylic fibers is reduced by subjecting the acrylic fibers that have been pressed with nip rolls in any of the stages before drying to predrying in a dryer into which steam is fed, and thereafter drying the predried fibers.

EXAMPLES

[0063] Hereinafter, embodiments of the present invention will be described in further detail using examples below. It should be noted that the present invention is not limited to the examples below.

Example 1

[0064] An acrylic copolymer (specific viscosity: 0.174) constituted by 46.1 mass % acrylonitrile (hereinafter, also referred to as “AN”), 51.7 mass % vinyl chloride (hereinafter, also referred to as “VCM”), and 2.0 mass % sodium styrenesulfonate (hereinafter, also referred to as “3S”) was dissolved in dimethyl sulfoxide (hereinafter, also referred to as “DMSO”) to produce a spinning solution having a resin concentration of 28.0 mass % and a water concentration of 3.5 mass %. The spinning solution was extruded into a coagulation bath of a 62 mass % DMSO aqueous solution at 20° C. using a spinning nozzle (hole diameter: 0.3 mm, the number of holes: 1250 holes) and coagulated to obtain fibers. Then, they were drawn to 3.2 times in a drawing bath of a 50 mass % DMSO aqueous solution at 80° C. In the drawn yarns obtained, the ratio of the total fineness to the width of the fiber bundle was 60,000 dtex/cm. As shown in FIG. 1, drawn yarns **1** (fiber bundle) obtained were passed through a washing device **10** having thirteen pairs of nip rolls **2** (diameter: 100 mm, width: 85 mm), each pair including an upper nip roll **21** and a lower nip roll **22**, and twelve shower nozzles **3** each producing a fan-shaped spray to remove DMSO in the drawn yarns **1**. Specifically, the drawn yarns **1** were washed by being alternately subjected to pressing with nip rolls, which was performed by applying a pressure to the upper nip roll **21** by a cylinder while passing the drawing yarns **1** between the upper nip roll **21** and the lower nip roll **22** of the nip roll **2**, and spraying of water

using the shower nozzle 3. The upper nip roll 21 was a rubber roll obtained by wrapping nitrile rubber (NBR) (hardness: 60, thickness: 6 mm) around a stainless roll, and the lower nip roll 22 was a metal roll made from SUS304. The washing device 10 was equipped with water receiving members 4, and washing water that was sprayed once was collected and drained by the water receiving members 4. Each pair of nip rolls applied a nip pressure of 0.96 MPa. The amount of water (amount of water sprayed) coming out from each of the shower nozzles per unit time was set to be five times the dry mass of the resin constituting the acrylic fibers passing through the nip rolls per unit time. The temperature of water sprayed by each shower nozzle was set at 70° C. After water washing, a finishing oil was applied to the washed yarns, and the washed yarns to which the finishing oil was applied were placed in a jet drier that directly blows hot air to fiber bundles. The yarns in the jet drier were subjected to predrying for three minutes while controlling the dry-bulb temperature and the wet-bulb temperature inside the jet drier to be 140° C. and 80° C., respectively, by feeding steam at 120° C. into the dryer. Then, the fiber bundle after predrying was dried at 140° C. for three minutes inside a jet dryer into which steam was not fed. The wet-bulb temperature inside the jet drier into which steam was not fed was 55° C. Then, the fiber bundle was wound around a heat roll at 165° C. for 30 seconds, drawn to two times under a dry heat atmosphere at 140° C., and subjected to thermal relaxation treatment at a relaxation rate of 20% under a dry heat atmosphere at 160° C. to obtain acrylic fibers having a single fiber fineness of about 47 dtex.

Example 2

[0065] Acrylic fibers of Example 2 having a single fiber fineness of about 47 dtex were obtained in the same manner as in Example 1 except that an acrylic polymer having the composition and specific viscosity shown in Table 1 below was used, and the relaxation rate in the thermal relaxation treatment was 15%.

Example 3

[0066] Acrylic fibers of Example 3 having a single fiber fineness of about 47 dtex were obtained in the same manner as in Example 2 except that the concentration of DMSO in the coagulation bath ("Concentration of coagulation bath" in Table 2) was 57 mass %.

Example 4

[0067] Acrylic fibers of Example 4 having a single fiber fineness of about 47 dtex were obtained in the same manner as in Example 3 except that an acrylic polymer having the composition and specific viscosity shown in Table 1 below was used, the spinning solution having the resin concentration and water concentration shown in Table 1 was used, the dry-bulb temperature in predrying, the drying temperature and the drawing temperature were 150° C., and the relaxation rate in the thermal relaxation treatment was 25%.

