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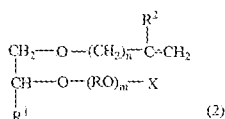
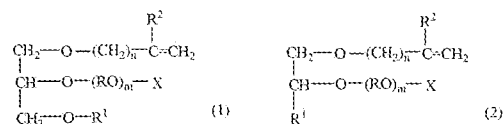
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RESIN COMPOSITION, OPTICAL FIBER, METHOD FOR PRODUCING OPTICAL FIBER, OPTICAL FIBER RIBBON, AND OPTICAL FIBER CABLE

(57)

A resin composition for primary coating of an optical fiber is a resin composition containing a photopolymerizable compound including a urethane (meth)acrylate and a reactive surfactant, and a photopolymerization initiator, in which the reactive surfactant includes at least one selected from the group consisting of a compound represented by the following Formula (1) and a compound represented by the following Formula (2):



(wherein R represents an alkylene group having 2 to 4 carbon atoms; R¹ represents a hydrocarbon group having 1 to 20 carbon atoms; R² represents a hydrogen atom or a methyl group; X represents a hydrogen atom or a -SO₃NH₄ group; m represents an integer of 0 to 100; and n represents an integer of 0 to 12).

TITLE

RESIN COMPOSITION, OPTICAL FIBER, METHOD FOR
PRODUCING OPTICAL FIBER, OPTICAL FIBER RIBBON, AND
OPTICAL FIBER CABLE

5 TECHNICAL FIELD

[0001] The present disclosure relates to a resin composition for primary
coating of an optical fiber, an optical fiber, a method for producing an
optical fiber, an optical fiber ribbon, and an optical fiber cable.

10 The present application claims the priority based on Japanese
application No. 2023-080639, filed on May 16, 2023, the entire
disclosure of which is incorporated herein by reference.

BACKGROUND

15 [0002] In recent years, there has been an increasing demand for high-
density cables with increased optical fiber packing density for use in data
centers. Generally, an optical fiber comprises a coating resin layer to
protect a glass fiber, which is an optical transmission medium. The
coating resin layer is composed of two layers, for example, a primary
resin layer in contact with the glass fiber, and a secondary resin layer
formed as an outer layer of the primary resin layer. When the packing
20 density of optical fibers is increased, external force (lateral pressure) is
applied to the optical fibers, and the microbending loss is likely to
increase. In order to improve the microbending resistance
characteristics of an optical fiber, it is known to decrease the Young's
modulus of the primary resin layer and to increase the Young's modulus
25 of the secondary resin layer. For example, resin compositions for
primary coating containing a urethane (meth)acrylate, which is a reaction

product of a polyol, a diisocyanate, and a hydroxyl group-containing (meth)acrylate, are described in Patent Literatures 1 to 5.

[0003] [Patent Literature 1] JP 2009-197163 A

[Patent Literature 2] JP 2012-111674 A

5 [Patent Literature 3] JP 2013-136783 A

[Patent Literature 4] JP 2013-501125 A

[Patent Literature 5] JP 2014-114208 A

SUMMARY

10 [0004] A resin composition for primary coating of an optical fiber according to an aspect of the present disclosure is a resin composition containing a photopolymerizable compound including a urethane (meth)acrylate and a reactive surfactant, and a photopolymerization initiator, in which the reactive surfactant includes at least one selected from the group consisting of a compound represented by Formula (1) that
15 will be described below and a compound represented by Formula (2) that will be described below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 is a schematic cross-sectional view illustrating an optical fiber according to an embodiment.

20 FIG. 2 is a schematic cross-sectional view illustrating an optical fiber ribbon according to an embodiment.

FIG. 3 is a schematic cross-sectional view illustrating an optical fiber ribbon according to an embodiment.

25 FIG. 4 is a plan view illustrating the appearance of an optical fiber ribbon according to an embodiment.

FIG. 5 is a schematic cross-sectional view illustrating an optical

fiber cable according to an embodiment.

FIG. 6 is a schematic cross-sectional view illustrating an optical fiber cable according to an embodiment.

DETAILED DESCRIPTION

5 [0006] [Problem to be solved by present disclosure]

When the Young's modulus of the primary resin layer is lowered, the crosslinking density is decreased, and water resistance may be deteriorated. Specifically, when an optical fiber is immersed in water, water bubbles are generated in the primary resin layer, and transmission
10 loss is likely to increase. An optical fiber may be used in the form of being accommodated in a cable in a state of being immersed in a jelly including oil. When the optical fiber is immersed in the jelly, the primary resin layer may absorb the oil, the strength may be decreased, and defects (voids) may occur. When voids occur, the transmission loss
15 is likely to increase at low temperatures. Therefore, the primary resin layer is required to have excellent oil resistance.

[0007] It is an object of the present disclosure to provide a resin composition that can form a resin layer that is excellent in water resistance and oil resistance and suitable for primary coating of an optical
20 fiber, and an optical fiber having excellent water resistance and oil resistance.

[0008] [Effect of present disclosure]

According to the present disclosure, a resin composition that can form a resin layer that is excellent in water resistance and oil resistance
25 and suitable for primary coating of an optical fiber, and an optical fiber having excellent water resistance and oil resistance can be provided.

[0009] [Description of embodiments of present disclosure]

Firstly, the present disclosure will be described by listing the contents of the embodiments.

[0010] (1) A resin composition for primary coating of an optical fiber according to an aspect of the present disclosure is a resin composition comprising a photopolymerizable compound including a urethane (meth)acrylate and a reactive surfactant, and a photopolymerization initiator, in which the reactive surfactant includes at least one selected from the group consisting of a compound represented by Formula (1) that will be described below and a compound represented by Formula (2) that will be described below. Such a resin composition can form a resin layer that is excellent in water resistance and oil resistance and suitable for primary coating of an optical fiber, and can produce an optical fiber having excellent water resistance and oil resistance.

[0011] (2) With regard to the above-described item (1), from the viewpoints of water resistance, oil resistance, and low-temperature characteristics of the optical fiber, a content of the reactive surfactant may be 0.01 parts by mass or more and 5.0 parts by mass or less based on a total amount of 100 parts by mass of the resin composition.

[0012] (3) With regard to the above-described item (1), from the viewpoints of water resistance, oil resistance, and low-temperature characteristics of the optical fiber, a content of the reactive surfactant may be 0.05 parts by mass or more and 3.5 parts by mass or less based on a total amount of 100 parts by mass of the resin composition.

[0013] (4) With regard to any one of the above-described items (1) to (3), from the viewpoint of improving the curing rate of the resin composition,

the photopolymerizable compound may further include an N-vinyl compound, and a content of the N-vinyl compound may be 1 part by mass or more and 15 parts by mass or less based on a total amount of 100 parts by mass of the resin composition.

5 [0014] (5) With regard to any one of the above-described items (1) to (4), from the viewpoint of improving the low-temperature characteristics and the microbending resistance characteristics of the optical fiber, a Young's modulus of a resin film obtained by ultraviolet-curing the above-described resin composition under the conditions of an accumulated
10 amount of light of 10 mJ/cm^2 and an illumination of 100 mW/cm^2 may be 0.10 MPa or more and 0.80 MPa or less at 23°C .

[0015] (6) With regard to the above-described item (5), from the viewpoint of improving the low-temperature characteristics and the microbending resistance characteristics of the optical fiber, the Young's
15 modulus of the resin film may be 0.10 MPa or more and 0.60 MPa or less at 23°C .

[0016] (7) An optical fiber according to an aspect of the present disclosure comprises: a glass fiber including a core and a cladding; a primary resin layer in contact with the glass fiber and coating the glass
20 fiber; and a secondary resin layer coating the primary resin layer, in which the primary resin layer includes a cured product of the resin composition according to any one of the above-described items (1) to (6). Such an optical fiber has excellent water resistance and oil resistance.

[0017] (8) A method for producing an optical fiber according to an aspect
25 of the present disclosure includes: an application step of applying the resin composition according to any one of the above-described items (1)

to (6) to a periphery of a glass fiber including a core and a cladding; and a curing step of curing the resin composition by irradiating with ultraviolet rays after the application step. As a result, an optical fiber having excellent water resistance and oil resistance can be produced.

5 [0018] (9) In an optical fiber ribbon according to an aspect of the present disclosure, a plurality of the optical fibers according to the above-described item (7) are arranged in parallel and coated with a resin for ribbon. Such an optical fiber ribbon has excellent water resistance and oil resistance and can be packed at high density in an optical fiber cable.

10 [0019] (10) In an optical fiber cable according to an aspect of the present disclosure, the optical fiber ribbon according to the above-described item (9) is accommodated in the cable. Such an optical fiber cable has excellent water resistance and oil resistance.

15 [0020] (11) In an optical fiber cable according to an aspect of the present disclosure, a plurality of the optical fibers according to the above-described item (7) are accommodated in the cable. Such an optical fiber cable has excellent water resistance and oil resistance.

[0021] [Details of embodiments of present disclosure]

20 Specific examples of the resin composition and the optical fiber according to the present embodiment will be described with reference to the drawings as necessary. The present disclosure is not limited to these examples but is shown in the scope of claims, and it is intended that all modifications within the meanings and scopes equivalent to the scope of claims are included in the present disclosure. In the following
25 description, the same elements in the description of the drawings will be assigned with the same reference numerals, and overlapping descriptions

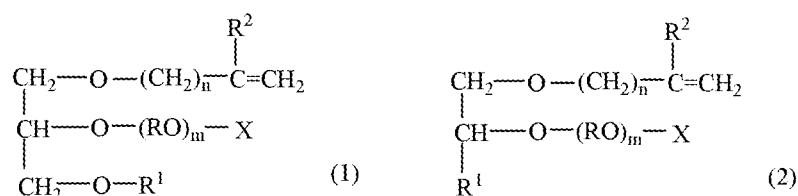
will not be repeated here. The term (meth)acrylate as used in the present specification means acrylate or methacrylate corresponding thereto, and the same also applies to other similar expressions such as (meth)acryloyl. In the present specification, the unit ppm indicates a mass ratio.

5 [0022] (Resin composition)

A resin composition according to the present embodiment is a resin composition for primary coating of an optical fiber, the resin composition containing a photopolymerizable compound including a urethane (meth)acrylate and a reactive surfactant, and a
10 photopolymerization initiator. The resin composition according to the present embodiment is an ultraviolet-curable resin composition.

