



(11) **EP 3 006 611 A1**

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
13.04.2016 Bulletin 2016/15

(21) Application number: **14808311.6**

(22) Date of filing: **28.05.2014**

(51) Int Cl.:
D02G 3/22 (2006.01) **D07B 1/02** (2006.01)
D07B 1/16 (2006.01) **E04C 5/07** (2006.01)
D06M 15/55 (2006.01)

(86) International application number:
PCT/JP2014/064127

(87) International publication number:
WO 2014/196432 (11.12.2014 Gazette 2014/50)

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**
Designated Extension States:
BA ME

(30) Priority: **05.06.2013 JP 2013119113**

(71) Applicant: **Komatsu Seiren Co., Ltd.**
Nomi-City
Ishikawa 929-0124 (JP)

(72) Inventors:
• **HAYASHI, Yutaka**
Nomi-City
Ishikawa 929-0124 (JP)

• **NAKAYAMA, Taketoshi**
Nomy-City
Ishikawa 929-0124 (JP)
• **NODA, Honami**
Nomy-City
Ishikawa 929-0124 (JP)

(74) Representative: **Winter, Brandl, Fürniss, Hübner,
Röss, Kaiser, Polte - Partnerschaft mbB**
Patent- und Rechtsanwaltskanzlei
Alois-Steinecker-Strasse 22
85354 Freising (DE)

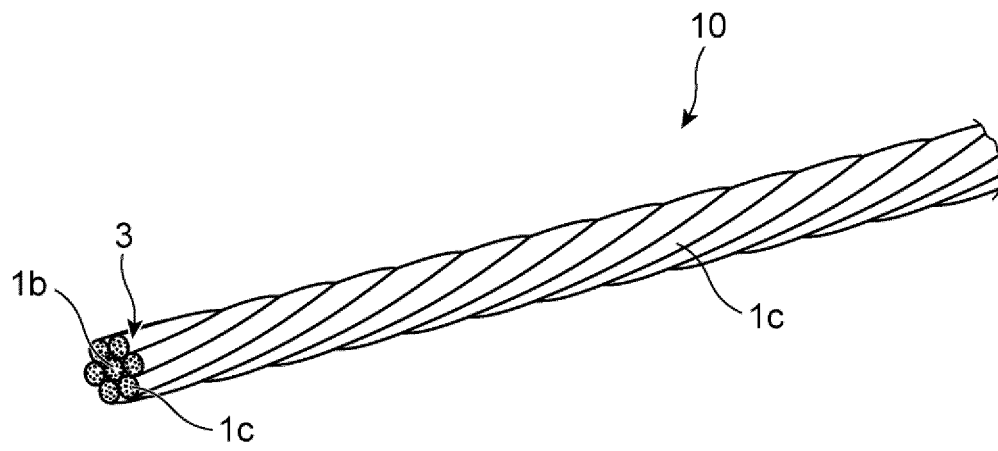
(54) **HIGH-STRENGTH FIBER COMPOSITE, STRAND STRUCTURE, AND MULTI-STRAND STRUCTURE**

(57) Provided are a high-strength fiber composite and an applied product thereof, whereby it is possible for the inherent tensile strength of high-strength fiber yarns to be obtained, even when used in applications in which bending stress occurs, such as wires, or when stored while wound around a drum or the like. This high-strength fiber composite has a core produced by imparting twist to a high-strength fiber bundle produced by bundling high-strength fiber yarns, and a stiffening the twisted high-strength fiber bundle with a stiffening agent. In this high-strength fiber composite, the high-strength fiber yarns are resistant to breakage even when flexed, have a superior shearing strength, and can maintain the inher-

ent tensile strength of high-strength fibers, even when used in applications in which bending stress occurs, such as wires, or when stored while wound onto a drum or the like. The strand structure, which has a strand construction composed of two or more of the high-strength fiber composites twisted together, maintains the inherent strength of the high-strength fibers, and affords more consistent tensile strength, as compared with when an equal number of high-strength fiber composites lacking the strand construction are used.

EP 3 006 611 A1

FIG. 4



Description

FIELD OF THE INVENTION

[0001] The invention relates to a high-strength fiber composite including a core comprised of bundled high-strength fiber yarns, a strand structure comprised of the high-strength fiber composites, and a multi-strand structure comprised of the strand structures.

BACKGROUND ART

[0002] A carbon fiber is excellent in physical properties such as a tensile strength and an elastic modulus, and a resistance to corrosion caused by acid and alkali, and further, is lightweight. Consequently, a carbon fiber is employed in various fields in industries such as an automobile, an airplane, electric/electronic devices, a toy, and domestic appliances, and is attempted to be applied to architectures. For instance, the patent document 1 suggests an example in which a carbon fiber composite is employed as a tensile member of a brace in a frame in order to enhance earthquake-proof of a building. Furthermore, the patent document 2 suggests an example of a wire made of carbon fiber composites.

[0003] A carbon fiber composite is able to enhance a tensile strength and a bending strength, but is accompanied with a problem of being weak against a shearing force. This problem is found not only in a carbon fiber yarn, but also in a high-strength fiber composite fabricated by bundling fibers called high-strength fibers such as basalt fiber yarns in a common direction to thereby fabricate a high-strength fiber bundle, and covering the thus fabricated high-strength fiber bundle at an outer surface thereof with another fiber.

[0004] In addition, the inventors have reported, in the patent document 3, a high-strength fiber composite (a cord-shaped reinforced fiber composite) including an internal layer comprised of a core composed of one or more bundle(s) of cord-shaped carbon fibers, an intermediate layer including resin surrounding the core, and an external layer comprised of a cylindrically knit cord surrounding the intermediate layer. The high-strength fiber composite has a superior tensile strength derived from carbon fibers, a superior shearing strength, and is able to change a shape thereof in the preferred embodiment of the high-strength fiber composite.

[0005] On the other hand, in the case that a bending stress is exerted onto the high-strength fiber composite, for instance, when the high-strength fiber composite is wound by means of a wire or a rope around a drum having a small diameter, the carbon fiber bundles defining the core of the high-strength fiber composite are sometimes partially broken, resulting in that a tensile strength of the high-strength fiber composite at an entirety thereof is afraid to be deteriorated. Furthermore, in the case that the high-strength fiber composite is employed as a rod of a tensile member, the high-strength fiber composite is

afraid to be accompanied with the above-mentioned problem, because the high-strength fiber composite having a great length is sometimes stored in such a condition as being wound around a drum.

PRIOR ART DOCUMENTS

PATENT DOCUMENTS

10 [0006]

Patent document 1: Japanese Patent Application Publication 2006-348506

Patent Document 2: United States Patent Application Publication 2008/0028740

Patent Document 3: Japanese Patent Application Publication 2012-136814

SUMMARY OF THE INVENTION

PROBLEM(S) TO BE SOLVED BY THE INVENTION

[0007] As mentioned above, a high-strength fiber composite comprised of a bundle of high-strength fibers fabricated by twisting high-strength fiber yarns such as carbon fiber yarns is accompanied with a problem that when the high-strength fiber composite is used under a bending stress, for instance, when the high-strength fiber composite is used as a wire or a rope, or when the high-strength fiber composite is stored in a condition of being wound around a drum, the high-strength fiber composite is sometimes not able to sufficiently provide superior inherent performances of high-strength fiber yarns, and thus, there is a need for improvement.

[0008] In view of the above-mentioned problem in the conventional high-strength fiber composite, it is an object of the present invention to provide a high-strength fiber composite capable of having an inherent tensile strength of high-strength fiber yarns, even when the high-strength fiber composite is used under a bending stress, and to provide products to which the high-strength fiber composite is applied.

SOLUTION TO THE PROBLEM(S)

[0009] The present invention provides the followings.

<1> A high-strength fiber composite including a core comprised of a bundle of high-strength fiber yarns, the bundle being twisted and stiffened with a stiffening agent.

<2> The high-strength fiber composite as set forth in <1>, further including a constraint wound around the bundle, the bundle and the constraint being stiffened together with the stiffening agent with the bundle being kept twisted, to define the core.

<3> The high-strength fiber composite as set forth in <1> or <2>, wherein a number of twisting the bun-

dle is in the range of 2 to 50 times per a meter both inclusive.

<4> The high-strength fiber composite as set forth in any one of <1> to <3>, wherein the stiffening agent is composed of thermoplastic resin.

<5> The high-strength fiber composite as set forth in <4>, wherein the thermoplastic resin is thermoplastic epoxy resin.

<6> The high-strength fiber composite as set forth in any one of <1> to <5>, wherein the core has a diameter in the range of 1 to 5 mm both inclusive.

<7> The high-strength fiber composite as set forth in any one of <1> to <6>, wherein the high-strength fiber yarns include carbon fiber or basalt fiber.

<8> A strand structure including a strand construction comprised of two or more twisted high-strength fiber composites defined in any one of <1> to <7>.

<9> The strand structure as set forth in <8>, wherein a number of twisting the high-strength fiber composites is in the range of 1.1 to 50 times per a meter both inclusive.

<10> The strand structure as set forth in <8> or <9>, wherein a number of the high-strength fiber composites defining the strand structure is 2 to 40 both inclusive.

<11> A multi-strand structure including a strand construction comprised of two or more twisted strand structures defined in any one of <8> to <10>.

<12> The multi-strand structure as set forth in <11>, wherein a number of twisting the strand structures is in the range of 0.3 to 30 times per a meter both inclusive.

<13> The multi-strand structure as set forth in <11> or <12>, wherein a number of the strand structures defining the multi-strand structure is in the range of 2 to 40 both inclusive.

[0010] Namely, the first aspect of the present invention in the application relates to a high-strength fiber composite including a core comprised of a bundle of high-strength fiber yarns, the bundle being twisted and stiffened with a stiffening agent.

[0011] In the above-identified high-strength fiber composite, since the core defining the high-strength fiber composite is stiffened with a stiffening agent in a condition that the bundle of high-strength fiber yarns are twisted, even if an external intensive force acts on the high-strength fiber composite, it is possible to prevent the high-strength fiber yarns defining the high-strength fiber bundle from being untied from one another, ensuring that the high-strength fiber yarns can stably have an inherent tensile strength thereof.

