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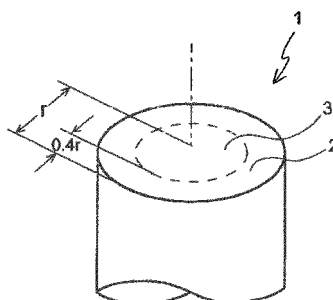
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(54) **CARBON STEEL WIRE AND METHOD FOR MANUFACTURING SAME**

(57) Provided is a carbon steel wire excellent in shear resistance as compared with a conventional one and a method of manufacturing such a carbon steel wire. Provided is a carbon steel wire 1 having a wire diameter of from 0.1 to 0.6 mm, and when the radius of a circular cross-section orthogonal to the longitudinal direction is r

and a region from the outer periphery of the circular cross-section toward the center to 0.4r is a surface layer portion 2, the occupancy ratio of a crystal texture in the [110] orientation with respect to the longitudinal direction in the surface layer portion 2 is 60% or less.

FIG. 1



Description

TECHNICAL FIELD

5 **[0001]** The present invention relates to a carbon steel wire and a method of manufacturing the same, and particularly to a carbon steel wire excellent in shear resistance as compared with a conventional one and a method of manufacturing such a carbon steel wire.

BACKGROUND ART

10 **[0002]** Conventionally, a steel wire used for reinforcing rubber articles such as tires and high pressure hoses is manufactured by drawing a carbon steel wire rod containing about 0.70 to 0.90 % by mass of carbon to a predetermined intermediate wire diameter and then applying a thermal treatment and a brass plating treatment to an intermediate wire rod, and further, drawing this intermediate wire rod to a final wire diameter. When used for reinforcing rubber articles, such a carbon steel wire is embedded in unvulcanized rubber as a single cord or a steel cord obtained by twisting, and vulcanization of rubber and bonding of the carbon steel wire and the rubber are carried out by heating.

15 **[0003]** In recent years, with a growing demand for energy saving and resource saving, development of a higher strength carbon steel wire is desired. In order to manufacture a high strength carbon steel wire by a manufacturing method as described above, the wire drawing amount to be applied to the carbon steel wire rod is needed to be increased. However, when the wire drawing amount is increased, the ductility of the carbon steel wire is decreased, and problems such as breakage during manufacturing or deterioration of durability at the time of use tend to occur. In particular, decrease in ductility of a surface layer portion may be a dominant factor with respect to a possible wire drawing amount, or an achievable strength. This is because a distortion due to wire drawing tends to concentrate on the surface layer portion of the carbon steel wire rather than the inside thereof, and the surface layer portion cannot bear the strong processing earlier than an inside portion. Age hardening or poor lubrication due to heat generation by friction with a die is further added, which promotes deterioration of ductility of the surface layer portion. In order to solve such a problem of deterioration of ductility, improvements have been made on wire drawing technique (for example, Patent Document 1).

RELATED ART DOCUMENT

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PATENT DOCUMENT

[0004] Patent Document 1: Japanese Unexamined Patent Application Publication No. 10-325089

SUMMARY OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

40 **[0005]** Today it is known that the strength of the steel cord obtained by twisting carbon steel wires is not the sum of the strength of the carbon steel wires which are constituent elements thereof. This is because when a tension is applied, a shearing force caused by twisting of a part of carbon steel wires in a steel cord becomes strong, and the carbon steel wire in that part causes a preceding fracture. As a result, the strength of the steel cord is considerably lower than the sum of the strengths of the carbon steel wires. Therefore, in order to further improve the strength of a steel cord, realization of a technique to solve a problem of a preceding fracture of a carbon steel wire is demanded.

45 **[0006]** Accordingly, an object of the present invention is to provide a carbon steel wire excellent in shear resistance as compared with a conventional one, which is hardly subject to preceding fracture even when twisted into a steel cord, and a method of manufacturing such a carbon steel wire.