[0023] The reactive surfactant includes at least one selected from the group consisting of a compound represented by the following Formula (1) and a compound represented by the following Formula (2). Since
15 the reactive surfactant according to the present embodiment is incorporated into crosslinking when the resin composition is cured by ultraviolet irradiation, a primary resin layer having excellent water resistance and oil resistance can be formed. In addition, the reactive surfactant according to the present embodiment can suppress an increase
20 in the transmission loss of the optical fiber by dispersing water and oil that have infiltrated into the primary resin layer.

[0024]



[0025] In Formula (1) and Formula (2), R represents an alkylene group having 2 to 4 carbon atoms; R¹ represents a hydrocarbon group having 1 to 20 carbon atoms; R² represents a hydrogen atom or a methyl group; X represents a hydrogen atom or a -SO₃NH₄ group; m represents an integer of 0 to 100; and n represents an integer of 0 to 12. When m is 2 or greater, a plurality of R may be the same or different.

[0026] Examples of the alkylene group having 2 to 4 carbon atoms as represented by R include an ethylene group, a propylene group, and a butylene group. From the viewpoint of having more excellent water resistance and oil resistance, R may be an ethylene group. The number of carbon atoms of the hydrocarbon group represented by R¹ may be 5 to 20, 8 to 18, or 10 to 15, from the viewpoint of having more excellent water resistance and oil resistance. The hydrocarbon group represented by R¹ may be a straight-chained, branched, or cyclic group. The hydrocarbon group represented by R¹ may be an aliphatic hydrocarbon group or an aromatic hydrocarbon group. Examples of the aliphatic hydrocarbon group include an alkyl group having 1 to 20 carbon atoms. Examples of the aromatic hydrocarbon group include a phenyl group substituted with an alkyl group. The number of carbon atoms of the alkyl group in the phenyl group substituted with an alkyl group may be 1 to 14 or 1 to 10. Examples of the phenyl group substituted with an alkyl group include an octylphenyl group and a nonylphenyl group. R² may be a hydrogen atom, from the viewpoint of having more excellent water resistance and oil resistance. m may be an integer of 1 to 50, 2 to 40, 3 to 30, 4 to 25, or 5 to 20. n may be an integer of 0 to 10, 0 to 8, 0 to 6, 0 to 3, or 1 to 3.

[0027] Examples of the compound represented by Formula (1) include ADEKA REASOAP SR-10, SR-20, SR-1025, SR-2025, SR-3025, SE-10 N, SE-1025 A, ER-10, ER-20, ER-30, ER-40, NE-10, NE-20, and NE-30 manufactured by ADEKA Corporation. Examples of the compound represented by Formula (2) include AQUALON KH-05, KH-10, and KH-20 manufactured by DKS Co. Ltd.

[0028] The content of the reactive surfactant may be 0.01 parts by mass or more, 0.03 parts by mass or more, 0.05 parts by mass or more, 0.07 parts by mass or more, or 0.09 parts by mass or more, and may be 5.0 parts by mass or less, 4.5 parts by mass or less, 4.0 parts by mass or less, 3.5 parts by mass or less, or 3.0 parts by mass or less, based on a total amount of 100 parts by mass of the resin composition. When the content of the reactive surfactant is 0.01 parts by mass or more based on a total amount of 100 parts by mass of the resin composition, the water resistance and oil resistance of the optical fiber are easily improved, and when the content is 5.0 parts by mass or less, the low-temperature characteristics of the optical fiber are easily improved. From the viewpoint of having more excellent water resistance, oil resistance, and low-temperature characteristics, the content of the reactive surfactant may be 0.01 parts by mass or more and 5.0 parts by mass or less, 0.03 parts by mass or more and 4.5 parts by mass or less, 0.05 parts by mass or more and 4.0 parts by mass or less, 0.05 parts by mass or more and 3.5 parts by mass or less, 0.07 parts by mass or more and 3.5 parts by mass or less, or 0.09 parts by mass or more and 3.0 parts by mass or less, based on a total amount of 100 parts by mass of the resin composition.

[0029] The urethane (meth)acrylate is a photopolymerizable compound

having a urethane bond. As the urethane (meth)acrylate, for example, a urethane (meth)acrylate (hereinafter, may be referred to as "urethane (meth)acrylate (A)") which is a reaction product of a diol, a diisocyanate, and a hydroxyl group-containing (meth)acrylate can be used.

5 [0030] Examples of the diol include a polyether diol, a polyester diol, a polycaprolactone diol, a polycarbonate diol, a polybutadiene diol, and a bisphenol A-ethylene oxide adduct diol. Examples of the polyether diol include polytetramethylene glycol (PTMG), polyethylene glycol (PEG), polypropylene glycol (PPG), a block copolymer of PTMG-PPG-PTMG, 10 a block copolymer of PEG-PPG-PEG, a random copolymer of PTMG-PEG, and a random copolymer of PTMG-PPG. From the viewpoint of easily adjusting the Young's modulus of the primary resin layer, polypropylene glycol may be used as the diol.

[0031] From the viewpoint of obtaining a Young's modulus suitable for 15 the primary resin layer, the number average molecular weight (M_n) of the diol may be 1800 or more and 20000 or less, 2000 or more and 19000 or less, or 2500 or more and 18500 or less.

[0032] Examples of the diisocyanate include 2,4-tolylene diisocyanate, 2,6-tolylene diisocyanate, isophorone diisocyanate, dicyclohexylmethane 20 diisocyanate, diphenylmethane diisocyanate, hexamethylene diisocyanate, xylylene diisocyanate, hydrogenated xylylene diisocyanate, 1,5-naphthalene diisocyanate, norbornene diisocyanate, 1,5-pentamethylene diisocyanate, tetramethylxylylene diisocyanate, and trimethylhexamethylene diisocyanate.

25 [0033] Examples of the hydroxyl group-containing (meth)acrylate include 2-hydroxyethyl (meth)acrylate, 2-hydroxypropyl (meth)acrylate,

2-hydroxybutyl (meth)acrylate, caprolactone (meth)acrylate, 2-hydroxy-3-phenoxypropyl (meth)acrylate, 2-(meth)acryloyloxyethyl-2-hydroxyethylphthalic acid, 2-hydroxy-o-phenylphenolpropyl (meth)acrylate, 2-hydroxy-3-methacrylpropyl acrylate, trimethylolpropane di(meth)acrylate, and pentaerythritol tri(meth)acrylate. From the viewpoint of reactivity, 2-hydroxyethyl acrylate may be used as the hydroxyl group-containing (meth)acrylate.

[0034] As a catalyst at the time of synthesizing the urethane (meth)acrylate, an organotin compound may be used. Examples of the organotin compound include dibutyltin dilaurate, dibutyltin diacetate, dibutyltin maleate, dibutyltin bis(2-ethylhexyl mercaptoacetate), dibutyltin bis(isooctyl mercaptoacetate), and dibutyltin oxide. From the viewpoint of easy availability or catalyst performance, dibutyltin dilaurate or dibutyltin diacetate may be used as the catalyst.

[0035] When the urethane (meth)acrylate is synthesized, 4-methoxyphenol or 2,6-di-tert-butyl-p-cresol may be added as a polymerization inhibitor.

[0036] Examples of a method for preparing the urethane (meth)acrylate (A) include a method of reacting a diol with a diisocyanate to synthesize an isocyanate group (NCO)-terminated prepolymer and then reacting the prepolymer with a hydroxyl group-containing (meth)acrylate; a method of reacting a diisocyanate with a hydroxyl group-containing (meth)acrylate and then reacting the resultant with a diol; and a method of simultaneously reacting a diol, a diisocyanate, and a hydroxyl group-containing (meth)acrylate. When preparing the urethane (meth)acrylate (A), the hydroxyl group-containing (meth)acrylate may be used as a

mixture with a monohydric alcohol or an active hydrogen-containing silane compound as needed.

[0037] By introducing a group based on the monohydric alcohol into the urethane (meth)acrylate (A), the proportion of a (meth)acryloyl group, which is a photopolymerizable group, can be reduced, and the Young's modulus of the primary resin layer can be reduced.

[0038] Examples of the monohydric alcohol include methanol, ethanol, 1-propanol, 2-propanol, 1-butanol, 2-butanol, 2-methyl-2-propanol, 1-pentanol, 2-pentanol, 3-pentanol, 2-methyl-1-butanol, 3-methyl-1-butanol, 2-methyl-2-butanol, and 3-methyl-2-butanol.

[0039] By introducing a group based on the active hydrogen-containing silane compound into the urethane (meth)acrylate (A), the proportion of a (meth)acryloyl group, which is a photopolymerizable group, can be reduced, the Young's modulus of the primary resin layer can be reduced, and the adhesive force to the glass fiber can be improved.

[0040] Examples of the active hydrogen-containing silane compound include N-2-(aminoethyl)-3-aminopropylmethyldimethoxysilane, N-2-(aminoethyl)-3-aminopropyltrimethoxysilane, 3-aminopropyltrimethoxysilane, 3-aminopropyltriethoxysilane, triethoxysilyl-N-(1,3-dimethyl-butylidene)propylamine, N-phenyl-3-aminopropyltrimethoxysilane, mercaptopropylmethyldimethoxysilane, and 3-mercaptopropyltrimethoxysilane.

[0041] The molar ratio between NCO and OH (NCO/OH) when a diol and a diisocyanate are reacted may be 1.1 or greater and 4.0 or less, 1.2 or greater and 3.5 or less, or 1.4 or greater and 3.0 or less. The molar

ratio of the hydroxyl group-containing (meth)acrylate with respect to NCO of the NCO-terminated prepolymer may be 1.00 or greater and 1.15 or less, or 1.03 or greater and 1.10 or less. In a case where the hydroxyl group-containing (meth)acrylate is used as a mixture with an active hydrogen-containing silane compound or a monohydric alcohol, the total molar ratio of the hydroxyl group-containing (meth)acrylate, the active hydrogen-containing silane compound, and the monohydric alcohol with respect to NCO of the NCO-terminated prepolymer may be 1.00 or greater and 1.15 or less, or 1.03 or greater and 1.10 or less, and the total molar ratio of the active hydrogen-containing silane compound and the monohydric alcohol with respect to NCO of the NCO-terminated prepolymer may be 0.01 or greater and 0.5 or less.