[0012] Furthermore, since the high-strength fiber yarns defining the high-strength fiber bundle are not untied from one another because the high-strength fiber bundle is stiffened with a stiffening agent in a condition that the bundle of high-strength fiber yarns are twisted, the high-strength fiber composite can have enhanced (stabilized)

handling property and strength, and the high-strength fiber yarns are hardly broken even if bent. If the high-strength fiber bundle is not twisted, the high-strength fiber composite may be broken in the case that the high-strength fiber composite is wound around a drum, or that the high-strength fiber composite is employed in such a condition that a bending stress acts thereon. Consequently, it is afraid that the high-strength fiber composite (and accordingly, a later-mentioned strand structure comprised of the high-strength fiber composite) cannot be employed, and cannot have an inherent strength of the high-strength fiber yarns. In addition, if the high-strength fiber bundle is not twisted, there may occur fluctuation in a length of each of the high-strength fiber yarns in the high-strength fiber bundle, the high-strength fiber bundle cannot have an inherent strength of a high-strength fiber which each of the high-strength fiber yarns have, resulting in that the high-strength fiber bundle may be short in a strength as an entirety thereof.

[0013] By imparting twist to the high-strength fiber bundle, it is possible to prevent the high-strength fiber composite from being broken, and the high-strength fiber yarns defining the high-strength fiber bundle can have a uniformized length, ensuring an inherent strength of a high-strength fiber. Thus, the high-strength fiber composite can keep an intensive tensile strength, even if a bending stress acts thereon, specifically, when the high-strength fiber composite is stretched after having been wound around a drum, or when the high-strength fiber composite is pulled with the high-strength fiber composite being kept bent.

[0014] If the high-strength fiber bundle is merely twisted without being stiffened with a stiffening agent, the resultant high-strength fiber composite can have a strength smaller than the same of the high-strength fiber composite in accordance with the present invention in which the high-strength fiber bundle is stiffened with a stiffening agent.

[0015] The high-strength fiber composite in accordance with the present invention may be designed to include any one of high-strength fibers to be described later in the embodiments. It is preferable for the high-strength fiber to include basalt fibers or carbon fibers, and more preferable to include carbon fibers. Accordingly, it is preferable for the high-strength fiber yarns defining the high-strength fiber bundle to include carbon fibers or basalt fibers, more preferable to be carbon fibers or basalt fibers, and particularly preferable to be carbon fibers.

[0016] Basalt fiber and carbon fiber have a high tensile strength, but have a low shearing strength, and accordingly, are easy to be broken. Consequently, in the case that a high-strength fiber composite including basalt fibers or carbon fibers are used under a bending stress, for instance, a high-strength fiber composite is used as a wire or a rope, or stored in a condition of being wound around a drum, the high-strength fiber composite is easy to be broken. However, by imparting twist to a high-strength fiber bundle comprised of basalt fibers or carbon

fibers, a high-strength fiber composite can be prevented from being broken even if a force acts thereon in a direction perpendicular to a length-wise direction of the high-strength fiber composite. Thus, the high-strength fiber composite including a high-strength fiber bundle comprised of basalt fibers or carbon fibers is able to have an inherent tensile strength of basalt fiber or carbon fiber, even if a bending stress acts thereon.

[0017] It is preferable for the high-strength fiber composite in accordance with the present invention to further include a constraint wound around the high-strength fiber bundle, the high-strength fiber bundle and the constraint being stiffened together with the stiffening agent with the high-strength fiber bundle being kept twisted, to define the core.

[0018] By winding a constraint around the twisted high-strength fiber bundle to thereby tie high-strength fibers together, and further by stiffening the high-strength fiber bundle and the constraint together with a stiffening agent to thereby define a core, it is possible to prevent high-strength fiber yarns defining the high-strength fiber bundle from being twisted, crossed and/or untied from one another, even if an external intensive force acts thereon, ensuring that the high-strength fiber composite is able to keep having a tensile strength inherent to high-strength fibers. In particular, by using twisted high-strength fiber bundle, the high-strength fiber composite can be prevented from being broken after being stiffened with a stiffening agent, even if a bending stress acts thereon.

[0019] Any constraint can be used, if it can be wound around a high-strength fiber bundle to thereby keep the high-strength fiber bundle twisted. In particular, it is preferable that a constraint covers an entire circumference of a high-strength fiber bundle therewith. By covering entirely circumferentially a high-strength fiber bundle (in particular, carbon fibers or basalt fibers) with a constraint, it is possible to obtain the above-mentioned advantages, and further possible to prevent the high-strength fiber yarns from being cut, even if the high-strength fiber makes contact with sharpened materials such as pebbles.

[0020] It is preferable for the constraint for bundling the high-strength fiber bundle to have a braid structure, because the high-strength fiber bundle can be covered therewith to such a degree that a surface of the high-strength fiber bundle is not visible with eyes, and accordingly, the constraint not only bundles the high-strength fiber bundle, but also acts as a protection layer for protecting high-strength fiber yarns of which the internal high-strength fiber bundle is comprised.

[0021] If the high-strength fiber bundle is not twisted, the high-strength fiber yarns defining the high-strength fiber bundle sometimes spring out beyond the constraint before being stiffened with a stiffening agent. By employing a twisted high-strength fiber bundle, it is possible to prevent the high-strength fiber yarns defining the high-strength fiber bundle from being twisted, crossed, untied, broken and/or cut, even if an external intensive force acts

thereon, ensuring that it is possible to maintain handling property of the high-strength fiber bundle even before the high-strength fiber bundle is stiffened with a resin, and hence, the high-strength fiber composite can sufficiently have an inherent tensile strength thereof.

[0022] In the present invention, a number of twisting the high-strength fiber bundle is preferably in the range of 2 to 50 times per a meter both inclusive, and more preferably in the range of 4 to 40 times per a meter both inclusive. The number is preferably is equal to or greater than 10 times per a meter, more preferably is equal to or greater than 15 times per a meter, and most preferably is equal to or greater than 20 times per a meter. The upper limit of the number is equal to or smaller than 50 times per a meter, and preferably is equal to or smaller than 40 times per a meter. If the number of twisting the high-strength fiber bundle is smaller than 2 times per a meter, the advantages obtained by twisting the high-strength fiber bundle are afraid of turning insufficient, and if the number is greater than 50 times per a meter, the high-strength fiber yarns defining the high-strength fiber bundle are afraid of being cut during being twisted.

[0023] As the stiffening agent to be used, there may be selected a thermoplastic resin or a thermosetting resin. It is preferable to select a thermoplastic resin, because it can be readily thermally deformed, can be readily wound around a thin drum while being heated, and can readily form a later-mentioned strand structure. Furthermore, it is preferable for the stiffening agent to have high affinity with the high-strength fiber yarns.

[0024] The stiffening agent will be explained in detail in the later-mentioned embodiments. It is preferable to select as a thermoplastic resin a thermoplastic epoxy resin (in particular, a thermoplastic epoxy resin having a straight-chain shaped polymeric structure). Among thermoplastic epoxy resins, it is preferable to employ a polymer type thermoplastic epoxy resin (in particular, a thermoplastic epoxy resin having a straight-chain shaped polymeric structure).

[0025] It is preferable in the high-strength fiber composite in accordance with the present invention that the core has a diameter in the range of 1 to 5 mm both inclusive. A diameter of the core is defined as the greatest diameter among diameters of portions of the high-strength fiber composite. In the case that the high-strength fiber composite includes a constraint, a thickness of the constraint is included in a diameter of the core.

[0026] By designing the core to have a diameter in the above-identified range, it is possible to wind the high-strength fiber composite around a drum having a small diameter (for instance, a drum having a diameter equal to or smaller than 70 cm), without heating the high-strength fiber composite. Furthermore, a strand structure comprised of the high-strength fiber composites can be readily wound around a drum having a small diameter, and the strand structure would have a large area when the strand structure is adhered at an end thereof to a jig for fixation, ensuring contribution to enhancement in an

adhesion strength of the strand structure with the jig.

[0027] Furthermore, the high-strength fiber composite in accordance with the present invention includes at least the above-mentioned core, and may be colored at an outer surface thereof, and/or may further include a protection layer covering an outermost layer therewith.

[0028] In the second aspect of the present invention, there is provided a strand structure including a strand construction comprised of two or more twisted high-strength fiber composites in accordance with the first aspect of the present invention.

[0029] Herein, "a strand construction" means a construction comprised of two to tens of strands twisted together in a single layer or a plurality of layers, the strands having a common diameter of diameters different from one another. The strand structure in accordance with the second aspect of the present invention is characterized in including, as strands, the high-strength fiber composites in accordance with the first aspect of the present invention.

[0030] Since the strand structure in accordance with the second aspect of the present invention is comprised of the high-strength fiber composites having the above-mentioned properties, the strand structure can act as a composite maintaining the above-mentioned performances of the high-strength fiber composite in accordance with the present invention, and further, being superior in a tensile strength.

[0031] A strand structure in accordance with a second aspect of the present invention can be fabricated by drawing elongate high-strength fiber composites out of a creel by a requisite number, and twisting them. In the case that a thermoplastic resin is used as the above-mentioned stiffening agent, it is preferable that the high-strength fiber composites are twisted while being heated at a temperature at which the thermoplastic resin is softened.

[0032] The thus fabricated strand structure is elongate, and can be stored in such a condition as being wound around a drum, similarly to the high-strength fiber composite. The strand structure is cut into pieces having a suitable length, and can be used as a wire, a rope, and so on. As an alternative, the strand structure may be cut into a rod-shape, and can be used as a reinforcing bar of concrete or a tensile member.

[0033] By being twisted, the resultant strand structure can be wholly tied with one another, ensuring is possible to prevent the strand structure from being untied from one another, and further ensuring that a tensile strength thereof can be maintained stable.

[0034] The strand structure in accordance with a second aspect of the present invention includes the high-strength fiber composites by two or greater. A number of the high-strength fiber composites to be included in the strand structure is determined in dependence on target performances (in particular, a tensile strength) and an intended use thereof. The number is generally in the range of 2 to 40 both inclusive, and preferably in the range of 7 to 37 both inclusive. If the number is greater than

40, it is afraid that it is difficult to twist the strand structure at a predetermined pitch.

[0035] A process of twisting the strand structure in accordance with a second aspect of the present invention may include steps of (1) bundling a requisite number of the high-strength fiber composites, and imparting twist wholly to the thus bundled high-strength fiber composites, or (2) centrally arranging a single or a plurality of the high-strength fiber composite(s) as a core, arranging other high-strength fiber composites to surround the core high-strength fiber composite(s), and imparting twist to the core high-strength fiber composite(s) and the other high-strength fiber composites together.

[0036] It is preferable that a number of twisting the strand structure in accordance with a second aspect of the present invention is in the range of 1.1 to 50 times per a meter both inclusive, regardless of whether the above-mentioned steps (1) or (2) are carried out. In particular, in the case that a number of the high-strength fiber composites defining the strand structure is in the range of 7 to 37 both inclusive, a number of twisting the strand structure is preferably in the range of 1.5 to 20 times per a meter.