MEANS FOR SOLVING THE PROBLEMS

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[0007] In order to solve the above-described problems, the inventor intensively studied to obtain the following findings. Specifically, a shear-resistant carbon steel wire having a low strength of about 2,750 MPa causes a large plastic deformation which causes necking against a shear, thereby alleviating a shear stress. On the other hand, the present inventor found that, since a carbon steel wire having a high strength of, for example, 3,500 MPa can hardly be plastically deformed, a shearing load concentrates on one point, thereby leading to fracture at this point. Based on such findings, the present inventor further intensively studied to find that the plastic deformation capacity of a carbon steel wire can be retained by setting a distribution of a crystal texture in a circular cross-section orthogonal to the longitudinal direction of the carbon steel wire to a predetermined distribution, whereby the shear resistance of the carbon steel wire can be improved, thereby

completing the present invention.

[0008] In other words, a carbon steel wire of the present invention is a carbon steel wire having a wire diameter of from 0.1 to 0.6 mm, characterized in that,

when the radius of a circular cross-section orthogonal to the longitudinal direction is r and a region from the outer periphery of the circular cross-section toward the center to $0.4r$ is a surface layer portion, the occupancy ratio of a crystal texture in the [110] orientation with respect to the longitudinal direction in the surface layer portion is 60% or less. Here, the crystal texture in the [110] orientation refers to a crystal texture which orients in a direction within 10° from the [110] direction when a longitudinal cross-section of a carbon steel wire is analyzed by Electron Backscatter Diffraction (EBSD).

[0009] In the carbon steel wire of the present invention, preferably, when a region inside the surface layer portion in the circular cross-section is a central portion, the occupancy ratio of a crystal texture in the [110] orientation with respect to the longitudinal direction in the central portion is greater than 60%. The carbon steel wire of the present invention can be suitably used for reinforcing rubber articles.

[0010] A method of manufacturing a carbon steel wire of the present invention is a method of manufacturing a carbon steel wire comprising a step of subjecting a carbon steel wire rod to wet wire drawing processing by using a plurality of dies, characterized in that

when the tensile strength of an eventually obtained carbon steel wire is T (MPa) and the number of dies used in the wet processing is n , a relationship represented by the following formula (1):

$$T/n \leq 155 \text{ (MPa)} \quad (1)$$

is satisfied, and when the radius of the carbon steel wire rod before the wet wire drawing processing is d_0 and the wire diameter of the carbon steel wire after the wet wire drawing is d_1 , the maximum value of a die drag at a die with a wire drawing distortion ε represented by the following formula (2):

$$\varepsilon = 2 \times \ln(d_0/d_1) \quad (2)$$

of 1.5 or less is 750 MPa or less. Here, the term "die drag" refers to a value calculated by (a tension applied to a wire passing through a die exit) - (a back tension applied to a wire before entering a die entrance).

EFFECTS OF THE INVENTION

[0011] According to the present invention, a carbon steel wire excellent in shear resistance as compared with a conventional one and a method of manufacturing such a carbon steel wire can be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012]

FIG. 1 is a cross-sectional view of a circular cross-section orthogonal to the longitudinal direction of a carbon steel wire of the present invention.

FIG. 2 is a longitudinal cross-sectional view of a carbon steel wire indicating measurement points of EBSD.

FIG. 3 is a graph illustrating relationships between distances from the surfaces of carbon steel wires of Example 1 and Comparative Example 2 and the occupancy ratios of a crystal texture in the [110] orientation with respect to the longitudinal direction of the carbon steel wires.

FIG. 4 is a schematic explanatory view of a method of measuring the shear breaking strength of a steel wire.

MODE FOR CARRYING OUT THE INVENTION

[0013] A carbon steel wire of the present invention will now be described in detail with reference to the drawings.

[0014] FIG. 1 is a cross-sectional view of a circular cross-section orthogonal to the longitudinal direction of a carbon steel wire of the present invention. A carbon steel wire of the present invention is a carbon steel wire 1 having a wire diameter of from 0.1 to 0.6 mm, and when the radius of a circular cross-section orthogonal to the longitudinal direction is r and a region from the outer periphery of the circular cross-section toward the center to $0.4r$ is a surface layer portion 2, the occupancy ratio of a crystal texture in the [110] orientation with respect to the longitudinal direction in the surface layer portion 2 is 60% or less. In other words, by making the occupancy ratio of a crystal texture in the [110] orientation

in the surface layer portion 2 smaller than conventional one, the ductility of the surface layer portion 2 is secured, the plastic deformation ability is maintained, and the shear resistance is improved. In a carbon steel wire of the present invention, in order to better obtain an effect of the present invention, the occupancy ratio of the crystal texture in the [110] orientation with respect to the longitudinal direction in a region of 0.4r from the outer periphery of a circular cross-section orthogonal to the longitudinal direction is preferably 60% or less.