[0042] The urethane (meth)acrylate may further include a urethane (meth)acrylate (hereinafter, may be referred to as "urethane (meth)acrylate (B)") which is a reaction product of a polyoxyalkylene monoalkyl ether, a diisocyanate, and a hydroxyl group-containing (meth)acrylate.

[0043] The polyoxyalkylene monoalkyl ether is a compound having an oxyalkylene group, an alkoxy group, and a hydroxyl group. Examples of the polyoxyalkylene monoalkyl ether include polyoxyethylene oleyl ether, polyoxyethylene lauryl ether, polyoxyethylene cetyl ether, polyoxyethylene stearyl ether, polyoxyethylene alkyl (C₁₂-C₁₄) ether, polyoxyethylene tridecyl ether, polyoxyethylene myristyl ether, polyoxyethylene isostearyl ether, polyoxyethylene octyl dodecyl ether, polyoxyethylene cholesteryl ether, polyoxypropylene butyl ether, polyoxypropylene myristyl ether, polyoxypropylene cetyl ether,

polyoxypropylene stearyl ether, polyoxypropylene lanolin alcohol ether, polyoxyethylene polyoxypropylene butyl ether, polyoxyethylene polyoxypropylene lauryl ether, polyoxyethylene polyoxypropylene cetyl ether, polyoxyethylene polyoxypropylene stearyl ether, and polyoxyethylene polyoxypropylene decyl tetradecyl ether.

[0044] From the viewpoint of the compatibility of the resin composition, the polyoxyalkylene monoalkyl ether may be polyoxypropylene monobutyl ether.

[0045] From the viewpoint of obtaining a Young's modulus suitable for the primary resin layer, the Mn of the polyoxyalkylene monoalkyl ether may be 2000 or greater, 2100 or greater, or 2200 or greater, and may be 10000 or less, 8000 or less, or 7000 or less.

[0046] The Mn of the diol and the polyoxyalkylene monoalkyl ether can be obtained by measuring the hydroxyl group value according to JIS K 0070 and calculating the Mn from the following formula. The number of functional groups of the diol is 2, and the number of functional groups of the polyoxyalkylene monoalkyl ether is 1.

$$\text{Mn} = 56.1 \times \text{number of functional groups} \times 1000 / \text{hydroxyl group value}$$

[0047] From the viewpoint of obtaining a Young's modulus suitable for the primary resin layer, the Mn of the urethane (meth)acrylate (A) may be 6000 or greater and 50000 or less, 8000 or greater and 45000 or less, 9000 or greater and 40000 or less, or 10000 or greater and 30000 or less. The weight average molecular weight (Mw) of the urethane (meth)acrylate (A) may be 6000 or greater and 80000 or less, 8000 or greater and 70000 or less, 10000 or greater and 60000 or less, or 15000

or greater and 40000 or less. The Mn of the urethane (meth)acrylate (B) may be 4000 or greater and 20000 or less, 5000 or greater and 18000 or less, or 6000 or greater and 15000 or less. The Mw of the urethane (meth)acrylate (B) may be 4000 or greater and 30000 or less, 4500 or greater and 25000 or less, or 5000 or greater and 20000 or less.

[0048] The Mn and Mw of the urethane (meth)acrylate (A) and the urethane (meth)acrylate (B) can be measured by gel permeation chromatography (GPC).

[0049] From the viewpoint of adjusting the Young's modulus of the primary resin layer, the content of the urethane (meth)acrylate (A) may be 15 parts by mass or greater and 85 parts by mass or less, 20 parts by mass or greater and 80 parts by mass or less, or 25 parts by mass or greater and 75 parts by mass or less, based on a total amount of 100 parts by mass of the resin composition.

[0050] The content of the urethane (meth)acrylate (B) may be 0 parts by mass or greater and 70 parts by mass or less, 10 parts by mass or greater and 65 parts by mass or less, or 20 parts by mass or greater and 60 parts by mass or less, based on a total amount of 100 parts by mass of the resin composition.

[0051] The content of the urethane (meth)acrylate may be 30 parts by mass or greater and 90 parts by mass or less, 40 parts by mass or greater and 80 parts by mass or less, or 45 parts by mass or greater and 75 parts by mass or less, based on a total amount of 100 parts by mass of the resin composition.

[0052] The photopolymerizable compound according to the present embodiment can include a photopolymerizable compound other than the

reactive surfactant and the urethane (meth)acrylate (hereinafter, referred to as "monomer"). Examples of the monomer include a (meth)acrylic acid ester, an N-vinyl compound, and a (meth)acrylamide compound. The monomer may be a monofunctional monomer having one photopolymerizable, ethylenically unsaturated group, or may be a polyfunctional monomer having two or more ethylenically unsaturated groups.

[0053] Examples of the monofunctional (meth)acrylic acid ester include methyl (meth)acrylate, ethyl (meth)acrylate, propyl (meth)acrylate, n-butyl (meth)acrylate, s-butyl (meth)acrylate, t-butyl (meth)acrylate, isobutyl (meth)acrylate, n-pentyl (meth)acrylate, isopentyl (meth)acrylate, hexyl (meth)acrylate, heptyl (meth)acrylate, isoamyl (meth)acrylate, 2-ethylhexyl (meth)acrylate, n-octyl (meth)acrylate, isooctyl (meth)acrylate, isodecyl (meth)acrylate, lauryl (meth)acrylate, phenoxyethyl (meth)acrylate, tetrahydrofurfuryl (meth)acrylate, benzyl (meth)acrylate, cyclic trimethylolpropane formal acrylate, dicyclopentenyl (meth)acrylate, dicyclopentenyl oxyethyl (meth)acrylate, dicyclopentanyl (meth)acrylate, methoxy polyethylene glycol (meth)acrylate, butoxy polyethylene glycol (meth)acrylate, nonylphenol polyethylene glycol (meth)acrylate, nonylphenoxy polyethylene glycol (meth)acrylate, isobornyl (meth)acrylate, 3-phenoxybenzyl (meth)acrylate, methylphenoxyethyl (meth)acrylate, phenoxy diethylene glycol (meth)acrylate, phenoxy polyethylene glycol (meth)acrylate, m-phenoxybenzyl (meth)acrylate, 2-(2-ethoxyethoxy)ethyl (meth)acrylate, 2-hydroxy-3-phenoxypropyl acrylate, carboxyethyl (meth)acrylate, carboxypentyl (meth)acrylate, and

ω -carboxy-polycaprolactone (meth)acrylate.

[0054] Examples of the polyfunctional (meth)acrylic acid ester include bifunctional monomers such as ethylene glycol di(meth)acrylate, polyethylene glycol di(meth)acrylate, polypropylene glycol di(meth)acrylate, neopentyl glycol di(meth)acrylate, tripropylene glycol di(meth)acrylate, triethylene glycol di(meth)acrylate, cyclohexane dimethanol di(meth)acrylate, dipropylene glycol di(meth)acrylate, tetraethylene glycol di(meth)acrylate, hydroxypivalic acid neopentyl glycol di(meth)acrylate, 1,3-butylene glycol di(meth)acrylate, 1,4-butanediol di(meth)acrylate, diethylene glycol di(meth)acrylate, 1,6-hexanediol di(meth)acrylate, 1,9-nonanediol di(meth)acrylate, 1,12-dodecanediol di(meth)acrylate, 1,14-tetradecanediol di(meth)acrylate, 1,16-hexadecanediol di(meth)acrylate, 1,20-eicosanediol di(meth)acrylate, isopentyldiol di(meth)acrylate, 3-ethyl-1,8-octanediol di(meth)acrylate, tricyclodecanol di(meth)acrylate, 9,9-bis[4-(2-hydroxyethoxy)phenyl]fluorene di(meth)acrylate, bisphenol A epoxy di(meth)acrylate, bisphenol F epoxy di(meth)acrylate, ethoxylated bisphenol A di(meth)acrylate, ethoxylated bisphenol F di(meth)acrylate, propoxylated bisphenol A di(meth)acrylate, and propoxylated bisphenol F di(meth)acrylate; and trifunctional or higher monomers such as trimethylolpropane tri(meth)acrylate, trimethyloloctane tri(meth)acrylate, trimethylolpropane polyethoxy tri(meth)acrylate, trimethylolpropane polypropoxy tri(meth)acrylate, trimethylolpropane polyethoxy polypropoxy tri(meth)acrylate, tris[(meth)acryloyloxyethyl] isocyanurate, pentaerythritol tri(meth)acrylate, pentaerythritol polyethoxy tetra(meth)acrylate, pentaerythritol polypropoxy

tetra(meth)acrylate, pentaerythritol tetra(meth)acrylate,
 ditrimethylolpropane tetra(meth)acrylate, dipentaerythritol
 tetra(meth)acrylate, dipentaerythritol penta(meth)acrylate,
 dipentaerythritol hexa(meth)acrylate, and caprolactone-modified
 5 tris[(meth)acryloyloxyethyl] isocyanurate.

[0055] Examples of the (meth)acrylamide compound include dimethyl
 (meth)acrylamide, diethyl (meth)acrylamide, (meth)acryloylmorpholine
 hydroxymethyl (meth)acrylamide, hydroxyethyl (meth)acrylamide,
 isopropyl (meth)acrylamide, dimethylaminopropyl (meth)acrylamide,
 10 dimethylaminopropyl acrylamide·methyl chloride salt, diacetone
 acrylamide, (meth)acryloylpiperidine, (meth)acryloylpyrrolidine,
 (meth)acrylamide, N-hexyl (meth)acrylamide, N-methyl
 (meth)acrylamide, N-butyl (meth)acrylamide, N-methylol
 (meth)acrylamide, and N-methylolpropane (meth)acrylamide.

15 [0056] Examples of the N-vinyl compound include N-vinylpyrrolidone,
 N-vinylcaprolactam, N-vinylmethyloxazolidinone, N-vinylimidazole,
 and N-vinyl-N-methylacetamide.

[0057] When the photopolymerizable compound includes an N-vinyl
 compound, the curing rate of the resin composition can be improved.

20 The N-vinyl compound may include at least one selected from N-
 vinylcaprolactam and N-vinylmethyloxazolidinone. The content of the
 N-vinyl compound may be 1 part by mass or more and 15 parts by mass
 or less, 2 parts by mass or more and 14 parts by mass or less, or 3 parts
 by mass or more and 13 parts by mass or less, based on a total amount of
 25 100 parts by mass of the resin composition.