[0037] As a third aspect of the present invention, there is provided a multi-strand structure including a strand construction comprised of two or more twisted strand structures, each strand structure being in accordance with the above-mentioned second aspect of the present invention. Herein, "a multi-strand construction" means a construction in which the strand structure in accordance with a second aspect of the present invention is used as a strand, and two to tens of strands (the strand structures) are twisted in a single layer or a plurality of layers, the strands having a common diameter with one another or having different diameters from one another.

[0038] By designing the strand construction (the multi-strand construction) to be comprised of twisted strand structures, as mentioned above, the resultant multi-strand construction can have a greater strength than a strand construction merely including strand structures by the same number. Thus, the multi-strand structure is useful particularly for a case that a high tensile strength is required, such as a reinforcing bar, a PC steel wire, or a PC steel member to be used in a big building, and a wire to be used in place of chains for mooring a big vessel.

[0039] The multi-strand structure in accordance with a third aspect of the present invention has advantages in having good handling property, because the strand structures defining the multi-strand structure are more difficult to be untied from one another than a multi-strand structure merely including the strand structures by the same number, and further, in having a stable strength.

[0040] A number of the strand structures (in accordance with a second aspect of the present invention) to define the multi-strand structure in accordance with a third aspect of the present invention is at least two, and is determined in dependence on required performances (in particular, a tensile strength) and uses thereof. The

number is generally in the range of 2 to 40 both inclusive. If a number of the strand structures for defining the multi-strand structure is greater than 40, it is afraid to be difficult to twist the strand structures at a predetermined pitch. The number is preferably in the range of 7 to 37 both inclusive.

[0041] A process of twisting the multi-strand structure in accordance with a third aspect of the present invention may include steps of (1) bundling a requisite number of the strand structures, and imparting twist wholly to the thus bundled strand structures, or (2) centrally arranging a single or a plurality of the strand structure(s) as a core (hereinafter, called "core strand"), arranging other strand structures to surround the core strand, and imparting twist to the core strand and the other strand structures together.

[0042] It is preferable that a number of twisting the multi-strand structure in accordance with a third aspect of the present invention is in the range of 0.3 to 30 times per a meter both inclusive, regardless of whether the above-mentioned steps (1) or (2) are carried out. In particular, in the case that a number of the strand structures defining the multi-strand structure is in the range of 7 to 37 both inclusive, a number of twisting the multi-strand structure is preferably in the range of 0.5 to 15 times per a meter.

[0043] The high-strength fiber composite in accordance with a first aspect of the present invention, the strand structure in accordance with a second aspect of the present invention, and the multi-strand structure in accordance with a third aspect of the present invention are applicable to all industrial fields such as civil engineering works, architecture, construction, vessel, mining and fishery, and are not to be limited with respect to an intended use thereof.

[0044] The high-strength fiber composite, the strand structure, and the multi-strand structure all in accordance with the present invention have a superior strength derived from high-strength fibers, and are lightweight, they can be preferably used in an architecture such as a steel skeleton construction, reinforced concrete, and a wooden building, and further in a brace member and a reinforcing member (including being used as a replacement of a reinforcing metal) both used as a bridge. Furthermore, since they have a sufficient strength, even though they are thin, they can be used in various items, for instance, a wire for suspending a furniture such as a light or a table, or a step, an interior such as a partition, a table, a chair, and a hand rail, a fence, a wall, an ivy support used for a green wall, and an exterior such as a net, ensuring fabrication of a building being superior in a design. In addition, they are useful as a replacement with chains used for mooring a vessel or a facility for carrying out wind power generation on a sea, both being likely to be suffered from salt damage. Furthermore, since they are difficult to be broken, even if a bending stress acts thereon, they can be preferably used as a long one by wind them around a drum, or used under a bending stress

environment.

[0045] The high-strength fiber composite, the strand structure, and the multi-strand structure all in accordance with the present invention may be colored at an outer surface thereof, or may be designed to further include a protection layer as an outermost layer.

[0046] Furthermore, the high-strength fiber composite (or the strand structure or the multi-strand structure) in accordance with the present invention may be compounded with any other item into a compound-structure item. As a preferable compound-structure item, there is provided a compound-structure item including the high-strength fiber composite (or the strand structure or the multi-strand structure) and a jig, wherein the high-strength fiber composite (or the strand structure or the multi-strand structure) is inserted through at least one of ends thereof into a body of the jig, and then, the high-strength fiber composite (or the strand structure or the multi-strand structure) is fixedly adhered at the end to the body of the jig to thereby define a compound-structure item in which the high-strength fiber composite (or the strand structure or the multi-strand structure) and the jig are joined into one piece.

[0047] In particular, in the strand structure fabricated by twisting a plurality of the high-strength fiber composites, the twisted high-strength fiber composites are not bundled together by means of a stiffening agent. Accordingly, the strand structure would have an increased surface area, ensuring that a contact strength with the jig is increased and stabilized. Thus, the strand structure is superior in stability in particular of a tensile strength and a strength, and hence, the compound-structure item including the high-strength fiber composite and the jig compounded with each other can be preferably used as a tensile member such as a brace. As a preferable jig to be compounded with the high-strength fiber composite in accordance with the present invention, there was suggested the jig by the inventors in Japanese Patent Application No. 2012-84240. Furthermore, since the twisted high-strength fiber composites are not bundled by means of a stiffening agent in the case that the strand structure is used as a reinforcing bar in concrete, the strand structure can have an increased surface area to thereby have an increased contact strength with concrete, ensuring an increase in a strength of a concrete architecture and so on.

ADVANTAGES PROVIDED BY THE INVENTION

[0048] The present invention provides a high-strength fiber composite having an inherent tensile strength of high-strength fibers, and being capable of being preferably used under a bending stress environment. The high-strength fiber composite in accordance with the present invention has advantages that it can be used in a bending stress environment, for instance, in the case that it can be used as a wire or a rope, and that a strength thereof is difficult to be reduced even if it is stored in such a

condition as being wound around a drum.

[0049] Furthermore, a strand structure and a multi-strand structure both comprised of the high-strength fiber composites in accordance with the present invention have a strength derived from high-strength fibers, and are lightweight and superior in a tensile strength, ensuring that they can be used for various purposes.

BRIEF DESCRIPTION OF THE DRAWINGS

[0050]

[FIG. 1] FIG. 1 is an illustration of the high-strength fiber composite in accordance with the first embodiment of the present invention.

[FIG. 2] FIG. 2 is an illustration of a process of fabricating the high-strength fiber composite in accordance with the present invention.

[FIG. 3A] FIG. 3A is an illustration (a side view) of the high-strength fiber composite 1a in accordance with the second embodiment of the present invention.

[FIG. 3B] FIG. 3B is an illustration (a cross-sectional view) of the high-strength fiber composite 1a in accordance with the second embodiment of the present invention.

[FIG. 4] FIG. 4 is an illustration of the strand structure 10 in accordance with the third embodiment of the present invention.

[FIG. 5A] FIG. 5A is an illustration (a side view) of the multi-strand structure 100 in accordance with the fourth embodiment of the present invention.

[FIG. 5B] FIG. 5B is an illustration (a cross-sectional view (seven strand structures 10)) of the multi-strand structure 100 in accordance with the fourth embodiment of the present invention.

[FIG. 6] FIG. 6 is a photograph of the high-strength fiber composite in accordance with the first embodiment.

[FIG. 7] FIG. 7 is a photograph of the strand structure (a pitch of twisting: 20 times per a meter) in accordance with the third embodiment.

[FIG. 8] FIG. 8 is a photograph of the strand structure (a pitch of twisting: 5 times per a meter) in accordance with the fourth embodiment.

[FIG. 9] FIG. 9 is a photograph of the multi-strand structure in accordance with the fifth embodiment.

INDICATION BY REFERENCE NUMERALS

[0051]

- 1, 1a High-strength fiber composite
- 1b High-strength fiber composite acting as a core
- 1c High-strength fiber composites surrounding the high-strength fiber composite acting as a core
- 2 Core
- 3 Constraint

- 4 High-strength fiber yarn
- 5 High-strength fiber bundle
- 7a Creel
- 7b Dice
- 7c Heating furnace
- 7d Roller
- 7e Drum
- 7g Pre-heating furnace
- 7f Dice
- 10 Strand structure
- 10a Strand structure acting as a core (Core strand)
- 10b Strand structures surrounding Core strand
- 100 Multi-strand structure

EMBODIMENTS FOR REDUCING THE INVENTION TO PRACTICE

[0052] Embodiments of the high-strength fiber composite in accordance with the present invention are explained hereinbelow with reference to drawings. It is to be understood that the subject matter encompassed by way of the present invention is not to be limited to those specific embodiments, and that it is intended for the subject matter of the present invention to include all alternatives, modifications and equivalents as can be included within the scope of the following claims. In the specification, the expression "the range A to B" means that A and B are both inclusive in the range.

(First Embodiment)

[0053] FIG. 1 illustrates a high-strength fiber composite 1 in accordance with the first embodiment of the present invention. The high-strength fiber composite 1 includes a core 2 comprised of a twisted high-strength fiber bundle 5 stiffened by means of a stiffening agent.

[0054] The high-strength fiber bundle 5 is comprised of a plurality of high-strength fiber yarns 4 (generally, thousands of to hundred thousands of high-strength fiber yarns, or millions of high-strength fiber yarns) bundled with one another, and has a circular or oval cross-section. The high-strength fiber composite 1 in accordance with the first embodiment is stiffened by means of a stiffening agent with the high-strength fiber bundle 5 being twisted by a predetermined number. A number of twisting the high-strength fiber bundle 5 is determined in dependence on a resistance of a resultant high-strength fiber composite to a bending stress, property of preventing the high-strength fiber yarns from being unbundled, and a strength of the high-strength fiber yarns 4 against being twisted (the high-strength fiber yarns are not broken even by being twisted), and further determined such that carbon fiber bundle does not spring out of a constraint when bound by the constraint before being stiffened with a later-mentioned stiffening agent. A number of twisting the high-strength fiber bundle 5 is preferably in the range of 2 to 50 times per a meter both inclusive., more preferably in the range of 5 to 40 times per a meter both inclusive,

and most preferably in the range of 10 to 30 times per a meter both inclusive.

[0055] The core 2 in the high-strength fiber composite 1 has a diameter preferably in the range of 1 to 10 mm both inclusive, and more preferably in the range of 1 to 5 mm both inclusive. In the first embodiment, a diameter of the high-strength fiber composite 1 is defined as a total of a diameter of the high-strength fiber bundle 5 and a thickness of a stiffening agent. A diameter of the high-strength fiber bundle 5 and an amount of a stiffening agent are determined such that the high-strength fiber composite 1 can have a target diameter.