[0015] In a carbon steel wire of the present invention, the occupancy ratio of a crystal texture in the [110] orientation with respect to the longitudinal direction in a central portion preferably exceeds 60%. Here, the central portion 3 is a region inside the surface layer portion 2 in a circular cross-section. In a carbon steel wire of the present invention, the occupancy ratio of a crystal texture in the [110] orientation with respect to the longitudinal direction in the surface layer portion 2 is 60% or less, which is smaller than in the past, and therefore, although the shear resistance is improved, the tensile strength is reduced accordingly. Therefore, in order to secure the tensile strength of the carbon steel wire, the strength of the central portion 3 of the carbon steel wire is increased. In a carbon steel wire of the present invention, preferably, the occupancy ratio of a crystal texture in the [110] orientation with respect to the longitudinal direction in the central portion 3 is 80% or more.

[0016] A carbon steel wire of the present invention is not particularly limited as long as the wire diameter is from 0.1 to 0.6 mm and the occupancy ratio of a crystal texture in the [110] orientation with respect to the longitudinal direction in the surface layer portion 2 is 60% or less. For example, for a material, a high carbon steel wire having a carbon content of 0.70 mass% or more is suitable.

[0017] A carbon steel wire of the present invention attains both tensile strength and shear resistance at a higher level than conventional one and can be suitably used for reinforcing rubber articles such as tires, belts, air springs and hoses. For example, when a carbon steel wire of the present invention is used as a reinforcing material for a tire, it can be used as a reinforcing material such as a carcass ply, a belt layer, a belt reinforcing layer, a reinforcing layer around a belt such as a flipper.

[0018] Next, a method of manufacturing a carbon steel wire of the present invention will be described in detail.

[0019] A method of manufacturing a carbon steel wire of the present invention is a method of manufacturing a carbon steel wire comprising a step of performing a wet wire drawing processing on a carbon steel wire rod by using a plurality of dies. In a method of manufacturing a carbon steel wire of the present invention, when the tensile strength of an eventually obtained carbon steel wire is T(MPa) and the number of dies used for wet wire drawing processing is n, the following formula (1):

$$T/n \leq 155 \text{ (MPa)} \quad (1)$$

is satisfied.

[0020] As described above, in the carbon steel wire of the present invention, the occupancy ratio of a crystal texture in the [110] orientation with respect to the longitudinal direction in the surface layer portion 2 is set to 60% or less. Such a carbon steel wire can be manufactured by retarding the [110] orientation with respect to the longitudinal direction of a crystal texture of the surface layer portion 2 of the carbon steel wire. For this purpose, it is only needed to mainly process the surface of the carbon steel wire rod in wet wire drawing processing. Therefore, it is better to use many dies so that the surface of a carbon steel wire rod frequently comes into contact with a die which is a processing jig. Therefore, in a method of manufacturing a carbon steel wire of the present invention, a value obtained by dividing the tensile strength (MPa) of an eventually obtained carbon steel wire by the number of dies used for wire drawing processing is set to 155 (MPa) or less as a reference thereof. The value is suitably 150(MPa) or less.

[0021] Further, in a method of manufacturing a carbon steel wire of the present invention, when the radius of the carbon steel wire rod before the wet wire drawing processing is d0 and the wire diameter of the carbon steel wire after the wet wire drawing is d1, the maximum value of a die drag at a die with a wire drawing distortion ε represented by the following formula (2):

$$\varepsilon = 2 \times \ln(d0/d1) \quad (2)$$

of 1.5 or less is 750 MPa or less. Orientation of a crystal occurs at an initial stage of drawing processing. Therefore, it is effective to reduce the processing amount in the first half of wire drawing processing. Accordingly, in a method of manufacturing a carbon steel wire of the present invention, the maximum value of a die drag in a die having a wire drawing distortion of 1.5 or less is set to 750 MPa or less. The value is suitably 700 MPa or less.