[0058] The content of the monomer may be 5 parts by mass or more and

70 parts by mass or less, 10 parts by mass or more and 60 parts by mass or less, or 15 parts by mass or more and 50 parts by mass or less, based on a total amount of 100 parts by mass of the resin composition.

[0059] The photopolymerization initiator can be appropriately selected from known radical photopolymerization initiators and used. Examples of the photopolymerization initiator include 1-hydroxycyclohexyl phenyl ketone (Omnirad 184, manufactured by IGM Resins B.V.), 2,2-dimethoxy-2-phenylacetophenone (Omnirad 651, manufactured by IGM Resins B.V.), 2,4,6-trimethylbenzoyldiphenylphosphine oxide (Omnirad TPO, manufactured by IGM Resins B.V.), ethyl (2,4,6-trimethylbenzoyl)-phenylphosphinate (Omnirad TPO-L, manufactured by IGM Resins B.V.), 2-benzyl-2-dimethylamino-4'-morpholinobutylphenone (Omnirad 369, manufactured by IGM Resins B.V.), 2-dimethylamino-2-(4-methyl-benzyl)-1-(4-morpholin-4-yl-phenyl)-butan-1-one (Omnirad 379, manufactured by IGM Resins B.V.), bis(2,4,6-trimethylbenzoyl)phenylphosphine oxide (Omnirad 819, manufactured by IGM Resins B.V.), and 2-methyl-1-[4-(methylthio)phenyl]-2-morpholinopropan-1-one (Omnirad 907, manufactured by IGM Resins B.V.).

[0060] Regarding the photopolymerization initiator, one kind thereof may be used alone, or two or more kinds thereof may be used in combination. From the viewpoint that the resin composition has excellent fast curability, 2,4,6-trimethylbenzoyldiphenylphosphine oxide may be used as the photopolymerization initiator.

[0061] The content of the photopolymerization initiator may be 0.1 parts by mass or more and 5 parts by mass or less, 0.3 parts by mass or more

and 4 parts by mass or less, or 0.4 parts by mass or more and 3 parts by mass or less, based on a total amount of 100 parts by mass of the resin composition.

[0062] The resin composition according to the present embodiment may further contain a sensitizer, a photo-acid generator, a silane coupling agent, a leveling agent, an antifoaming agent, an antioxidant, an ultraviolet absorber, and the like.

[0063] Examples of the sensitizer include anthracene compounds such as 9,10-dibutoxyanthracene, 9,10-diethoxyanthracene, 9,10-dipropoxyanthracene, and 9,10-bis(2-ethylhexyloxy)anthracene; thioxanthone compounds such as 2,4-diethylthioxanthone, 2,4-diethylthioxanthene-9-one, 2-isopropylthioxanthone, and 4-isopropylthioxanthone; amine compounds such as triethanolamine, methyldiethanolamine, and triisopropanolamine; benzoin compounds, anthraquinone compounds, ketal compounds, and benzophenone compounds.

[0064] As the photo-acid generator, an onium salt having a structure of A^+B^- may be used. Examples of the photo-acid generator include sulfonium salts such as CPI-100P, 101A, 110P, 200K, 210S, 310B, 410S (manufactured by San-Apro, Ltd.), and Omnicat 270, 290 (manufactured by IGM Resins B.V.); and iodonium salts such as CPI-IK-1 (manufactured by San-Apro, Ltd.), Omnicat 250 (manufactured by IGM Resins B.V.), and WPI-113, 116, 124, 169, 170 (manufactured by FUJIFILM Wako Pure Chemical Corporation).

[0065] Examples of the silane coupling agent include tetramethyl silicate, tetraethyl silicate, mercaptopropyltrimethoxysilane,

vinyltrichlorosilane, vinyltriethoxysilane, vinyltris(β -methoxyethoxy)silane, β -(3,4-epoxycyclohexyl)-ethyltrimethoxysilane, dimethoxydimethylsilane, diethoxydimethylsilane, 3-(meth)acryloxypropyltrimethoxysilane γ -glycidoxypentyltrimethoxysilane, γ -glycidoxypentylmethyldiethoxysilane, γ -methacryloxypropyltrimethoxysilane, N-(β -aminoethyl)- γ -aminopentyltrimethoxysilane, N-(β -aminoethyl)- γ -aminopentyltrimethyldimethoxysilane, N-phenyl- γ -aminopentyltrimethoxysilane, γ -chloropentyltrimethoxysilane, γ -mercaptopentyltrimethoxysilane, γ -aminopentyltrimethoxysilane, bis-[3-(triethoxysilyl)propyl] tetrasulfide, bis-[3-(triethoxysilyl)propyl] disulfide, γ -trimethoxysilylpropyl dimethylthiocarbamoyl tetrasulfide, and γ -trimethoxysilylpropyl benzothiazyl tetrasulfide.

[0066] From the viewpoint of coating properties, the viscosity at 25°C of the resin composition according to the present embodiment may be 0.5 Pa·s or greater and 20 Pa·s or less, 0.8 Pa·s or greater and 18 Pa·s or less, or 1 Pa·s or greater and 15 Pa·s or less. The viscosity at 25°C of the resin composition can be measured by using a rheometer ("MCR-102" manufactured by Anton Paar GmbH) with cone-plate CP25-2 under the conditions of a shear rate of 10 s⁻¹.

[0067] The Young's modulus of a resin film obtained by ultraviolet-curing the resin composition under the conditions of an accumulated amount of light of 10 mJ/cm² and an illumination of 100 mW/cm² may be 0.10 MPa or greater and 0.80 MPa or less at 23°C. When the Young's modulus of the resin film is 0.10 MPa or greater, the low-temperature

characteristics of the optical fiber are likely to improve, and when the Young's modulus of the resin film is 0.80 MPa or less, the microbending resistance characteristics of the optical fiber are likely to improve. From the viewpoint of the low-temperature characteristics of the optical fiber, the Young's modulus of the resin film may be 0.15 MPa or greater or 0.20 MPa or greater at 23°C, and from the viewpoint of the microbending resistance characteristics of the optical fiber, the Young's modulus may be 0.70 MPa or less, 0.60 MPa or less, or 0.50 MPa or less at 23°C. From the viewpoints of the low-temperature characteristics and the microbending resistance characteristics of the optical fiber, the Young's modulus of the resin film may be 0.10 MPa or greater and 0.60 MPa or less, 0.10 MPa or greater and 0.50 MPa or less, 0.15 MPa or greater and 0.50 MPa or less, or 0.20 MPa or greater and 0.50 MPa or less at 23°C. The Young's modulus of the resin film can be determined by the method described in the Examples.

[0068] (Optical fiber)

FIG. 1 is a schematic cross-sectional view illustrating an optical fiber according to an embodiment. The optical fiber 10 includes: a glass fiber 13 including a core 11 and a cladding 12; and a coating resin layer 16 including a primary resin layer 14 and a secondary resin layer 15 provided to the periphery of the glass fiber 13.

[0069] The cladding 12 surrounds the core 11. The core 11 and the cladding 12 mainly include glass such as quartz glass, and for example, germanium-added quartz glass or pure quartz glass can be used for the core 11, while pure quartz glass or fluorine-added quartz glass can be used for the cladding 12.

[0070] In FIG. 1, for example, the outer diameter (D2) of the glass fiber 13 is about 100 μm to 125 μm , and the diameter (D1) of the core 11 constituting the glass fiber 13 is about 7 μm to 15 μm . The thickness of the coating resin layer 16 is usually about 22 μm to 70 μm . The thickness of each layer of the primary resin layer 14 and the secondary resin layer 15 may be about 5 μm to 50 μm .

[0071] In a case where the outer diameter of the glass fiber 13 is about 125 μm , and the thickness of the coating resin layer 16 is 60 μm or greater and 70 μm or less, the thickness of each layer of the primary resin layer 14 and the secondary resin layer 15 may be about 10 μm to 50 μm , and for example, the thickness of the primary resin layer 14 may be 35 μm , while the thickness of the secondary resin layer 15 may be 25 μm . The outer diameter of the optical fiber 10 may be about 245 μm to 265 μm .

[0072] In a case where the outer diameter of the glass fiber 13 is about 125 μm , and the thickness of the coating resin layer 16 is 20 μm or greater and 48 μm or less, the thickness of each layer of the primary resin layer 14 and the secondary resin layer 15 may be about 8 μm to 38 μm , and for example, the thickness of the primary resin layer 14 may be 25 μm , while the thickness of the secondary resin layer 15 may be 10 μm . The outer diameter of the optical fiber 10 may be about 165 μm to 221 μm .

[0073] In a case where the outer diameter of the glass fiber 13 is about 100 μm , and the thickness of the coating resin layer 16 is 22 μm or greater and 37 μm or less, the thickness of each layer of the primary resin layer 14 and the secondary resin layer 15 may be about 5 μm to 32 μm , and for example, the thickness of the primary resin layer 14 may be 25 μm , while the thickness of the secondary resin layer 15 may be 10 μm . The outer

diameter of the optical fiber 10 may be about 144 μm to 174 μm .

[0074] The method for producing an optical fiber according to the present embodiment includes an application step of applying the above-described resin composition to the periphery of a glass fiber including a core and a cladding; and a curing step of curing the resin composition by irradiating with ultraviolet rays after the application step. When the resin composition according to the present embodiment is applied to the primary resin layer, an optical fiber having excellent water resistance and oil resistance can be produced.

[0075] From the viewpoint of improving the microbending resistance characteristics of the optical fiber, the Young's modulus of the primary resin layer may be 0.80 MPa or less, 0.70 MPa or less, 0.60 MPa or less, or 0.50 MPa or less at $23 \pm 2^\circ\text{C}$. When the Young's modulus of the primary resin layer is 0.80 MPa or less, it is difficult for external force to be transmitted to the glass fiber, and an increase in the transmission loss by microbending can be suppressed. From the viewpoint of improving the low-temperature characteristics of the optical fiber, the Young's modulus of the primary resin layer may be 0.10 MPa or greater, 0.15 MPa or greater, or 0.20 MPa or greater at $23 \pm 2^\circ\text{C}$.