[0056] By designing the core to have a diameter in the range of 1 to 10 mm both inclusive (preferably, in the range of 1 to 5 mm both inclusive), the high-strength fiber composite, a later-mentioned strand structure, and a later-mentioned multi-strand structure can be readily wound around a drum, and can have flexibility sufficient to follow an arbitrary shape. Furthermore, by designing the core to have a diameter in the range of 1 to 10 mm both inclusive (preferably, in the range of 1 to 5 mm both inclusive), a strand structure and a multi-strand structure can have a large surface area with a jig when they are adhered at an end thereof to the jig, ensuring enhancement in an adhesion strength between the jig and the strand structure or the multi-strand structure.

[0057] As the high-strength fiber yarn 4 defining the high-strength fiber bundle 5, there may be employed fiber sometimes called super fiber. As the high-strength fiber yarn 4, there may be employed, for instance, carbon fiber, basalt fiber, para-series aramid fiber, meta-series aramid fiber, polyethylene fiber having a super-high molecular weight, polyarylate fiber, PBO (polyparaphenylenbenzoxazole) fiber, polyphenylenesulfide (PPS) fiber, polyimide fiber, fluorine fiber, and polyvinyl alcohol (PVA) fiber. The high-strength fiber yarn 4 in the present invention may be comprised of carbon fiber or basalt fiber having a high strength in a direction in which fiber extends, but being weak against a shearing force. In particular, carbon fiber is useful as the high-strength fiber yarn.

[0058] The high-strength fiber bundle 5 may be defined with a single kind of the above-identified high-strength fiber yarn, or with a mixture of two or more kinds of the above-identified high-strength fiber yarns. The high-strength fiber bundle 5 may be designed to further include yarns comprised of organic fibers other than the above-identified high-strength fibers as long as a strength and/or a bending property thereof are (is) not deteriorated. Furthermore, the high-strength fiber bundle 5 may include a sizing agent and/or a bundling agent.

[0059] In the case that carbon fibers are employed as the high-strength fiber yarns 4 defining the high-strength fiber bundle 5, polyacrylonitrile (PAN)-series and pitch-series carbon fiber yarn may be employed. Among them, it is preferably to employ PAN-series carbon fiber yarn in the standpoint of a balance between a strength and an elastic modulus of a resultant product.

[0060] The high-strength fiber bundle fabricated by

bundling the high-strength fiber yarns may be comprised of a single bundle or a plurality (two or more) of bundles of carbon fiber yarns in dependence on a required strength. The bundle may be comprised of 6000 carbon fiber yarns (6K), 12000 carbon fiber yarns (12K), 24000 carbon fiber yarns (24K), and so on, supplied from a carbon fiber manufacturer. A number of the high-strength fiber bundles in the case that a plurality of the high-strength fiber bundles each fabricated by bundling carbon fiber yarns is bundled is not to be limited to a particular number. The number is determined in dependence on a purpose and/or an intended use thereof, and is generally equal to or smaller than 100.

[0061] Any one of thermoplastic resin and thermosetting resin may be used as a stiffening agent. It is preferable that a stiffening agent has high affinity with the high-strength fiber yarn. A stiffening agent is comprised preferably of thermoplastic resin, because thermoplastic resin can be deformed when being heated.

[0062] As preferable examples of thermoplastic resin, there are polyetheretherketone (PEEK), polypropylene, polyethylene, polystyrene, polyamide (nylon 6, nylon 66, nylon 12, nylon 42, and so on), ABS resin, acrylate resin, vinyl chloride resin, vinylidene chloride resin, polyphenylene oxide, polybutylene terephthalate, polyethylene terephthalate, polysulfone, polyethersulfone, polyetherimide, polyarylate, epoxy resin, urethane resin, polycarbonate resin, resorcinol resin, and so on. Preferable thermoplastic resin is not to be limited to the above-mentioned ones.

[0063] Among the above-identified resins, it is preferable in a standpoint of a durability against acid and alkali to use polyetheretherketone (PEEK), acrylic resin, vinyl chloride resin, vinylidene chloride resin, polyethylene resin, epoxy resin, urethane resin, polycarbonate resin, and resorcinol resin. It is particularly preferable to use epoxy resin, because it is superior in a resistance to impact. Furthermore, since thermoplastic epoxy resin is soluble in ketone solution, it can be divided from other resins, and hence, be recycled.

[0064] It is preferable to employ, among thermoplastic epoxy resins, polymeric thermoplastic epoxy resin capable of formulating polymer, and more preferably to employ polymeric thermoplastic epoxy resin capable of formulating polymer in a straight-chain shape.

[0065] If the high-strength fiber bundle defining a core were twisted, and/or if the high-strength fiber bundle were covered with a constraint, it would be difficult to allow resin to be impregnated into the high-strength fiber bundle.

[0066] In contrast, it is easy to control a viscosity of polymeric thermoplastic epoxy resin, because thermoplastic epoxy resin before being polymerized can be diluted with organic solvent.

[0067] Accordingly, it is possible to allow thermoplastic epoxy resin before being polymerized to penetrate the twisted high-strength fiber bundle (furthermore, the high-strength fiber bundle through a constraint with which the

high-strength fiber bundle is covered even in the case of the high-strength fiber bundle which is covered with a constraint) by means of resin solution having a low viscosity and being diluted with organic solvent. After thermoplastic epoxy resin before being polymerized was allowed to be impregnated into the high-strength fiber bundle, the polymeric thermoplastic epoxy resin is polymerized to thereby obtain the high-strength fiber composite including the high-strength fiber bundle and the constraint both joined together through thermoplastic epoxy resin, and having a superior strength.

[0068] General thermoplastic resin used by being heated to be molten to thereby provide fluidity thereto is difficult to be controlled with respect to a viscosity thereof, and is afraid that arrangement of crystal thereof is varied by being heated and molten, because thermoplastic resin is generally crystalline, and hence, inherent properties thereof such as a strength may be deteriorated. In contrast, since polymeric thermoplastic epoxy resin is amorphous before and after being polymerized, polymeric thermoplastic epoxy resin has small risk against deterioration even by being heated to be molten or by heated to be deformed.

[0069] A process of applying the above-mentioned resin (a stiffening agent) to the high-strength fiber bundle 5 may include steps of coating by spraying or coating the resin onto high-strength fibers with a brush, but, on a standpoint of productivity, preferably includes step of dipping or steps of dipping the high-strength fibers into resin (a stiffening agent) solution, and squeezing excessive resin through a dice. As a preferable example of an apparatus for applying resin (a stiffening agent) to the high-strength fiber bundle, there is an apparatus illustrated in FIG. 2, which can control a shape of the high-strength fiber composite, and has a dice capable of controlling impregnation of resin and an amount of resin to be applied to the high-strength fiber bundle.

[0070] Hereinbelow is explained a process of fabricating the core 2 in accordance with the first embodiment, by means of the apparatus illustrated in FIG. 2, in the case of selecting thermoplastic resin as the resin to be applied to the high-strength fiber bundle. First, the high-strength fiber bundle 5 twisted by a predetermined number is supplied from a creel 7a, and is immersed in molten thermoplastic resin, thermoplastic resin solved into solvent, or emulsion containing thermoplastic resin therein. While the high-strength fiber bundle 5 is being immersed in the thermoplastic resin, the high-strength fiber bundle 5 is squeezed by means of a dice 7f in order for the resin to be impregnated into the high-strength fiber bundle 5. Then, the high-strength fiber bundle 5 is forced to pass through a dice 7b to remove excessive resin, adjust a diameter and a shape thereof into a desired one, and allow the resin to be further impregnated into the high-strength fiber bundle 5. Thereafter, the high-strength fiber bundle 5 is heated in a heater 7c including a pre-heater 7g to remove the solvent to be dried, resulting in that the thermoplastic resin is cured. Thus, there

is completed the core 2 comprised of the high-strength fiber bundle 5 to which the thermoplastic resin (a stiffening agent) is applied. The high-strength fiber composite comprised of the core 2 is stored, being kept elongate, in such a condition that the high-strength fiber composite is wound around a drum 7e. After a construction in which the high-strength fiber composite is used has been determined, the high-strength fiber composite is cut into a certain length. As an alternative, the fabricated high-strength fiber composite is cut into a certain length for storage without being wound around a drum.

[0071] In the above-mentioned process, after the twisted high-strength fiber bundle was wound around a drum, the drum is attached to a creel for application of the resin to the high-strength fiber bundle. As an alternative, after the non-twisted high-strength fiber bundle was twisted, the resin may be applied to the high-strength fiber bundle without winding high-strength fiber bundle around a drum.

(Second Embodiment)

[0072] Hereinbelow is explained, with reference to FIGs. 3A and 3B, the high-strength fiber composite in accordance with the second embodiment. The high-strength fiber composite is comprised of a core including a high-strength fiber bundle with a constraint wound therearound, the high-strength fiber bundle being integral with the constraint through a stiffening agent in such a condition that the high-strength fiber bundle is kept twisted. Parts or elements illustrated in FIGs. 3A and 3B that correspond to those illustrated in FIG. 1 have been provided with the same reference numerals, and will not be explained.

[0073] The high-strength fiber composite 1a illustrated in FIGs. 3A and 3B is comprised of a core 2 comprising a twisted high-strength fiber bundle 5, and a constraint 3 wound around the high-strength fiber bundle 5, where the high-strength fiber bundle 5 and the constraint 3 are stiffened by means of a stiffening agent. Since the structure except the constraint 3 of the high-strength fiber composite 1a is identical with that of the core 2 described in the first embodiment, the structure is not explained.

[0074] The constraint 3 bundles high-strength fiber yarns 4 at an outer surface of the high-strength fiber bundle 5 in order to prevent the high-strength fiber bundle 5 from being unbundled. In the second embodiment, the high-strength fiber bundle 5 is constrained with the constraint 3 to keep the high-strength fiber bundle twisted, and a stiffening agent is applied to both the high-strength fiber bundle and the constraint to thereby allow them to be integrated with each other by means of the stiffening agent.

[0075] In the high-strength fiber composite 1a in accordance with the second embodiment, the constraint 3 is formed into a braid by winding fibers into a cylindrical braid (a cord). By designing the constraint 3 into a braid shape, it is possible to cover the high-strength fiber bun-

dle with the constraint 3 to such a degree that the high-strength fiber bundle 5 is invisible at an outer surface, and accordingly, the high-strength fiber bundle 5 can be kept bundled, and the constraint acts as a protection layer for protecting the high-strength fiber yarns defining the high-strength fiber bundle 5 covered with the constraint. Thus, in the case that the high-strength fiber composite having the above-mentioned structure is used as a brace member or a reinforcement in concrete, it is possible to prevent the high-strength fiber composite from being cut or broken, even if it makes contact with acute materials such as pebbles. Furthermore, since it is no longer necessary for the high-strength fiber composite to additionally include a protection layer, a single high-strength fiber composite can be thinned, and further, fabrication costs can be reduced.