[0022] Supplementally, when the wire drawing distortion is 2.5 or more, the orientation of the metallographic structure to the [110] orientation with respect to the longitudinal direction is almost completed. Although the crystal texture in the

[110] orientation is nearly perfectly aligned in the wire drawing direction and the tensile strength increases as the fiber spacing decreases with the processing amount, ductility values such as elongation and drawing are unambiguously reduced. For this reason, a steel wire having a tensile strength of 3,000 MPa or more with a drawing distortion of 2.5 or more weakens against a shearing force.

[0023] The method of manufacturing a carbon steel wire of the present invention is not particularly limited as long as it satisfies the above-described manufacturing conditions in a wet wire drawing process. For example, as a carbon steel wire rod subjected to wire drawing, one containing 0.70% by mass of carbon can be suitably used. A processing method, processing conditions, or the like of the above-described wet wire drawing processing can be appropriately designed according to a usual method as desired. Further, there are no particular restrictions on various processes performed prior to the above-described wet wire drawing processing process, and after carrying out processes such as dry drawing, patenting heat treatment and plating treatment, a method of manufacturing a carbon steel wire of the present invention may be applied. In this case, a dry wire drawing, a patenting heat treatment, and a plating treatment can be carried out by a method similar to a conventional method.

EXAMPLES

[0024] The present invention will now be described in more detail by way of Examples.

< Examples 1 to 3 and Comparative Examples 1 to 6 >

[0025] Evaluation was carried out using steel wires having a wire diameter of 0.24 mm and tensile strengths listed on Tables 1 and 2. Steel wires subjected to the evaluation were manufactured according to conditions listed on Tables 1 and 2 below. For each steel wire, the shear strength exhibition index was calculated according to the following procedure. The obtained results are listed on the same Tables in combination. The occupancy ratio of a crystal texture in the [110] orientation with respect to the longitudinal direction was measured by using D8 DISCOVER manufactured by Bruker Corporation.

< Measurement of Crystal Texture in [110] Orientation >

[0026] In measurement of EBSD, the magnification was set to 5000 times and 50 nm pitch, and seven visual fields were measured from the outside to the center of a longitudinal cross-section of a carbon steel wire. FIG. 2 is a longitudinal cross-sectional view of a carbon steel wire indicating measurement positions of the EBSD, and the seven areas surrounded by the dotted lines in the figure are seven visual fields to be measured. From the obtained results, the occupancy ratio of a crystal texture in the [110] orientation with respect to the longitudinal direction in a surface layer portion and a central portion and the occupancy ratio of a crystal texture in the [110] orientation with respect to the longitudinal direction in a region from the outer periphery to 0.4r were calculated. FIG. 3 is a graph illustrating relationships between distances from the surfaces of carbon steel wires of Example 1 and Comparative Example 2 and the occupancy ratios of a crystal texture in the [110] orientation with respect to the longitudinal direction of the carbon steel wires.

< Shear Strength Exhibition Index >

[0027] A steel wire was held in a bent state at 165°, and a jig as illustrated in FIG. 4 was pressed against this steel wire, thereby obtaining the breaking strength of the steel wire, and the shear strength exhibition index of the steel wire was calculated from the ratio thereof to the simple tensile strength. FIG. 4 is a schematic explanatory view of a method of measuring the shear breaking strength of a steel wire. The R of a jig 4 illustrated in the figure was set to 0.2 mm. A steel wire with a tensile strength of 3,500 MPa was represented by an index with Comparative Example 1 taken as 100, a steel wire with a tensile strength of 3,750 MPa was represented by an index with Comparative Example 5 taken as 100, and a steel wire with a tensile strength of 3,200 MPa was represented by an index with Comparative Example 6 taken as 100. In Tables 1 and 2, they were expressed as the shear strength exhibition index.