[0076] The Young's modulus of the primary resin layer can be measured by a Pullout Modulus (POM) method at 23°C . Two sites of an optical fiber are fixed with two chuck devices, the coating resin layer (primary resin layer and secondary resin layer) portion between the two chuck devices is removed, and then one chuck device is fixed, while the other chuck device is gently moved in a direction opposite to the fixed chuck device. In a case where the length of the portion of the optical fiber

clamped by the moving chuck device is designated as L , the amount of movement of the chuck as Z , the outer diameter of the primary resin layer as D_p , the outer diameter of the glass fiber as D_f , the Poisson's ratio of the primary resin layer as n , and the load at the time of movement of the chuck device as W , the Young's modulus of the primary resin layer can be determined from the following formula.

$$\text{Young's modulus (MPa)} = ((1 + n) W / \pi LZ) \times \ln (D_p / D_f)$$

[0077] The secondary resin layer 15 can be formed by, for example, curing a resin composition containing a photopolymerizable compound including a urethane (meth)acrylate, a photopolymerization initiator, and the like. The resin composition for forming the secondary resin layer has a composition different from that of the resin composition for primary coating. The resin composition for secondary coating can be prepared using a conventionally known technology.

[0078] From the viewpoint of improving the microbending resistance characteristics of the optical fiber, the Young's modulus of the secondary resin layer may be 800 MPa or greater, 1000 MPa or greater, or 1200 MPa or greater at $23 \pm 2^\circ\text{C}$. The upper limit value of the Young's modulus of the secondary resin layer is not particularly limited; however, from the viewpoint of imparting moderate toughness to the secondary resin layer, the upper limit value may be 3000 MPa or less, 2500 MPa or less, or 2000 MPa or less at $23 \pm 2^\circ\text{C}$.

[0079] The Young's modulus of the secondary resin layer can be measured by the following method. First, an optical fiber is immersed in a mixed solvent of acetone and ethanol, and only the coating resin layer is pulled out in a tubular shape. At this time, the primary resin layer and

the secondary resin layer are integrated; however, since the Young's modulus of the primary resin layer is $1/10000$ or greater and $1/1000$ or less of the Young's modulus of the secondary resin layer, the Young's modulus of the primary resin layer can be neglected. Next, the solvent is removed from the coating resin layer by vacuum drying, subsequently a tensile test (tensile rate is 1 mm/min) is performed at 23°C, and the Young's modulus can be determined by a secant expression at 2.5% strain.

[0080] The method for producing an optical fiber according to the present embodiment can produce an optical fiber that is excellent in terms of not only the water resistance and oil resistance but also the microbending resistance characteristics and low-temperature characteristics by using the resin composition according to the present embodiment as the resin composition for primary coating.

[0081] (Optical fiber ribbon)

An optical fiber ribbon can be produced using the optical fiber according to the present embodiment. In the optical fiber ribbon, a plurality of the above-described optical fibers are arranged in parallel and are coated with a resin for ribbon.

[0082] FIG. 2 is a schematic cross-sectional view illustrating the optical fiber ribbon according to an embodiment. The optical fiber ribbon 100 has a plurality of optical fibers 10 and a connective resin layer 40 in which the optical fibers 10 are (integrally) coated by a resin for ribbon and connected. In FIG. 2, four optical fibers 10 are shown as an example; however, the number of the optical fibers is not particularly limited.

[0083] The optical fibers 10 may be integrated in a state of being arranged in parallel and in contact with each other, or some or all of the

optical fibers 10 may be integrated in a state of being arranged in parallel at a constant interval. The center-to-center distance F between adjoining optical fibers 10 may be $220\text{ }\mu\text{m}$ or greater and $280\text{ }\mu\text{m}$ or less. In a case where the center-to-center distance is set to $220\text{ }\mu\text{m}$ or greater and $280\text{ }\mu\text{m}$ or less, it is easy to place the optical fibers on existing V-grooves, and an optical fiber ribbon having excellent simultaneous fusibility can be obtained. The thickness T of the optical fiber ribbon 100 may vary depending on the outer diameter of the optical fiber 10; however, the thickness T may be $164\text{ }\mu\text{m}$ or greater and $285\text{ }\mu\text{m}$ or less.

[0084] FIG. 3 is a schematic cross-sectional view illustrating an example of an optical fiber ribbon in which optical fibers are integrated in a state of being arranged in parallel at a constant interval. In the optical fiber ribbon 100A shown in FIG. 3, pairs of optical fibers 10 are connected at regular intervals with a resin for a ribbon, thereby connecting a total of twelve optical fibers 10. The resin for ribbon forms a connective resin layer 40.

[0085] As the resin for ribbon, a resin material that is generally known as a ribbon material can be used. From the viewpoints of the damage preventing property for the optical fiber 10, easy separability, and the like, the resin for ribbon may contain a thermosetting resin such as a silicone resin, an epoxy resin, or a urethane resin; or an ultraviolet-curable resin such as epoxy acrylate, urethane acrylate, or polyester acrylate.

[0086] In a case where the optical fibers 10 are arranged in parallel at a constant interval, that is, in a case where adjoining optical fibers 10 are joined through a resin for ribbon without being in contact with each other, the thickness of the connected part at the center between the optical fibers

10 may be 150 μm or greater and 220 μm or less. From the viewpoint of being susceptible to deformation when the optical fiber ribbon is accommodated in a cable, the optical fiber ribbon may have a depression at the connected part of the optical fibers. The depression may be
5 formed into a triangular shape with a narrowing angle on one surface of the connected part.

[0087] The optical fiber ribbon according to the present embodiment may have connected parts and non-connected parts intermittently in the longitudinal direction and the width direction. FIG. 4 is a plan view
10 illustrating the appearance of the optical fiber ribbon according to an embodiment. The optical fiber ribbon 100B has a plurality of optical fibers, a plurality of connected parts 20, and non-connected parts (separated parts) 21. The non-connected parts 21 are formed intermittently in the longitudinal direction of the optical fiber ribbon.
15 The optical fiber ribbon 100B is an intermittently connected-type optical fiber ribbon in which connected parts 20 and non-connected parts 21 are intermittently provided in the longitudinal direction for every two optical fibers 10A. The term "connected part" refers to a portion in which adjoining optical fibers are integrated by means of the connective resin
20 layer, and the term "non-connected part" refers to a portion in which adjoining optical fibers are not integrated by means of the connective resin layer, and there are gaps between the optical fibers.

[0088] In the optical fiber ribbon having the above-described configuration, since the non-connected parts 21 are intermittently
25 provided to the connected parts 20 provided for every two cores, the optical fiber ribbon is easily deformable. Therefore, when the optical

fiber ribbon is packaged in an optical fiber cable, since the optical fiber ribbon can be easily rolled and packaged, the optical fiber ribbon can be produced as an optical fiber ribbon appropriate for high-density packaging. Furthermore, since the connected parts 20 can be easily torn by taking the non-connected parts 21 as starting points, single core separation of the optical fibers 10 in the optical fiber ribbon is easily achieved.

[0089] By using the above-describe optical fiber, the optical fiber ribbon according to the present embodiment is excellent in terms of not only the water resistance and oil resistance but also the microbending resistance characteristics and low-temperature characteristics, and can be packed at high density in an optical fiber cable.

[0090] (Optical fiber cable)

With regard to an optical fiber cable according to the present embodiment, the above-described optical fiber ribbon is accommodated in a cable. Examples of the optical fiber cable include a slot-type optical fiber cable having a plurality of slots (grooves). Inside the slots, the above-described optical fiber ribbon can be packaged such that the packaging density in each slot is about 25 to 65%. The packaging density means the ratio of the cross-sectional area of optical fiber ribbon packaged within the slots with respect to the cross-sectional area of the slots. The optical fiber cable according to the present embodiment may be in the form in which a plurality of the above-described optical fibers are accommodated inside a cable without coating the plurality of optical fibers with a resin for ribbon.

[0091] An example of the optical fiber cable according to the present

embodiment will be described with reference to FIG. 5 and FIG. 6. In FIG. 5 and FIG. 6, intermittently connected-type optical fiber ribbons are accommodated; however, a plurality of optical fibers that are not coated with a resin for ribbon may be accommodated in a bundled state.

[0092] FIG. 5 is a schematic cross-sectional view of a slotless type optical fiber cable 60 in which the above-mentioned intermittently connected-type optical fiber ribbon 100B is used. The optical fiber cable 60 has a cylindrical-type tube 61 and a plurality of optical fiber ribbons 100B. The plurality of optical fiber ribbons 100B may be bundled with an interposition 62 such as an aramid fiber. Furthermore, each of the plurality of optical fiber ribbons 100B may have a different marking. The optical fiber cable 60 has a structure formed by twisting a plurality of bundled optical fiber ribbons 100B, extrusion molding a resin that becomes the tube 61 around the optical fiber ribbons 100B, and covering the resultant with a jacket 64 together with a tension member 63. In a case where waterproofing is required, a water-absorbing yarn may be inserted inside the tube 61. The tube 61 can be formed by using, for example, a resin such as polybutylene terephthalate or a high-density polyethylene. On the outside of the tube 61, a tear cord 65 may be provided.

[0093] FIG. 6 is a schematic cross-sectional view of a slotted-type optical fiber cable 70 that uses the above-mentioned intermittently connected-type optical fiber ribbon 100B. The optical fiber cable 70 has a slot rod 72 having a plurality of slots 71, and a plurality of optical fiber ribbons 100B. The optical fiber cable 70 has a structure in which a plurality of slots 71 are radially provided on a slot rod 72 having a tension member

73 at the center. The plurality of slots 71 may be provided in a shape twisted into a spiral shape or an SZ shape in the longitudinal direction of the optical fiber cable 70. In each slot 71, a plurality of optical fiber ribbons 100B that have been separated from a parallel state and arranged into a densely packed state are accommodated. Each of the optical fiber ribbon 100B may be bundled with a bundling material for identification. A press-winding tape 74 is wound around the slot rod 72, and a jacket 75 is formed around the press-winding tape 74.

[0094] An optical fiber cable including the optical fiber or optical fiber ribbon according to the present embodiment has not only excellent water resistance and oil resistance but also excellent microbending resistance characteristic and low-temperature characteristics.