[0076] A tensile strength acts on the high-strength fiber bundle 5 constrained with the constraint in a length-wise direction of fibers when excessive resin is squeezed out by means of a dice, after the high-strength fiber bundle 5 was dipped into a resin (a stiffening agent) solution. Since the constraint has a braid structure, spaces surrounded with the fibers are not widened like a knit, but a diameter of a braid is thinned with the spaces being kept closed. Accordingly, adhesion between the constraint and the high-strength fiber bundle can be enhanced without exposure of the high-strength fiber bundle covered with the constraint, which is preferable in the standpoint of a strength of the resultant high-strength fiber composite 1a.

[0077] The constraint 3 is designed to have at least a function of preventing the high-strength fiber yarns 4 defining the high-strength fiber bundle 5 from being unbundled. The arrangement of the constraint 3 is not to be limited to a braid illustrated in FIGs. 3A and 3B. Furthermore, it is not always necessary to entirely cover the high-strength fiber bundle with the constraint. A part of the high-strength fiber bundle may not be covered with the constraint.

[0078] As examples of arrangement of other constraints, a single constraint may be spirally wound around the high-strength fiber bundle, fibers defining a constraint may be wound around the high-strength fiber bundle to thereby bundle the high-strength fiber yarns by a constraint having a shape of knitted cord and fabricated by knitting coarse cylindrical round braid, or the high-strength fiber yarns may be bundled with a constraint in which fibers listed as the constraint are arranged at a predetermined pitch, as a constraint for bundling the high-strength fiber yarns of the high-strength fiber composite.

[0079] In a standpoint of protection of the high-strength fiber bundle, it is preferable to form the constraint in the shape of a braid, and entirely cover the high-strength fiber bundle with the braid-shaped constraint.

[0080] The braid-shaped constraint 3 illustrated in FIGs. 3A and 3B may be fabricated by means of an apparatus for fabricating a cord. The high-strength fiber

bundle 5 is forced to pass through a center of the apparatus, and the high-strength fiber bundle 5 is covered with the constraint 3 to thereby form the braid. Thus, the braid-shaped constraint 3 is formed on an outer surface of the high-strength fiber bundle 5. The constraint 3 for bundling the high-strength fiber bundle 5 may be twisted or not.

[0081] The constraint 3 is preferably soft. As the constraint, there may be used synthetic fiber such as polyamide (nylon and so on), vinylon, polyacryl, polypropylene, vinyl chloride, aramide, cellulose, polyamide, polyester, and polyacetal, recycled fiber such as rayon, half-synthetic fiber such as acetate, and natural fiber such as silk, wool, hemp and cotton. The constraint 3 is comprised preferably of fibers being stable against heat in the case that the constraint is heated during steps of fabricating the high-strength fiber composite or is in an environment of being heated, though dependent on a resistance of the stiffening agent to heat and/or condition of being stiffened. Specifically, it is preferably that the constraint is comprised of polyester fibers, glass fibers or basalt fibers, and it is more preferably that the constraint is comprised of glass fibers. By comprising the constraint of fibers having stability against heat, it is possible to prevent the high-strength fiber yarns and the constraint from being deviated from each other when heated, ensuring accomplishment of a stable tensile strength.

[0082] It is preferable in the core 2 that a stiffening agent is impregnated into the high-strength fiber bundle bundled with the constraint to thereby cure the high-strength fiber bundle together with the constraint, in order to intensively bundle the high-strength fiber yarns 4. This ensures that the high-strength fiber bundle and the constraint can be intensively integrated with each other.

[0083] The high-strength fiber composite including the intensively integrated core 2 may be formed in a shape of a rod, in which case, the high-strength fiber composite can be stored or carried in a condition of being wound around a drum, or the high-strength fiber composite can be stored or carried after being cut into pieces having a length of a few centimeters to a few meters. In particular, the high-strength fiber composite formed in a shape of a rod can be readily arranged in a narrow groove or inserted into a deep hole, because the high-strength fiber composite does not lose its shape.

[0084] In the high-strength fiber composite 1a, the constraint 3 and the stiffening agent act as a protection layer, but the high-strength fiber composite 1a may be designed to further include an actual protection layer (a cylindrical cover comprised of fibers or a resin layer) covering an outer surface of the high-strength fiber composite therewith.

[0085] The high-strength fiber composite 1a in accordance with the second embodiment can be fabricated by means of the apparatus used for fabricating the high-strength fiber composite 1. Specifically, the high-strength fiber bundle 5 supplied from the creel 7a is twisted, and then, is fed to an apparatus (not illustrated) for fabricating a cord. Then, the twisted high-strength fiber bundle is fed

into a round braid apparatus (not illustrated) to thereby be constrained with a constraint. Thus, there is obtained a high-strength fiber bundle bundled with the constraint. The resultant high-strength fiber bundle bundled with the constraint is immersed in the above-mentioned molten thermoplastic resin, thermoplastic resin solved into solvent, or emulsion containing therein thermoplastic resin. The high-strength fiber composite in accordance with the second embodiment can be obtained by carrying out the steps having been carried out in the above-mentioned first embodiment, except these steps. The high-strength fiber composite in accordance with the second embodiment can be wound around a drum without cutting the high-strength fiber bundle 5, keeping the high-strength fiber composite elongate, and be cut into a certain length after a construction in which the high-strength fiber composite is used has been determined. As an alternative, the high-strength fiber composite may be cut into a certain length without being wound around a drum.

[0086] The high-strength fiber bundle 5 may be passed through an apparatus for fabricating a cord, after being twisted, or may be covered with a constraint by means of a round braid apparatus (not illustrated). The resultant high-strength fiber bundle constrained with a constraint is wound around a drum. By equipping the drum to the creel 7a, and carrying out the above-mentioned steps, there can be obtained the high-strength fiber composite in accordance with the second embodiment.

(Third Embodiment)

[0087] The third embodiment of the present invention is explained hereinbelow with reference to FIG. 4. Parts or elements illustrated in FIG. 4 that correspond to those illustrated in FIGs. 1, 2, 3A and 3B have been provided with the same reference numerals, and will not be explained.

[0088] A strand structure 10 illustrated in FIG. 4 is comprised of seven high-strength fiber composites 1a each in accordance with the second embodiment. The centrally arranged high-strength fiber composite 1a (hereinafter, referred to as "high-strength fiber composite 1b") is surrounded by the rest of the high-strength fiber composites 1a (hereinafter, referred to as "high-strength fiber composites 1c").

[0089] Since each of the high-strength fiber composites 1a (1b and 1c) has the structure illustrated in FIGs. 3A and 3B, they are not explained in detail. Though not illustrated in FIG. 4, each of the seven high-strength fiber composites 1a (1b and 1c) defining the strand structure 10 is entirely covered at an outer surface thereof with the constraint 3 like a braid.

[0090] Though FIG. 4 illustrates the high-strength fiber composites 1a illustrated in FIGs. 3A and 3B as high-strength fiber composites of which the strand structure 10 is comprised, a high-strength fiber composite of which the strand structure 10 is comprised is not to be limited to the high-strength fiber composite 1a, but any high-

strength fiber composite in accordance with the present invention may be employed. In the third embodiment, though both of the high-strength fiber composite 1b and the high-strength fiber composites 1c are identical with the high-strength fiber composite 1a, the high-strength fiber composite 1b and the high-strength fiber composites 1c may be different from each other, if they are a high-strength fiber composite or high-strength fiber composites in accordance with the present invention.

[0091] Since the strand structure 10 in accordance with the third embodiment is designed to have a strand construction in which the high-strength fiber composite 1b acting as a core and the six high-strength fiber composites 1c surrounding the high-strength fiber composite 1b are twisted together, it is possible to prevent the strand structure 10 from being unbundled, even if the high-strength fiber composites are not integrated with one another by means of resin. Consequently, the strand structure 10 can have a stable tensile strength. In the case that the strand structure 10 is adhered at an end thereof to a fixation jig, since each of the high-strength fiber composites 1a (1b and 1c) of which the strand structure 10 is comprised is independent from one another, and accordingly, the strand structure 10 has a big surface area, an adhesive for adhering the high-strength fiber composites to the fixation jig can penetrate spaces formed among the high-strength fiber composites, ensuring that an adhesion strength between the fixation jig and the strand structure 10 is enhanced. Furthermore, since the strand structure is comprised of the high-strength fiber composites 1a (1b and 1c) having a tensile strength inherent to a high-strength fiber yarn and being superior in durability against a bending stress, the strand structure can maintain a superior tensile strength even in the case that the strand structure is stretched after having been wound around a drum and hence having been put in a bending stress environment, or that the strand structure is used in a bending stress environment.

[0092] A direction in which the high-strength fiber bundles are twisted may be selected from any one of directions identified below.

[0093] High-strength fiber bundle $\times$ Strand structure = Direction S $\times$ Direction Z, Direction S $\times$ Direction S, Direction Z $\times$ Direction Z, Direction Z $\times$ Direction S

[0094] If the strand structure is kept to have a fixed diameter, a diameter of strand (a diameter of the high-strength fiber composite) is smaller in the strand structure including a greater number of strands, in which case, though the strand has enhanced flexibility, it is afraid of deterioration in a resistance against being worn out and a resistance against losing its shape.

[0095] A number by which the strand structure 10 illustrated in FIG. 4 is twisted is set to be 20 times per a meter. The number is not to be limited to 20 times per a meter, but may be set to be in the range of 1.1 to 50 times per a meter both inclusive in dependence on a purpose. If the number is too small, the high-strength fiber composites 1a are easy to be unbundled into individual high-

strength fiber composite. In contrast, if the number is too great, it is afraid that the strand structure has a deteriorated tensile strength. In the case that a number of the high-strength fiber composites is in the range of 7 to 37 both inclusive, the number by which the strand structure 10 is twisted is preferably in the range of 1.5 to 20 times per a meter both inclusive, and more preferably in the range of 2 to 10 times per a meter both inclusive.

[0096] The strand structure illustrated in FIG. 4 includes the high-strength fiber composite 1b acting as a core, and the high-strength fiber composites 1c surrounding the high-strength fiber composite 1b, where the high-strength fiber composite 1b and the high-strength fiber composites 1c are twisted together. The strand structure 10 may be fabricated by bundling a necessary number (for instance, 2 to 50 both inclusive) of the high-strength fiber composites, and imparting twist entirely to the thus bundled high-strength fiber composites.