Example 5

[0068] Acrylic fibers of Example 5 having a single fiber fineness of about 47 dtex were obtained in the same manner as in Example 4 except that the concentration of DMSO in the coagulation bath was 52 mass %.

Comparative Example 1

[0069] Acrylic fibers of Comparative Example 1 having a single fiber fineness of about 47 dtex were obtained in the same manner as in Example 1 except that predrying was not performed, and the acrylic fibers were dried for six minutes in a jet drier at 140° C.

Comparative Example 2

[0070] Acrylic fibers of Comparative Example 2 having a single fiber fineness of about 47 dtex were obtained in the same manner as in Example 2 except that predrying was not performed, and the acrylic fibers were dried for six minutes in a jet drier at 140° C.

Comparative Example 3

[0071] Acrylic fibers of Comparative Example 3 having a single fiber fineness of about 47 dtex were obtained in the same manner as in Example 3 except that predrying was not performed, and the acrylic fibers were dried for six minutes in a jet drier at 140° C.

Comparative Example 4

[0072] Acrylic fibers of Comparative Example 4 having a single fiber fineness of about 47 dtex were obtained in the same manner as in Example 4 except that predrying was not performed, and the acrylic fibers were dried for six minutes in a jet drier at 150° C.

Comparative Example 5

[0073] Acrylic fibers of Comparative Example 5 having a single fiber fineness of about 47 dtex were obtained in the same manner as in Example 5 except that predrying was not performed, and the acrylic fibers were dried for six minutes in a jet drier at 150° C.

[0074] The deformation degrees of the cross sections of the acrylic fibers obtained in Examples 1-5 and Comparative Examples 1-5 and the surface roughnesses thereof were measured and calculated as described below. The hackling properties of the acrylic fibers obtained in Examples 1-5 and Comparative Examples 1-5 were evaluated in the manner described below. Table 2 below shows the results. Table 2 also indicates spinning conditions.

[0075] (Deformation Degree)

[0076] (1) The cross sections of the fiber bundle having a total fineness of about 14000 dtex were observed with an ultra-deep color 3S profile measurement microscope (model "VK-9500" manufactured by KEYENCE) at 40th magnification (object lens: 20× magnification, internal lens: 20× magnification). An area including about 70 fibers was selected arbitrarily to obtain images of the fiber cross sections as shown in FIG. 3A, for example.

[0077] (2) The images of the fiber cross sections were analyzed by ImageJ. First, the outline of each fiber cross section was extracted as shown in FIG. 3B. Next, an ellipse fitting the outline of the fiber cross section was drawn as shown in FIG. 3C. A major axis (L) and a minor axis (W) of the ellipse were measured as shown in FIG. 3D to calculate an aspect ratio (major axis/minor axis) of the ellipse. Then, a standard deviation of the aspect ratios of all the fiber cross sections used for the analysis was calculated to determine the deformation degree. As the standard deviation (deformation degree) increases, the number of fibers with

deformed cross sections increases, and the fiber bundle includes more fibers with cross-sectional collapse.

[0078] (Surface Roughness)

[0079] The side surfaces of the fibers were observed with an ultra-deep color 3S profile measurement microscope (model “VK-9500” manufactured by KEYENCE) at 300th magnification (object lens: 150× magnification, internal lens: 20× magnification) to obtain images of the side surfaces. Sections each having a length of 40 μm and a width of 80 μm were selected arbitrarily from the obtained images to measure the surface areas of the sections each having a length of 40 μm and a width of 80 μm using an image analysis software VK Analyzer (model “VK-H1XA” manufactured by KEYENCE). These surface areas measured were averaged (n) to determine the surface roughness.

[0080] (Hackling Properties)

[0081] The acrylic fibers were crimped with a crimping machine so that the crimp waveform length (length from the top to the bottom of the crimp waveform) would be about 3 mm. The crimped fibers (total fineness: 1129000 dtex) were cut into a length of 2 m. The mass of the fibers before

hackling was measured. Then, near the center of the cut fibers was grasped, and the fibers were tossed on a hackling table (table on which 1470 needles are arranged, width: 66 cm, length: 120 cm) and pulled out therefrom. This operation was repeated 10 times in total, 5 times for the front side and 5 times for the back aide. The mass of the fibers after hackling was measured in the same manner as that before hackling. A hackling loss rate was calculated from the formula (1) below. The hackling properties were evaluated using the following criteria with three levels on the basis of the hackling loss rate. The “before HL” in the formula (1) indicates the mass (g) before hackling, and the “after HL” indicates the mass (g) after hackling. The evaluation of B or higher indicates that the fibers have good hackling properties.

$$\text{Hackling loss rate (\%)} = \frac{\{(\text{before HL} - \text{after HL}) / \text{before HL}\} \times 100}{\quad} \quad (1)$$

[0082] A: Hackling loss rate is 2% or less.