EXAMPLES

[0095] Hereinafter, results of evaluation tests using the Examples and Comparative Examples according to the present disclosure will be shown, and the present disclosure will be described in more detail. Meanwhile, the present disclosure is not limited to these Examples.

[0096] [Synthesis of urethane acrylate (A)]

(A-1)

Polypropylene glycol having an Mn of 3000 (manufactured by Sanyo Chemical Industries, Ltd., product name: SANNIX PP-3000) and 2,4-tolylene diisocyanate (TDI) were fed into a reaction kettle such that the molar ratio of NCO and OH (NCO/OH) was 1.5. Subsequently, 200 ppm of dibutyltin dilaurate was added based on the final total fed amount as a catalyst, and 500 ppm of 2,6-di-tert-butyl-p-cresol (BHT) was added based on the final total fed amount as a polymerization inhibitor. Then,

the mixture was reacted at 60°C for 1 hour, and an NCO-terminated prepolymer was prepared. Next, methanol was added thereto such that the molar ratio of OH of methanol with respect to NCO of the NCO-terminated prepolymer (MeOH/NCO) was 0.2, HEA was added such that the molar ratio of OH of 2-hydroxyethyl acrylate (HEA) with respect to NCO of the NCO-terminated prepolymer was 0.85, and the mixture was reacted at 60°C for 1 hour to obtain a urethane acrylate (A-1). The urethane acrylate (A-1) had an Mn of 13100 and an Mw of 17700.

[0097] (A-2)

Polypropylene glycol having an Mn of 4000 (manufactured by Sanyo Chemical Industries, Ltd., product name: SANNIX PP-4000) and TDI were fed into a reaction kettle such that the ratio of NCO/OH was 1.5. Subsequently, 200 ppm of dibutyltin dilaurate was added based on the final total fed amount as a catalyst, and 500 ppm of BHT was added based on the final total fed amount as a polymerization inhibitor. Then, the mixture was reacted at 60°C for 1 hour, and an NCO-terminated prepolymer was prepared. Next, HEA was added thereto such that the molar ratio of OH of HEA with respect to NCO of the NCO-terminated prepolymer was 1.05, and the mixture was reacted at 60°C for 1 hour to obtain a urethane acrylate (A-2). The urethane acrylate (A-2) had an Mn of 18100 and an Mw of 23400.

[0098] The Mn of each of the polypropylene glycols is a value determined from the hydroxyl group value and is a value described in the catalog of each commercially available product. The Mn and Mw of the urethane acrylates were measured using an ACQUITY APC RI system manufactured by Waters Corporation under the following conditions:

sample concentration: 0.2% by mass THF solution

injection amount: 20 μL

sample temperature: 15°C

mobile phase: THF

5 XT columns for organic solvent: particle size of 2.5 μm , pore size of 450Å, column inner diameter of 4.6 $\times$ column length of 150 mm + particle size of 2.5 μm , pore size of 125Å, column inner diameter of 4.6 $\times$ column length of 150 mm + particle size of 1.7 μm , pore size of 45Å, column inner diameter of 4.6 $\times$ column length of 150 mm

10 column temperature: 40°C

flow rate: 0.8 mL/min.

[0099] As monomers of a resin composition for primary coating, nonylphenol polyethylene glycol acrylate (manufactured by Miwon Specialty Chemical Co., Ltd., product name: Miramer M164),
 15 acryloylmorpholine (ACMO), and N-vinylcaprolactam (NVCL) were prepared. As a photopolymerization initiator, 2,4,6-trimethylbenzoyldiphenylphosphine oxide (Omnirad TPO) was prepared. As a silane coupling agent, 3-acryloxypropyltrimethoxysilane (APTMS) was prepared. As reactive surfactants, compounds represented by
 20 Formula (1) and compounds represented by Formula (2) as shown in Table 1 were prepared. As other surfactants, sorbitan monooleate (manufactured by Kao Corporation, product name: RHEODOL AO-10V) and tetraoleic acid polyoxyethylene sorbite (manufactured by Kao Corporation, product name: RHEODOL 460V) were prepared.

25 [0100] [Table 1]

	Product name	R	R ¹	R ²	X	n	m	Manufacturer
Compound represented by Formula (1)	ADEKA REA SOAP NE-10	Ethylene group	Nonylphenyl group	H	H	1	10	ADEKA Corporation
	ADEKA REA SOAP NE-20	Ethylene group	Nonylphenyl group	H	H	1	20	ADEKA Corporation
	ADEKA REA SOAP SE-10N	Ethylene group	Nonylphenyl group	H	SO ₃ NH ₄	1	10	ADEKA Corporation
	ADEKA REA SOAP ER-10	Ethylene group	Alkyl group	H	H	1	10	ADEKA Corporation
	ADEKA REA SOAP SR-10	Ethylene group	Alkyl group	H	SO ₃ NH ₄	1	10	ADEKA Corporation
Compound represented by Formula (2)	AQUALON KH-05	Ethylene group	Alkyl group	H	SO ₃ NH ₄	1	5	DKS Co. Ltd.
	AQUALON KH-10	Ethylene group	Alkyl group	H	SO ₃ NH ₄	1	10	DKS Co. Ltd.
	AQUALON KH-20	Ethylene group	Alkyl group	H	SO ₃ NH ₄	1	20	DKS Co. Ltd.

[0101] [Resin composition for primary coating]

Each component in the blending amount (parts by mass) indicated in Table 2 and Table 3 was mixed to produce a resin composition for primary coating of each Test Example. Test Examples 1 to 14 correspond to Examples, and Test Examples 15 to 17 correspond to Comparative Examples.

[0102] [Resin film]

The resin composition was applied to a polyethylene terephthalate (PET) film by using a spin coater, subsequently the resin composition was cured using an electrodeless UV lamp system (D Bulb, manufactured by Heraeus Group) under the conditions of an accumulated amount of light of 10 mJ/cm² and an illumination of 100 mW/cm², and a resin film having a thickness of 200 μm was formed on the PET film. The resin film was obtained by peeling it off from the PET film.

[0103] (Young's modulus)

The resin film was punched into a dumb-bell shape of JIS K 7127 Type-5 and pulled under the conditions of 23°C and 50 ± 10% RH, by using a tensile tester under the conditions of a tensile speed of 1 mm/min and a gauge length of 25 mm, and a stress-strain curve was obtained. The Young's modulus of the resin film was determined by dividing the stress calculated with a secant expression of 2.5% strain by the cross section of the resin film. The results are shown in the following Tables 2 and 3.

[0104] [Resin composition for secondary coating]

Polypropylene glycol having an Mn of 600 (manufactured by Sanyo Chemical Industries, Ltd., product name: PP-600) and TDI were

reacted at a ratio of NCO/OH of 2.0, and an NCO-terminated prepolymer was prepared. 200 ppm of dibutyltin dilaurate was added based on the final total fed amount as a catalyst, and 500 ppm of BHT was added based on the final total fed amount as a polymerization inhibitor. Next, HEA was added thereto such that the molar ratio of OH of HEA with respect to NCO of the NCO-terminated prepolymer was 1.05, and the mixture was reacted at 60°C for 1 hour to obtain a urethane acrylate (Z-1). The urethane acrylate (Z-1) had an Mn of 2300 and an Mw of 2700.

[0105] 25 parts by mass of the urethane acrylate (Z-1), 36 parts by mass of tripropylene glycol diacrylate, 37 parts by mass of VISCOAT #540 (manufactured by OSAKA ORGANIC CHEMICAL INDUSTRY, LTD.), 1 part by mass of Omnirad TPO, and 1 part by mass of 1-hydroxycyclohexyl phenyl ketone (Omnirad 184) were mixed to obtain a resin composition for secondary coating.

[0106] [Optical fiber]

The resin composition for primary coating and the resin composition for secondary coating were each applied to the peripheral surface of a glass fiber 13 having a diameter of 125 μm . Next, each of the resin compositions was cured by irradiating with ultraviolet rays, a coating resin layer 16 including a primary resin layer 14 and a secondary resin layer 15 was formed, and an optical fiber 10 was produced. The thickness of the primary resin layer 14 was set to 20 μm , the thickness of the secondary resin layer 15 was set to 15 μm , and an optical fiber having an outer diameter of 195 μm was obtained. Production of the optical fiber was carried out at a production speed of 3000 m/min.

[0107] (Water resistance)

The optical fiber 10 was immersed in water at 23°C such that the entire coating resin layer 16 completely submerged, and the transmission loss of light having a wavelength of 1550 nm was measured by an optical time domain reflectometer (OTDR) method. Next, the optical fiber 10 was immersed for 120 days, and then the transmission loss of light having a wavelength of 1550 nm was measured by the OTDR method. A case where the increase in the transmission loss was less than 0.03 dB/km was evaluated as "A"; a case where the increase was 0.03 dB/km or more and less than 0.05 dB/km was evaluated as "B"; and a case where the increase was 0.05 dB/km or more was evaluated as "C". The results are shown in the following Tables 2 and 3.

[0108] (Oil resistance)

The optical fiber 10 was immersed in a jelly heated to 85°C for 120 days such that the entire coating resin layer 16 completely submerged. The jelly was obtained by adding a thickener to mineral oil having an Mn of about 300 to 600. The transmission loss of light having a wavelength of 1550 nm was measured by the OTDR method under each of the temperature conditions of 23 and -40°C. A case where the difference (transmission loss difference) obtained by subtracting the transmission loss at 23°C from the transmission loss at -40°C was less than 0 dB/km (transmission loss at -40°C was smaller) was evaluated as "A"; a case where the difference was 0 dB/km or more and less than 0.01 dB/km was evaluated as "B"; and a case where the difference was 0.01 dB/km or more was evaluated as "C". The results are shown in the following Tables 2 and 3.

[0109] (Low-temperature characteristics)

The optical fiber was wound in one layer around a glass bobbin at a tension of 50g, the transmission characteristics of signal light having a wavelength of 1550 nm were measured by the OTDR method under each of the temperature conditions of 23 and -40°C, and the transmission loss was determined. A case where the transmission loss difference obtained by subtracting the transmission loss at 23°C from the transmission loss at -40°C was less than 0 dB/km was evaluated as "A"; a case where the transmission loss difference was 0 dB/km or more and 0.01 dB/km or less was evaluated as "B"; and a case where the transmission loss difference was more than 0.01 dB/km was evaluated as "C". The results are shown in the following Tables 2 and 3.