[Table 1]

	Example 1	Comparative Example 1	Comparative Example 2	Comparative Example 3	Comparative Example 4
Tensile strength (MPa)	3500	3500	3500	3500	3500
Tensile strength /number of dies used	152	167	152	159	152

(continued)

	Example 1	Comparative Example 1	Comparative Example 2	Comparative Example 3	Comparative Example 4
Die drag *1	718	815	908	753	827
Occupancy ratio (%) of crystal texture in [110] orientation of central portion	84	84	88	84	87
Occupancy ratio (%) of crystal texture in [110] orientation of surface 0.4r region *2	49	65	68	61	67
Shear strength exhibition index	108	100	100	101	100
*1: Maximum value of die drag of a die with the drawing distortion of 1.5 or less *2: The occupancy ratio of a crystal texture in the [110] orientation in a region from the outer periphery of a circular cross-section orthogonal to the longitudinal direction to 0.4r					

[Table 2]

	Example 2	Comparative Example 5	Example 3	Comparative Example 6
Tensile strength (MPa)	3200	3200	3750	3750
Tensile strength /number of dies used	145	168	152	165
Die drag *1	672	827	705	837
Occupancy ratio (%) of crystal texture in [110] orientation of central portion	80	82	92	88
Occupancy ratio (%) of crystal texture in [110] orientation of surface 0.4r region *2	45	67	55	72
Shear strength exhibition index	105	100	110	100

[0028] From the above Tables 1 and 2 and FIG. 3, it is known that the carbon steel wires of the present invention exhibit more excellent shear strength exhibition indexes than those of conventional ones, and that the carbon steel wires of the present invention are more excellent in shear resistance than conventional ones.

DESCRIPTION OF SYMBOLS

[0029]

- 1 carbon steel wire
- 2 surface layer portion
- 3 central portion
- 4 jig

Claims

1. A carbon steel wire having a wire diameter of from 0.1 to 0.6 mm, **characterized in that**, when the radius of a circular cross-section orthogonal to the longitudinal direction is r and a region from the outer periphery of the circular cross-section toward the center to 0.4r is a surface layer portion, the occupancy ratio of a crystal texture in the [110] orientation with respect to the longitudinal direction in the surface layer portion is 60% or less.
2. The carbon steel wire according to claim 1, wherein, when a region inside the surface layer portion in the circular

cross-section is a central portion, the occupancy ratio of a crystal texture in the [110] orientation with respect to the longitudinal direction in the central portion is greater than 60%.

3. The carbon steel wire according to claim 1 which is for reinforcing rubber articles.
4. The carbon steel wire according to claim 2 which is for reinforcing rubber articles.
5. A method of manufacturing a carbon steel wire comprising a step of subjecting a carbon steel wire rod to wet wire drawing processing by using a plurality of dies, **characterized in that** when the tensile strength of an eventually obtained carbon steel wire is T (MPa) and the number of dies used in the wet processing is n, a relationship represented by the following formula (1):

$$T/n \leq 155 \text{ (MPa)} \quad (1)$$

is satisfied, and when the radius of the carbon steel wire rod before the wet wire drawing processing is d0 and the wire diameter of the carbon steel wire after the wet wire drawing is d1, the maximum value of a die drag at a die with a wire drawing distortion ε represented by the following formula (2):

$$\varepsilon = 2 \times \ln(d0/d1) \quad (2)$$

of 1.5 or less is 750 MPa or less.