[0083] B: Hackling loss rate is more than 2% and 5% or less.

[0084] C: Hackling loss rate exceeds 5%.

TABLE 1

	Spinning solution					
	Acrylic polymer				Resin	Water
	AN [mass %]	VCM [mass %]	3S [mass %]	Specific viscosity	concentration [mass %]	concentration [mass %]
Ex. 1	46.1	51.7	2.0	0.174	28.0	3.5
Ex. 2	46.5	51.3	2.0	0.178	28.0	3.5
Ex. 3	46.5	51.3	2.0	0.178	28.0	3.5
Ex. 4	46.3	51.5	2.0	0.186	29.0	3.6
Ex. 5	46.3	51.5	2.0	0.186	29.0	3.6
Comp. Ex. 1	46.1	51.7	2.0	0.174	28.0	3.5
Comp. Ex. 2	46.5	51.3	2.0	0.178	28.0	3.5
Comp. Ex. 3	46.5	51.3	2.0	0.178	28.0	3.5
Comp. Ex. 4	46.3	51.5	2.0	0.186	29.0	3.6
Comp. Ex. 5	46.3	51.5	2.0	0.186	29.0	3.6

* Ex.: Example, Comp. Ex.: Comparative Example

TABLE 2

										Thermal relaxation		Hackling properties			
			Predrying		Drying		Drawing		treatment			Hack-			
Coagulation			Dry-	Wet-	Dry-	Wet-	Draw-	Draw-	Relax-			Surface	ling		
	Temp. of coagulation bath [° C.]	Concentration of coagulation bath [mass %]	bulb temp. [° C.]	bulb temp. [° C.]	bulb temp. [° C.]	bulb temp. [° C.]	ing temp. [° C.]	ing ratio [times]	Temp. rate [° C.]	ation ratio [%]	Deformation degree	roughness (μm ²)	loss rate (%)	Judge-ment	
Ex. 1	20	62	140	80	140	55	140	2.0	160	20	0.111	4853	1.5	A	
Ex. 2	20	62	140	80	140	55	140	2.0	160	15	0.126	4972	3.7	B	
Ex. 3	20	57	140	80	140	55	140	2.0	160	15	0.107	4979	1.3	A	
Ex. 4	20	57	150	80	150	55	150	2.0	160	25	0.107	5343	1.8	A	
Ex. 5	20	52	150	80	150	55	150	2.0	160	25	0.062	5938	3.9	B	
Comp. Ex. 1	20	62		—	140	55	140	2.0	160	20	0.175	4985	7.4	C	
Comp. Ex. 2	20	62		—	140	55	140	2.0	160	15	0.148	5256	6.4	C	
Comp. Ex. 3	20	57		—	140	55	140	2.0	160	15	0.155	5188	6.6	C	
Comp. Ex. 4	20	57		—	150	55	150	2.0	160	25	0.113	6004	7.3	C	

TABLE 2-continued

												Hackling properties		
												Hack-		
	Coagulation		Predrying		Drying		Drawing		Thermal relaxation treatment					
	Temp. of coagulation bath [° C.]	Concentration of coagulation bath [mass %]	Dry- bulb temp. [° C.]	Wet- bulb temp. [° C.]	Dry- bulb temp. [° C.]	Wet- bulb temp. [° C.]	Draw- ing temp. [° C.]	Draw- ing ratio [times]	Temp. rate [° C.]	Relax- ation ratio [%]	Deformation degree	Surface rough- ness (μm ²)	loss rate (%)	Judge- ment
Comp. Ex. 5	20	52	—		150	55	150	2.0	160	25	0.140	6498	9.8	C

* Ex.: Example, Comp. Ex.: Comparative Example, Temp.: Temperature

[0085] FIGS. 4 and 5 are photographs (400× magnification) showing the cross sections of the acrylic fibers of Example 1 and the cross sections of acrylic fibers of Comparative Example 1, respectively, observed with an ultra-deep color 3S profile measurement microscope (model “VK-9500” manufactured by KEYENCE).