[0110] (Microbending resistance characteristics)

The transmission loss of light having a wavelength of 1550 nm obtained when the optical fiber 10 was wound in a single layer around a bobbin having the surface covered with sandpaper and having a diameter of 280 mm, was measured by the optical time domain reflectometer (OTDR) method. The transmission loss of light having a wavelength of 1550 nm obtained when the optical fiber 10 was wound in a single layer around a bobbin without sandpaper and having a diameter of 280 mm was measured, and a case where the difference between the two transmission losses was less than 0.5 dB/km was evaluated as "A"; a case where the difference was 0.5 dB/km or more and 1.0 dB/km or less was evaluated as "B"; while a case where the difference was more than 1.0 dB/km was evaluated as "C". The results are shown in the following Tables 2 and 3.

[0111] [Table 2]

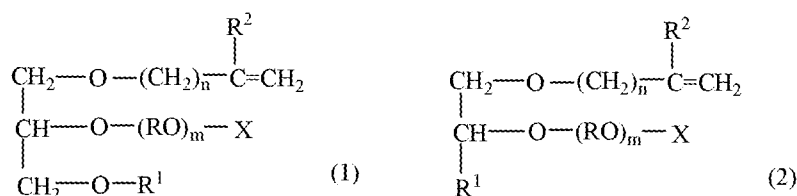
Test Example	1	2	3	4	5	6	7
A-1	75	—	—	—	—	—	—
A-2	—	75	75	75	75	75	75
Miramir M164	17.5	17.5	14.95	14.9	14.5	12.5	11.5
ACMO	—	—	3	3	3	3	3
NVCL	5	5	5	5	5	5	5
ADEKA REASOAP NE-10	0.5	0.5	0.05	0.1	0.5	2.5	3.5
Omni-rad TPO	1	1	1	1	1	1	1
APTMS	1	1	1	1	1	1	1
Young's modulus (Mpa)	0.69	0.34	0.37	0.37	0.37	0.36	0.33
Water resistance	A	A	B	A	A	A	A
Oil resistance	A	A	B	A	A	A	A
Low-temperature characteristics	A	A	A	A	A	A	B
Microbending resistance characteristics	B	A	A	A	A	A	A

CONCLUSIES

1. Een harssamenstelling voor primaire coating van een optische vezel, bestaande uit:

- 5 een fotopolymeriseerbare verbinding die een urethaan(meth)acrylaat en een reactieve oppervlakteactieve stof omvat; en een initiator van fotopolymerisatie,

10 waarbij de reactieve oppervlakteactieve stof ten minste één verbinding omvat die is geselecteerd uit de groep die bestaat uit een verbinding die wordt weergegeven door de volgende formule (1) en een verbinding die wordt weergegeven door de volgende formule (2):



15 (waarin R een alkyleengroep vertegenwoordigt met 2 tot 4 koolstofatomen; R¹ vertegenwoordigt een koolwaterstofgroep met 1 tot 20 koolstofatomen; R² staat voor een waterstofatoom of een methylgroep; X staat voor een waterstofatoom of een -SO₃NH₄-groep; m staat voor een geheel getal van 0 tot 100; en n staat voor een geheel getal van 0 tot 12).

20 2. De harssamenstelling volgens conclusie 1, waarbij het gehalte aan de reactieve oppervlakteactieve stof 0,01 massadelen of meer is en 5,0 massadelen of minder op basis van een totale hoeveelheid van 100 massadelen van de harssamenstelling.

25 3. De harssamenstelling volgens conclusie 1, waarbij het gehalte aan reactieve oppervlakteactieve stof 0,05 massadelen of meer is en 3,5 massadelen of minder op basis van een totale hoeveelheid van 100 massadelen van de harssamenstelling.

4. De harssamenstelling volgens conclusie 1, waarbij de fotopolymeriseerbare verbinding verder een N-vinylverbinding omvat, en een

gehalte van de N-vinylverbinding 1 massadeel of meer is en 15 massadelen of minder op basis van een totale hoeveelheid van 100 massadelen van de harssamenstelling.

5. De harssamenstelling volgens conclusie 1, waarbij een Young's modulus
5 van een harsfilm verkregen door ultraviolette uitharding van de harssamenstelling onder de omstandigheden van een geaccumuleerde hoeveelheid licht van 10 mJ/cm² en een verlichting van 100 mW/cm², 0,10 MPa of meer en 0,80 MPa of minder bij 23°C.

6. De harssamenstelling volgens conclusie 5, waarbij de Young's modulus
10 van de harsfilm 0,10 MPa of meer is en 0,60 MPa of minder bij 23°C.

7. Een optische vezel bestaande uit:

een glasvezel inclusief een kern en een bekleding;

een primaire harslaag die in contact komt met de glasvezel en de glasvezel bedekt; en

15 een secundaire harslaag die de primaire harslaag bedekt;

waarbij de primaire harslaag een uitgehard product van de harssamenstelling bevat volgens een van de conclusies 1 tot en met 6.

8. Een methode voor het produceren van een optische vezel, bestaande uit:

een toepassingsstap van het aanbrengen van de harssamenstelling volgens

20 een van de conclusies 1 tot en met 6 op een omtrek van een glasvezel met inbegrip van een kern en een bekleding; en

een uithardingsstap van het uitharden van de harssamenstelling door bestraling met ultraviolette stralen na de toepassingsstap.

9. Een glasvezellint, waarin een veelvoud van de optische vezels
25 volgens conclusie 7 parallel is gerangschikt en bedekt met een hars als lint.

10. Een optische vezelkabel, waarbij het glasvezellint volgens conclusie 9 in een kabel is ondergebracht.

11. Een optische vezelkabel, waarbij een veelvoud van de optische vezels volgens conclusie 7 in een kabel is ondergebracht.