[0097] The strand structure 10 can be fabricated by means of a known apparatus. Specifically, the strand structure can be fabricated by winding the high-strength fiber composite 1a around a drum, setting the drum into a creel, and twisting the high-strength fiber composite by a predetermined number by means of a fiber twisting machine, a fiber gathering machine or a fiber collecting machine.

[0098] The fabricated strand structure 10 can be wound around a drum without cutting into pieces, keeping the strand structure elongate, and be cut into a certain length after a construction in which the strand structure is used has been determined. As an alternative, the strand structure may be cut into a certain length without being wound around a drum.

[0099] A number of the high-strength fiber composites 1a (1b and 1c) of which the strand structure 10 is comprised is seven. However, the number is not to be limited to seven, but is determined in dependence on required performances (in particular, a tensile strength) and an intended use thereof. The number is generally in the range of 2 to 50 both inclusive, and preferably in the range of 7 to 37 both inclusive, though the number is not to be limited to those.

[0100] For instance, in the case that the high-strength fiber bundle 5 is comprised of a bundle of 24000 carbon fiber yarns (24k), the strand structure can be preferably used as a brace member, if a number of the high-strength fiber composites of which the strand structure is comprised is in the range of about 2 to about 50 both inclusive.

[0101] When a number of the high-strength fiber composites of which the strand structure is comprised is greater than seven, and the high-strength fiber bundles are put one upon another in two or more layers, there may be selected any one of a cross twisting in which the high-strength fiber bundles in each of the layers are twisted by a common twisting angle, and a parallel twisting in which the high-strength fiber bundles are twisted in a single step such that the high-strength fiber bundles in each of the layers are arranged at a common pitch.

[0102] In the case that the strand structure is used as a composite including the strand structure and a fixation jig both of which are integrated together, for instance, as a bar to be used in place of a steel bar, a number of the high-strength fiber composites of which the strand structure is comprised is set in the range of about 2 to about 50 both inclusive.

[0103] In the case that the high-strength fiber bundle 5 is comprised of a bundle of 12000 carbon fiber yarns (12k) to thereby obtain the strand structure to be used as a wire, a number of the high-strength fiber composites of which the strand structure is comprised is set in the range of about 2 to about 50 both inclusive.

[0104] If the strand structure comprised of the high-strength fiber bundles by the above-mentioned number is short of a strength, the strand structure may be designed to include the high-strength fiber bundles by a greater number than the above-mentioned number. From a standpoint of a tensile strength of the strand structure, it is preferable to twist two or more strand structures to thereby define a multi-strand structure in accordance with the fourth embodiment explained hereinbelow.

(Fourth Embodiment)

[0105] The fourth embodiment of the present invention is explained hereinbelow with reference to FIGs. 5A and 5B. Parts or elements illustrated in FIGs. 5A and 5B that correspond to those illustrated in FIGs. 1 to 4 have been provided with the same reference numerals, and will not be explained.

[0106] FIG. 5A is a cross-sectional view of a multi-strand structure 100 in accordance with the fourth embodiment, and FIG. 5B is a side view of the same. The multi-strand structure 100 is comprised of seven strand structures 10 in accordance with the third embodiment. A centrally arranged single strand structure 10a (hereinafter, referred to as "core strand 10a") is surrounded by the rest of strand structures 10b, that is, the six strand structures 10b. Specifically, the multi-strand structure 100 has a strand construction in which the core strand 10a and the six strand structures 10b surrounding the core strand 10a therewith are twisted together, and furthermore, since the strand structures 10 of which the multi-strand structure 100 is comprised have high performances derived from the high-strength fiber composites 1a, the strand structures can have a strength more stable than the same of the seven strand structures 10 merely bundled together. Furthermore, as mentioned earlier, the strand structure 10 is comprised of the seven high-strength fiber composites 1a each entirely covered at an outer surface thereof with the constraint 3 arranged in a shape of a braid, and thus, the constraint 3 arranged in a shape of a braid acts as a protection layer for the high-strength fiber bundles 5 defining the high-strength fiber composite 1a.

[0107] Thus, the multi-strand structure is useful as a member to be used in place of a reinforcement steel, or

as a rod such as a tension member to be used in place of a PC steel wire, and is particularly useful to a case that a high tensile strength is required.

[0108] Though the multi-strand structure 100 is comprised of the strand structures 10, elements for defining the multi-strand structure are not to be limited to the strand structures 10, but may be other strand structures such as the strand structure in accordance with the third embodiment.

[0109] A number of the strand structures 10 of which the multi-strand structure 100 is comprised is seven. However, the number is not to be limited to seven, but is determined in dependence on required performances (in particular, a tensile strength) and an intended use thereof. The number is generally in the range of 2 to 40 both inclusive, and preferably in the range of 7 to 37 both inclusive, because it may be difficult to twist the strand structures by a predetermined pitch, if a number of the strand structures is greater than forty.

[0110] A number by which the multi-strand structure 100 is twisted is determined in dependence on required performances (in particular, a tensile strength) and an intended use thereof.

[0111] A number by which the multi-strand structure 100 is twisted is preferably in the range of 0.3 to 30 times per a meter both inclusive, and is preferably in the range of 0.5 to 15 times per a meter both inclusive in the case that the multi-strand structure 100 includes the strand structures 10 by a number of 7 to 37 both inclusive.

[0112] Though the multi-strand structure 100 illustrated in FIGs. 5A and 5B is designed to have a strand construction in which the core strand 10a and the strand structures 10b surrounding the core strand 10a therewith are twisted together, the multi-strand structure 100 may be designed to have a structure in which a necessary number (for instance, 2 to 50) of the strand structures 10 is bundled, and the thus bundled strand structures are twisted to thereby define a multi-strand structure having no core strand.

[0113] The multi-strand structure 100 can be fabricated by means of a known apparatus such as a fiber twisting machine, a fiber gathering machine and a fiber collecting machine. Specifically, the multi-strand structure can be fabricated by twisting the strand structures 10 by a predetermined number. The fabricated multi-strand structure 100 can be wound around a drum without cutting into pieces, keeping the multi-strand structure elongate, and be cut into a certain length after a construction in which the multi-strand structure is used has been determined. As an alternative, the multi-strand structure may be cut into a certain length without being wound around a drum.

[0114] While the present invention has been described in connection with the preferred embodiments with reference to the drawings, it is to be understood that the embodiments are just examples of the present invention, and the present invention includes all alternatives, modifications and equivalents as can be included within the

spirit and scope of the subject matter of the present invention.

EXAMPLES

[0115] Hereinbelow is explained the present invention in further detail with reference to examples, but it is to be understood that the scope of the present invention is not to be limited to those specific examples, unless the gist of the present invention is not changed.

Example 1: High-strength fiber composite

[0116] The 24K carbon fiber bundle was constrained at an outer surface thereof entirely with polyester fibers in a shape of a braid by means of a cord fabricating apparatus (24-beating machine) through a process of 8-beat grain beating, in which as a twisted high-strength fiber bundle was used a single 24K carbon fiber bundle (PAN carbon fibers commercially available from Toray Industries, Inc., T700SC) having been twisted by 30 times per a meter in a S-direction, and as a constraint was used polyester fibers (a polyester fiber bundle having 1100 decitex). A ratio with which the carbon fiber bundle was covered at an outer surface thereof with the constraint was almost 100%, and hence, the carbon fiber bundle covered with the constraint was invisible.

[0117] Then, the solution (viscosity: 100 mPa-s, B-type viscosity meter, Rotor No. 20, 12 rpm. TVB-15 type viscosity meter commercially available from Toki Sangyo Co., Ltd) containing ingredients identified below was applied to the constrained carbon fiber bundle at 20 degrees centigrade by means of the apparatus illustrated in FIG. 2.

Polymer type thermoplastic epoxy resin (DENATITE TPEP-AA-MEK-05B commercially available from Nagase ChemteX Corporation): 100 mass parts
Curing agent (XNH6850RIN-K commercially available from Nagase ChemteX Corporation): 6.5 mass parts
Methylethylketone (MEK): 1.6 mass parts

Then, the carbon fiber bundle was heated (150 degrees centigrade, 20 minutes) to polymerize the above-mentioned polymer type thermoplastic epoxy resin, resulting in that there was fabricated the high-strength fiber composite in accordance with Example 1, comprised of a core including the twisted carbon fiber bundle and the constraint, both being integrated with each other through thermoplastic epoxy resin (a stiffening agent). FIG. 6 is a photograph showing an appearance of the high-strength fiber composite in accordance with Example 1. The thus fabricated high-strength fiber composite in accordance with Example 1 had a diameter of 2.0 mm (measured with calipers).

[0118] The high-strength fiber composite in accordance with Example 1 was wound at a room temperature

around a drum having a diameter of 50 cm. The high-strength fiber composite could be smoothly wound without being flexed.

Example 2: High-strength fiber composite

[0119] A high-strength fiber composite in accordance with Example 2 was fabricated in the same way as that of Example 1 except that vinylon fibers (vinylon fiber having 1100 decitex) was used in place of polyester fibers (polyester fiber having 1100 decitex).

[0120] A bundle of the thus fabricated ten high-strength fiber composites was wound at a room temperature around drums having diameters of 60 centimeters and 50 centimeters, respectively, and then, was aged by a month. Then, the high-strength fiber composites having been aged by a month were cut into pieces having a length of 60 centimeters. Ten high-strength fiber composites were bundled, and then, were inserted through an end thereof into a threaded steel pipe (a length of 120 mm, an inner diameter of 14 mm, an outer diameter of 20 mm). Then, the high-strength fiber composites were fixed in the steel pipes by means of urethane adhesive (commercially available from CEMEDINE CO., LTD., UM890 Kai 1, a main agent: 1 mass part, and a curing agent: 2 mass parts). Then, a tensile strength of the resultant was measured by means of a tensile tester, AG-100kN plus commercially available from SHIMADZU CORPORATION, in accordance with JIS K7165, in which a test piece was A-type, a test speed was 2 mm per a minute, and a jig used for a round rod, was formed with V-shaped grooves extending in parallel with one another. Furthermore, the bundle having been not wound around a drum, and having been aged in a condition of being straight was also measured with respect to a tensile strength.

[0121] The measured tensile strength were as follows.

Not wound around a drum: 41.7 kN

Wound around a drum having a diameter of 50 cm: 42.0 kN

Wound around a drum having a diameter of 60 cm: 44.9 kN

Reduction in a tensile strength was not found in the bundles having been wound around a drum for aging.

Example 3: Strand structure

[0122] The high-strength fiber composites in accordance with Example 1, wound around a drum, were bundled by ten. While being heated at 120 degrees centigrade, the bundled ten high-strength fiber composites were twisted in a Z-direction at 20 times per a meter. The thus twisted ten high-strength fiber composites was wound at a room temperature around a drum having a diameter of 70 cm. Thus, there was fabricated the strand structure in accordance with Example 3. The thus fabri-

cated strand structure in accordance with Example 3 had a structure having no high-strength fiber composite acting as a core. FIG. 7 is a photograph showing an appearance of the strand structure in accordance with Example 3.