[0086] As can be seen from the results of Table 2 above, the acrylic fibers of Examples 1-5, which were subjected to predrying before the drying step in the dryer into which steam was fed, had lower deformation degree and less cross-sectional collapse than the corresponding acrylic fibers of Comparative Examples 1-5, which were not subjected to predrying. Moreover, the acrylic fibers of the examples, which were subjected to predrying in the dryer into which steam was fed, had lower surface roughness and smoother surfaces than the corresponding acrylic fibers of the comparative examples, which were not subjected to predrying. The acrylic fibers of the examples had a hackling loss rate of 5% or less, and exhibited favorable hackling properties.

[0087] Although the disclosure has been described with respect to only a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that various other embodiments may be devised without departing from the scope of the present invention. Accordingly, the scope of the invention should be limited only by the attached claims.

LIST OF REFERENCE NUMERALS

- [0088] 1, 300 Acrylic fiber
- [0089] 2, 100 Nip roll
- [0090] 3 Shower nozzle
- [0091] 4 Water receiving member
- [0092] 10 Washing device
- [0093] 21, 101 Upper nip roll
- [0094] 22, 102 Lower nip roll
- [0095] 200 Cylinder
- [0096] 210 Inner cylinder of cylinder
- [0097] 400 Contact portion between fiber bundle and nip roll

What is claimed is:

1. An acrylic fiber composed of an acrylic polymer, the acrylic polymer comprising acrylonitrile, wherein the acrylic fiber has a deformation degree of 0.13 or less and a surface roughness of 6000 μm² or less.

2. The acrylic fiber according to claim 1, wherein the acrylic fiber has a deformation degree of 0.05 to 0.13 and a surface roughness of 3500 to 6000 μm².

3. The acrylic fiber according to claim 1, wherein the acrylic polymer comprises the acrylonitrile in an amount of 20 to 85 mass %, halogen-containing vinyl and/or halogen-containing vinylidene in an amount of 15 to 80 mass %, and a sulfonic acid group-containing monomer in an amount of 0 to 10 mass %, with respect to the total mass of the acrylic polymer.

4. The acrylic fiber according to claim 1, wherein the acrylic fiber has a fineness of 10 to 100 dtex.

5. A method for producing an acrylic fiber by wet spinning or dry-wet spinning, the method comprising:

dissolving an acrylic polymer in an organic solvent to form a spinning solution, the acrylic polymer comprising acrylonitrile;

discharging the spinning solution into a coagulation bath to form an acrylic fiber;

water washing the acrylic fiber; and

drying the acrylic fiber,

wherein, before drying the acrylic fiber, the acrylic fiber is pressed with a nip roll and subjected to pre-drying using a dryer into which steam is fed.

6. The method for producing an acrylic fiber according to claim 5, further comprising bath drawing the acrylic fiber by drawing the acrylic fiber in a drawing bath before or after water washing the acrylic fiber.

7. The method for producing an acrylic fiber according to claim 5, wherein water washing the acrylic fiber comprises spraying water on the acrylic fiber and pressing with the nip roll the acrylic fiber on which water is sprayed.

8. The method for producing an acrylic fiber according to claim 5, wherein the pre-drying is performed at a dry-bulb temperature of 100 to 160° C. and a wet-bulb temperature of 60 to 100° C.

9. The method for producing an acrylic fiber according to claim 5, wherein the organic solvent in the spinning solution is at least one selected from the group consisting of dimethyl sulfoxide, dimethylacetamide, and N,N-dimethylformamide.

10. The method for producing an acrylic fiber according to claim 5, wherein the coagulation bath comprises at least one organic solvent selected from the group consisting of dimethyl sulfoxide, dimethylacetamide, and N,N-dimethylformamide.

11. The method for producing an acrylic fiber according to claim 5, wherein the acrylic polymer comprises the acrylonitrile in an amount of 20 to 85 mass %, halogen-containing vinyl and/or halogen-containing vinylidene in an amount of 15 to 80 mass %, and a sulfonic acid group-

containing monomer in an amount of 0 to 10 mass %, with respect to the total mass of the acrylic polymer.

12. The method for producing an acrylic fiber according to claim **5**, wherein the acrylic polymer has a specific viscosity of 0.1 to 0.3.

13. The method for producing an acrylic fiber according to claim **5**, wherein the acrylic fiber has a fineness of 10 to 100 dtex after drying the acrylic fiber.

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