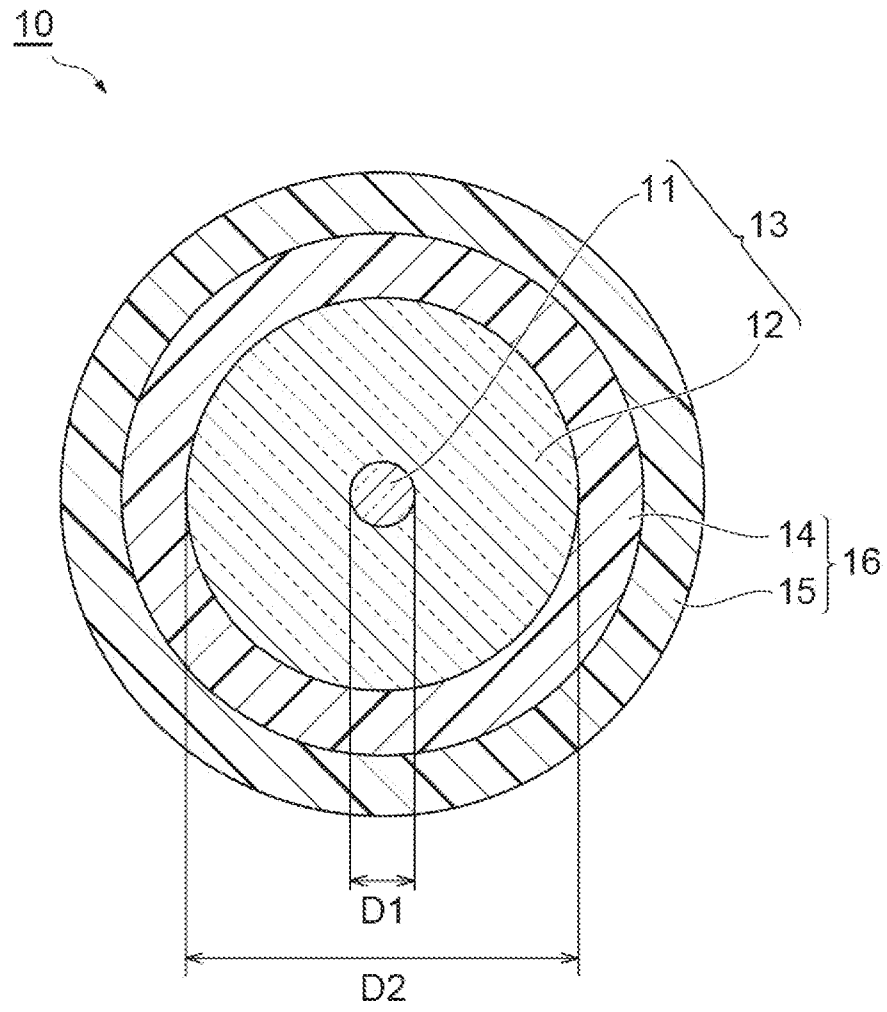
Fig.1

Fig.2

2 / 6

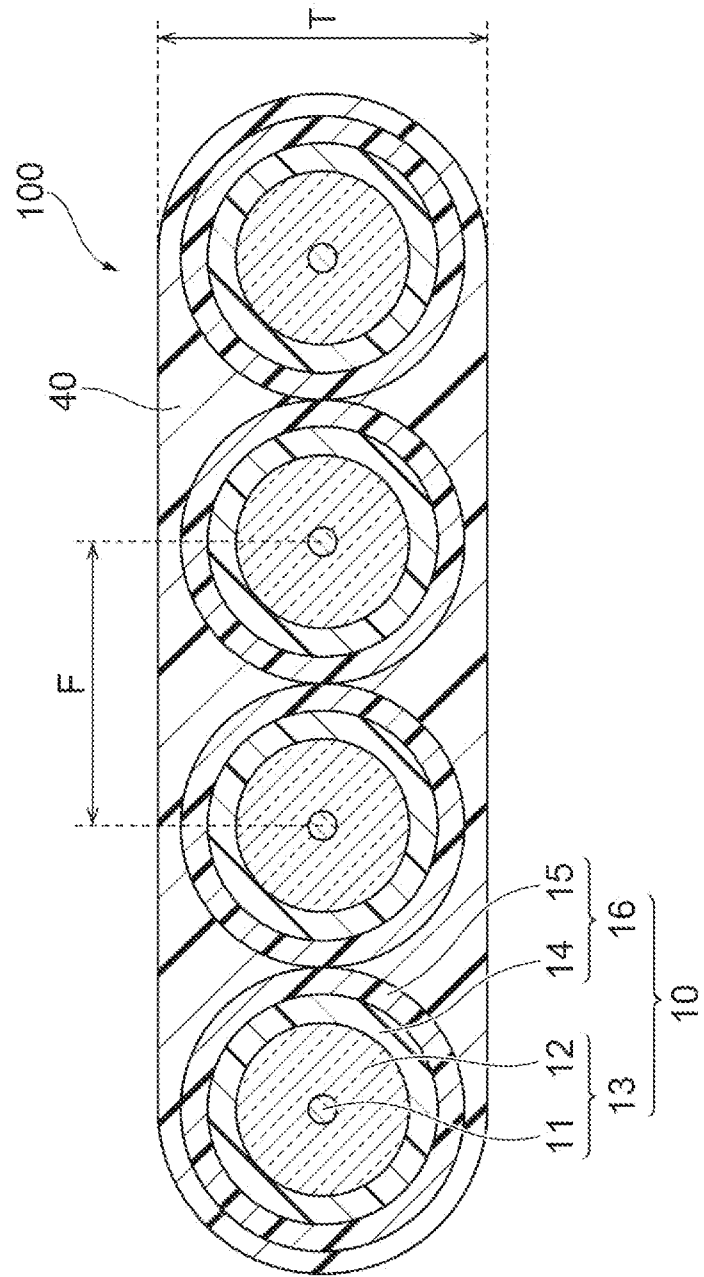


Fig.3

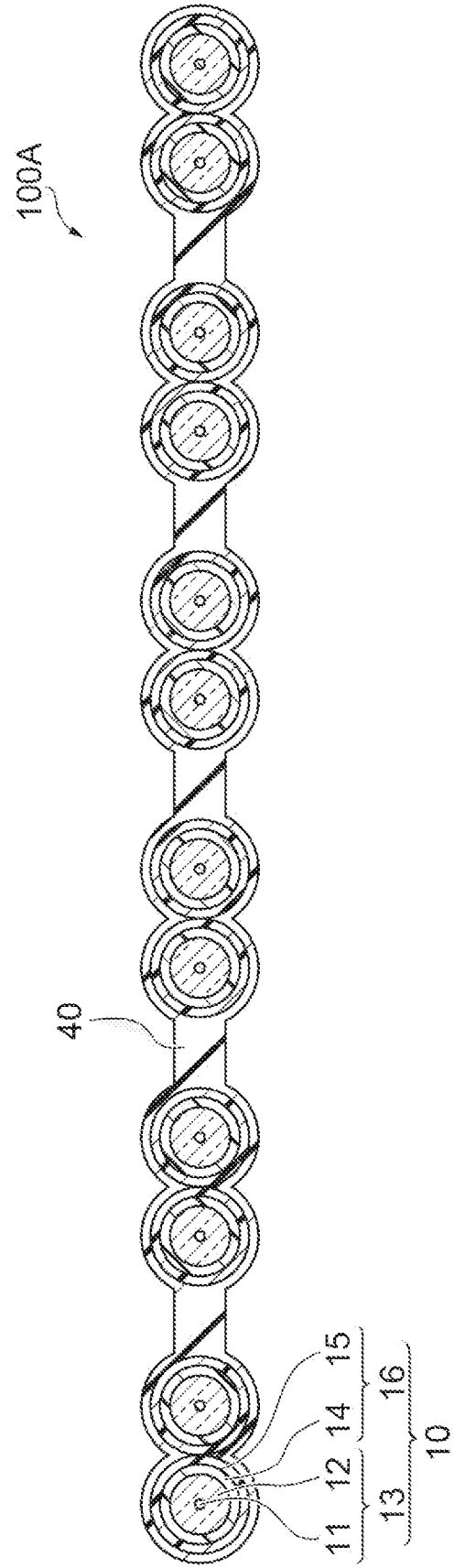


Fig.4

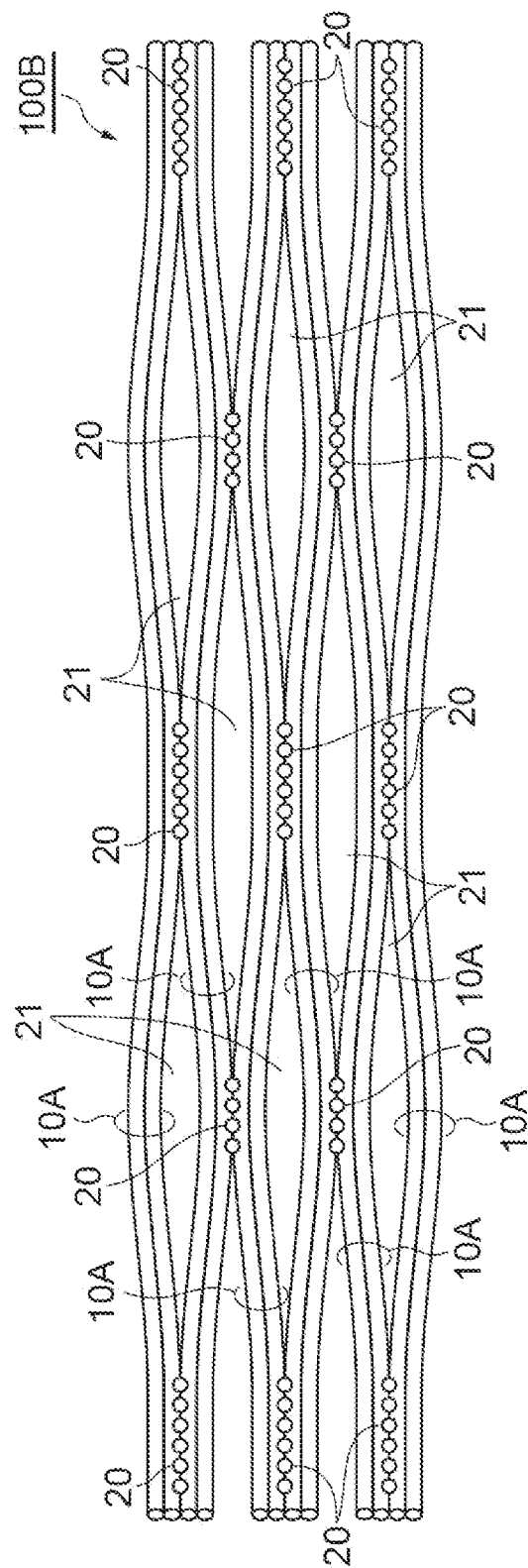


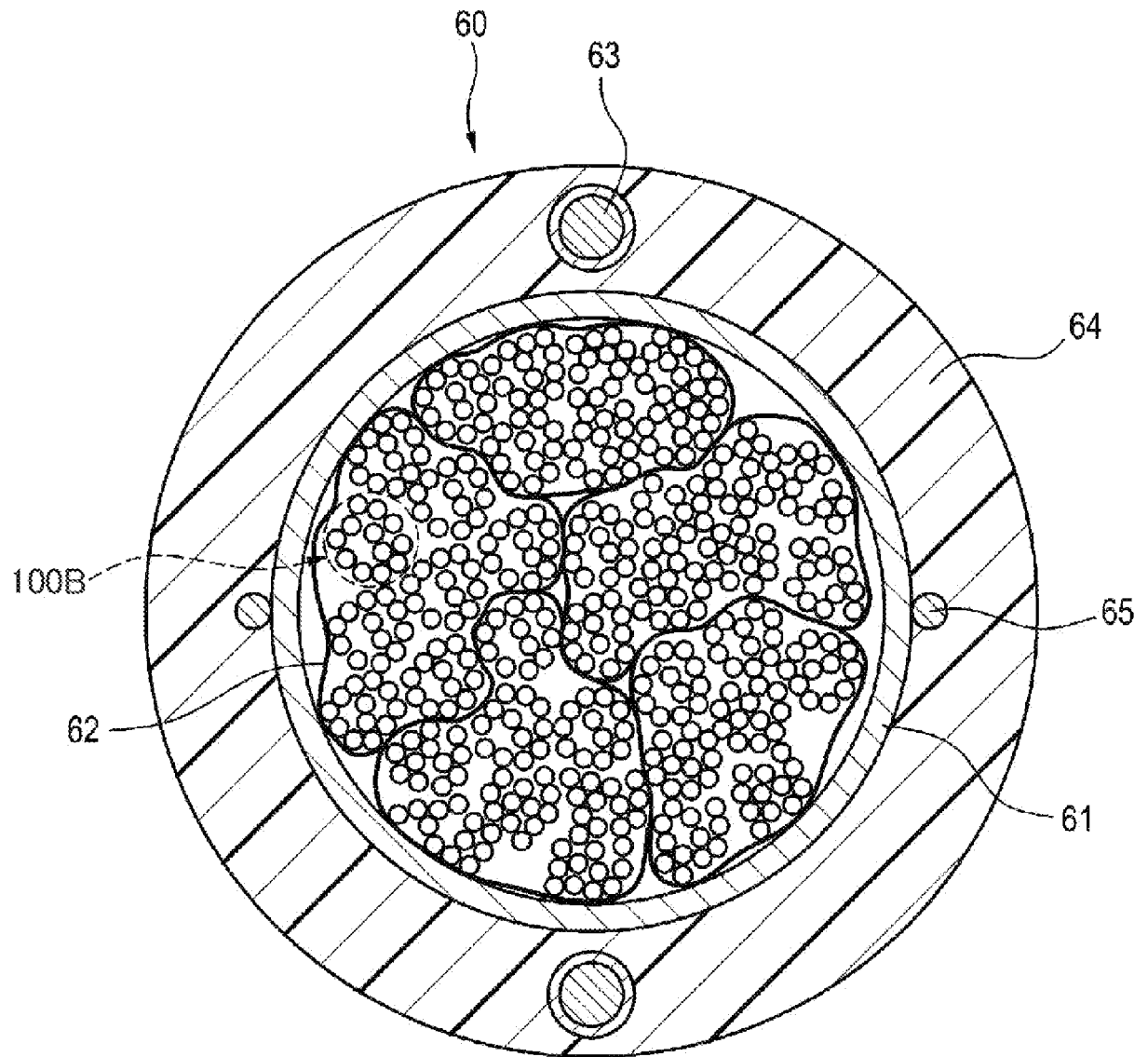
Fig.5

Fig.6