[0123] The thus fabricated elongate strand structure was cut into rods each having a length of 2 m. The rods were inserted through an end thereof into a threaded steel pipe (a length of 120 mm, an inner diameter of 14 mm, an outer diameter of 20 mm). Then, the rods were fixed in the steel pipes by means of urethane adhesive (commercially available from CEMEDINE CO., LTD., UM890 Kai 1, a main agent: 1 mass part, and a curing agent: 2 mass parts). Then, a bending tensile strength of the strand structure in accordance with Example 3 was measured by means of a bending tensile strength evaluation machine (commercially available from TOKYO TESTING MACHINE CO., LTD., RAT100DE-S) in accordance with JSCE-E532-1995. R portions having been used in the bending tensile strength test had diameters of 300 mm and 500 mm. The test was carried out at a speed in the range of 100 to 500 N/mm² both inclusive. A bending angle was 180 degrees.

[0124] The bending tensile strength was 66 kN for the R portion of 300 mm, and 66 kN for the R portion of 500 mm, both being superior tensile strength. When the rods were attached to the jigs having the above-mentioned diameters, the rods were not heated, but were attached to the jigs at a room temperature.

Example 4: Strand structure

[0125] The high-strength fiber composites in accordance with Example 1 were prepared by seven. One of the seven high-strength fiber composites was determined to be a core. While being heated at 120 degrees centigrade, the seven high-strength fiber composites in which the core high-strength fiber composite was surrounded by the other six high-strength fiber composites were twisted in a Z-direction by 5 times per a meter to thereby obtain the strand structure in accordance with Example 4. FIG. 8 is a photograph showing an appearance of the resultant strand structure.

Example 5: Multi-strand structure

[0126] The high-strength fiber composites in accordance with Example 1 were prepared by thirty seven. While being heated at 120 degrees centigrade, the 37 high-strength fiber composites were twisted in a S-direction by 8 times per a meter to thereby obtain the strand structure having a four-layered structure of 1×6×12×18. Then, the thus fabricated strand structures were prepared by seven such that one of the strand structures acted as a core and the other six strand structures surrounded the strand structure acting as a core. While being heated at 120 degrees centigrade, the seven strand structures were twisted in a Z-direction by 5 times per a

meter to thereby obtain the strand structure in accordance with Example 5. FIG. 9 is a photograph showing an appearance of the strand structure in accordance with Example 5.

Comparison Example 1

[0127] There was fabricated the high-strength fiber composite in accordance with Comparison Example 1 in the same way as Example 1 except that a single non-twisted 24K carbon fiber bundle (PAN carbon fiber commercially available from Toray Industries, Inc., T700SC) was used as a high-strength fiber bundle. A bending tensile strength test was carried out to the high-strength fiber composite in accordance with Comparison Example 1 in the same way as Example 3. Attaching the high-strength fiber composites to an R portion of 300 mm and an R portion of 500 mm, respectively, the high-strength fiber composites were broken.

Comparison Example 2

[0128] The ten high-strength fiber composites each in accordance with Comparison Example 1 were bundled without being twisted as an example analogous to the strand structure in accordance with Example 3. A bending tensile strength test was carried out to the ten high-strength fiber composites in the same way as Example 3. When the ten high-strength fiber composites were attached to an R portion of 500 mm, the ten high-strength fiber composites were broken.

INDUSTRIAL APPLICABILITY

[0129] The high-strength fiber composite, the strand structure, and the multi-strand structure all in accordance with the present invention can sufficiently have mechanical performances such as a tensile strength and an elastic modulus inherent to high-strength fiber yarn such as carbon fiber yarn, and accordingly, are applicable to various industrial fields such as civil engineering works, construction, vessel, mining and fishery, and are industrially promising.

Claims

1. A high-strength fiber composite including a core comprised of a bundle of high-strength fiber yarns, the bundle being twisted and stiffened with a stiffening agent.
2. The high-strength fiber composite as set forth in claim 1, further including a constraint wound around the bundle, the bundle and the constraint being stiffened together with the stiffening agent with the bundle being kept twisted, to define the core.

3. The high-strength fiber composite as set forth in claim 1 or 2, wherein a number of twisting the bundle is in the range of 2 to 50 times per a meter both inclusive.
4. The high-strength fiber composite as set forth in any one of claims 1 to 3, wherein the stiffening agent is composed of thermoplastic resin.
5. The high-strength fiber composite as set forth in claim 4, wherein the thermoplastic resin is thermoplastic epoxy resin.
6. The high-strength fiber composite as set forth in any one of claims 1 to 5, wherein the core has a diameter in the range of 1 to 5 mm both inclusive.
7. The high-strength fiber composite as set forth in any one of claims 1 to 6, wherein the high-strength fiber yarns include carbon fiber or basalt fiber.
8. A strand structure including a strand construction comprised of two or more twisted high-strength fiber composites defined in any one of claims 1 to 7.
9. The strand structure as set forth in claim 8, wherein a number of twisting the high-strength fiber composites is in the range of 1.1 to 50 times per a meter both inclusive.
10. The strand structure as set forth in claim 8 or 9, wherein a number of the high-strength fiber composites defining the strand structure is 2 to 40 both inclusive.
11. A multi-strand structure including a strand construction comprised of two or more twisted strand structures defined in any one of claims 8 to 10.
12. The multi-strand structure as set forth in claim 11, wherein a number of twisting the strand structures is in the range of 0.3 to 30 times per a meter both inclusive.
13. The multi-strand structure as set forth in claim 11 or 12, wherein a number of the strand structures defining the multi-strand structure is in the range of 2 to 40 both inclusive.