FIG. 1

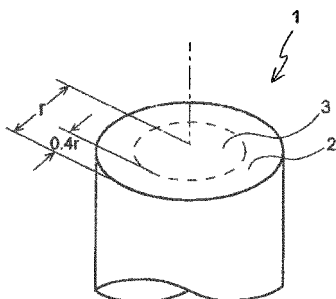


FIG. 2

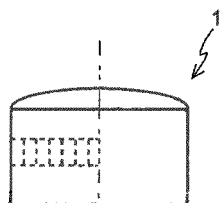


FIG. 3

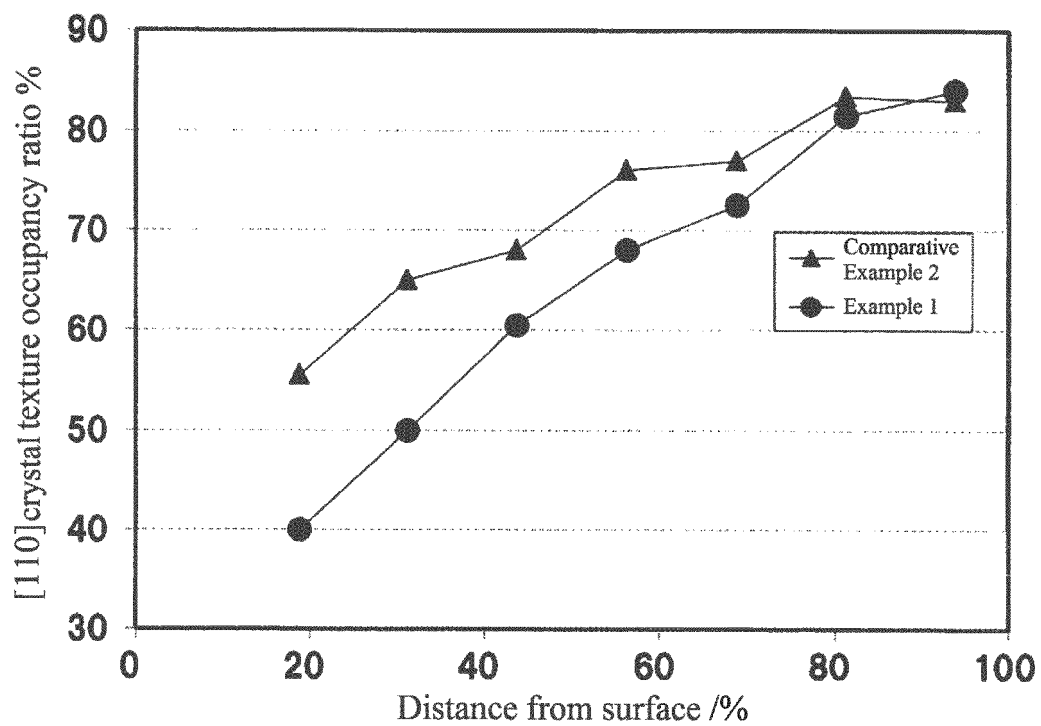
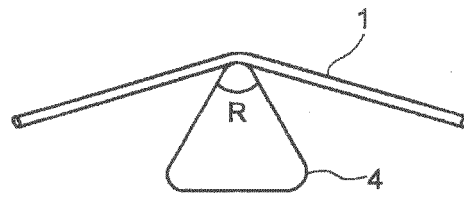


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/082465

A. CLASSIFICATION OF SUBJECT MATTER

B21C1/00(2006.01)i, B21C1/12(2006.01)i, C21D7/02(2006.01)i

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)

B21C1/00, B21C1/12, C21D7/02

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 1996-2016

Kokai Jitsuyo Shinan Koho 1971-2016 Toroku Jitsuyo Shinan Koho 1994-2016

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.
Y A	JP 9-99312 A (Nippon Steel Corp.), 15 April 1997 (15.04.1997), tables 2 to 3, 15 to 16, 19 to 20 (Family: none)	5 1-4
Y	JP 2013-104154 A (Bridgestone Corp.), 30 May 2013 (30.05.2013), 0005 to 0007; table 1; fig. 2 & US 2014/0315044 A1 fig. 2; table 1; paragraphs [0005] to [0007] & WO 2013/073452 A1 & EP 2781649 A1 & CN 103930614 A & KR 10-2014-0102214 A	5
Y	JP 2004-66316 A (Bridgestone Corp.), 04 March 2004 (04.03.2004), 0008, 0039 (Family: none)	5

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

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Date of the actual completion of the international search
20 January 2016 (20.01.16)Date of mailing of the international search report
02 February 2016 (02.02.16)Name and mailing address of the ISA/
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3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/082465

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2014/054756 A1 (Nippon Steel & Sumitomo Metal Corp.), 10 April 2014 (10.04.2014), & US 2015/0301297 A1 & EP 2905353 A1 & CN 104662190 A	1-5
A	JP 7-268547 A (Nippon Steel Corp.), 17 October 1995 (17.10.1995), (Family: none)	1-5

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

REFERENCES CITED IN THE DESCRIPTION

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