FIG. 1

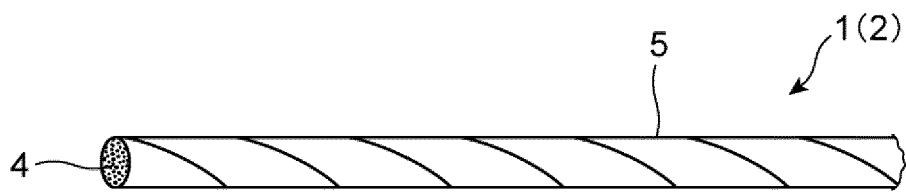


FIG. 2

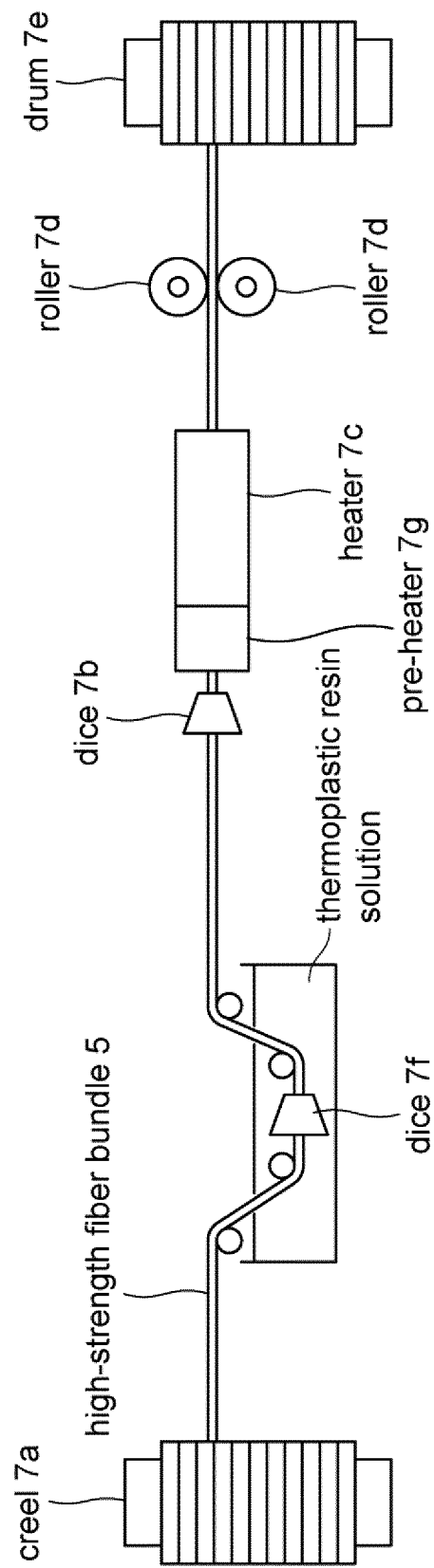


FIG. 3A

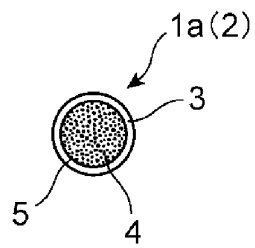


FIG. 3B

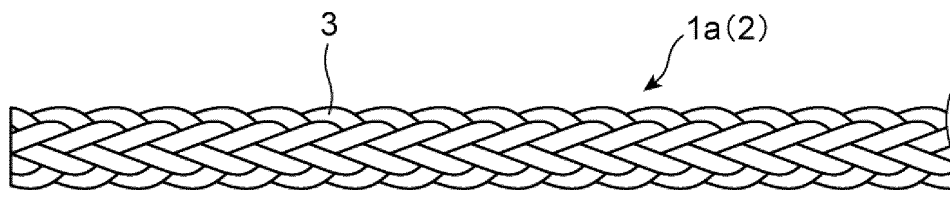


FIG. 4

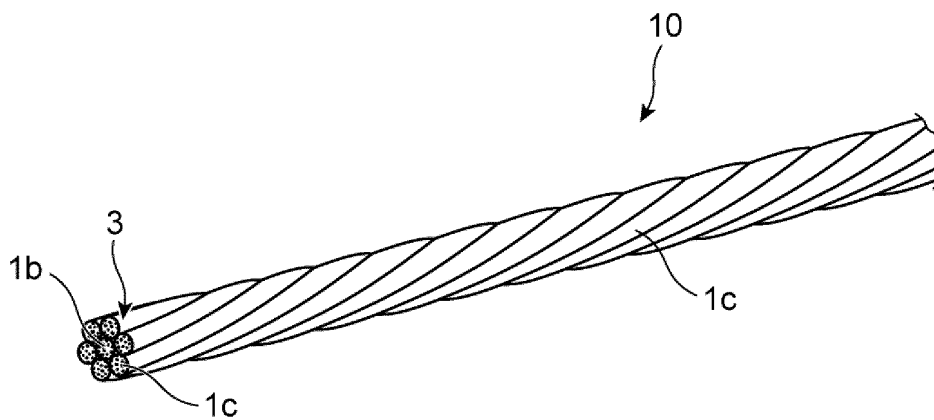


FIG. 5A

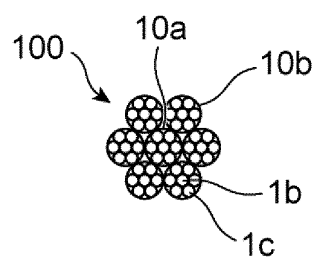


FIG. 5B

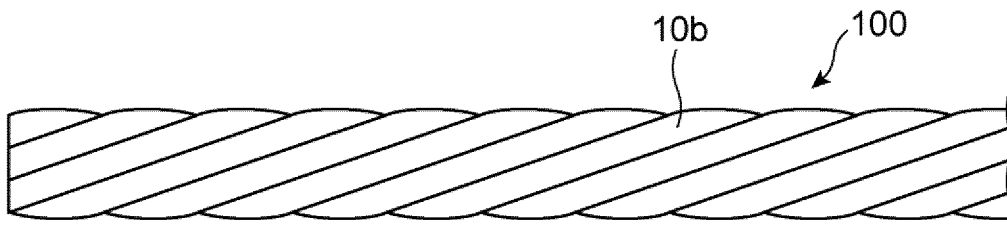


FIG. 6

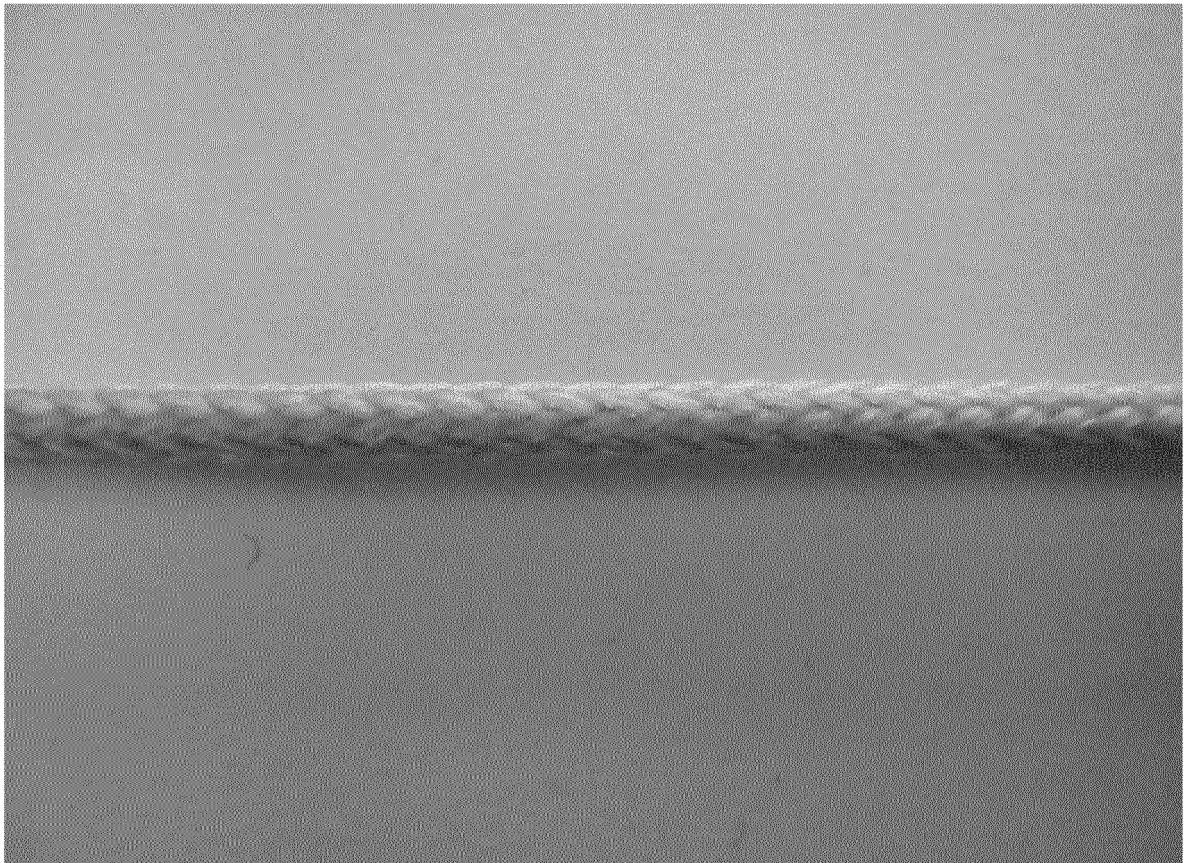


FIG. 7



FIG. 8

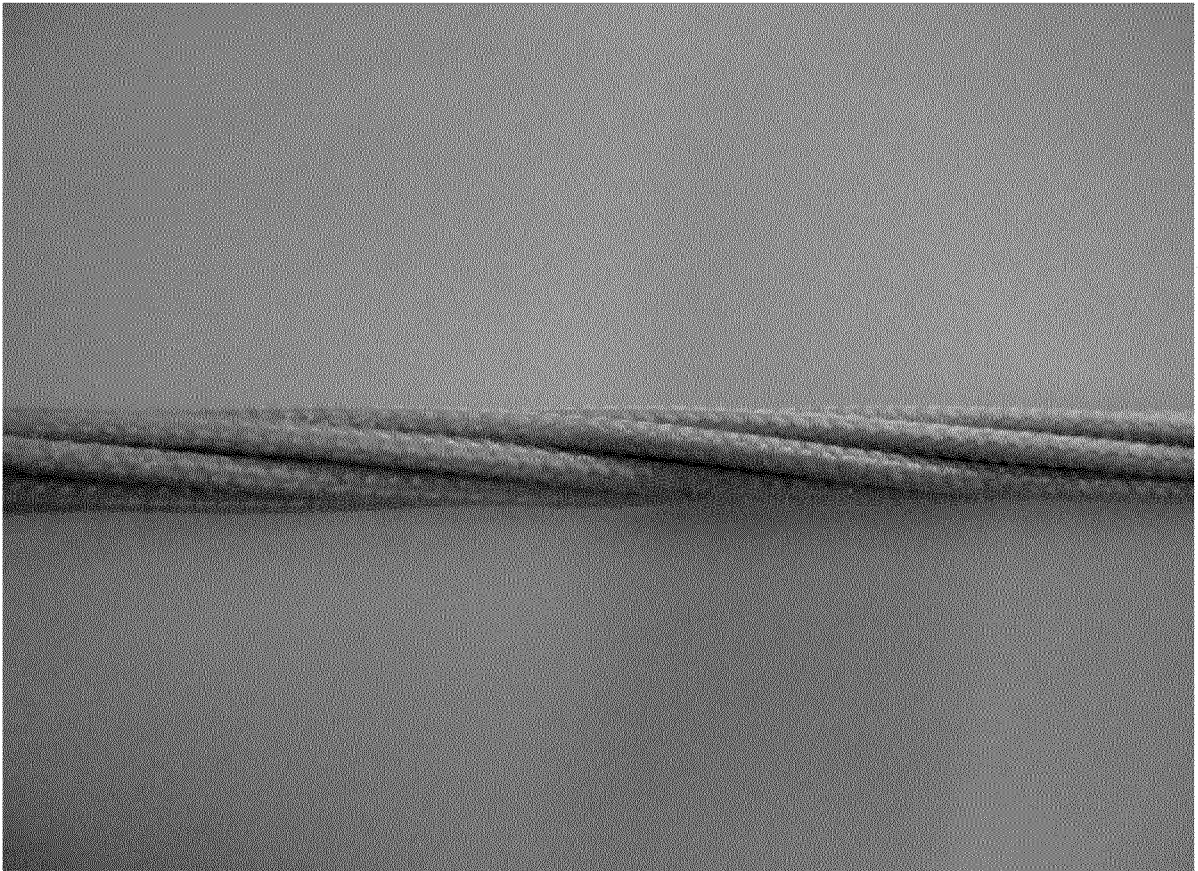


FIG. 9



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2014/064127

A. CLASSIFICATION OF SUBJECT MATTER

D02G3/22(2006.01)i, D07B1/02(2006.01)i, D07B1/16(2006.01)i, E04C5/07
(2006.01)i, D06M15/55(2006.01)n

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

D02G3/00-3/48, D07B1/00-9/00, E04C5/07, D06M15/00-15/70

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

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2014

Kokai Jitsuyo Shinan Koho 1971-2014 Toroku Jitsuyo Shinan Koho 1994-2014

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	WO 2006/043311 A1 (Tokyo Rope Mfg. Co., Ltd.), 27 April 2006 (27.04.2006), paragraphs [0006] to [0007], [0012], [0017] to [0035], [0040]; fig. 2 to 14 & US 2008/0028740 A1 & CN 101044284 A	1, 3, 6-13 2, 4, 5
X Y	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 33632/1990 (Laid-open No. 125089/1991) (Toray Industries, Inc.), 18 December 1991 (18.12.1991), page 4, line 1 to page 5, line 20; page 7, lines 3 to 11; page 8, line 14 to page 9, line 11; fig. 1, 2 (Family: none)	1, 3, 4, 6-10 2, 5

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

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
11 July, 2014 (11.07.14)

Date of mailing of the international search report
22 July, 2014 (22.07.14)

Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

Facsimile No.

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2014/064127

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2012-136814 A (Komatsu Seiren Co., Ltd.), 19 July 2012 (19.07.2012), paragraphs [0011] to [0014], [0024] to [0027], [0042], [0048] to [0053]; fig. 1 to 3 (Family: none)	2, 4, 5
Y	JP 2012-251378 A (Komatsu Seiren Co., Ltd.), 20 December 2012 (20.12.2012), paragraphs [0024] to [0026], [0041], [0047] to [0051]; fig. 1 to 3 (Family: none)	2, 4, 5
Y	JP 2013-11162 A (Komatsu Seiren Co., Ltd.), 17 January 2013 (17.01.2013), paragraphs [0064] to [0066], [0090] to [0099]; fig. 17 (Family: none)	2, 4, 5
A	JP 2006-182915 A (Daicel Chemical Industries, Ltd.), 13 July 2006 (13.07.2006), entire text (Family: none)	1-13
P, X	JP 2013-213305 A (Komatsu Seiren Co., Ltd.), 17 October 2013 (17.10.2013), entire text; all drawings (Family: none)	1-13

Form PCT/ISA/210 (continuation of second sheet) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 2006348506 A [0006]
- US 20080028740 A [0006]
- JP 2012136814 A [0006]
- JP 2012084240 A [0047]