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(54) **STEEL ROD**

(57) A bar-shaped steel product extends unidirectionally and has a chemical composition including, by mass%, 0.001 to 0.20% of C, 0.01 to 3.0% of Si, 0.01 to 2.0% of Mn, 0.01 to 5.0% of Ni, 7.0 to 35.0% of Cr, 0.01 to 5.0% of Mo, 0.01 to 3.0% of Cu, 0.001 to 0.10% of N, 0.2 to 2.0% of Nb, optional element(s), and a balance

consisting of Fe and inevitable impurities, and has 0.5 or less of a rolling-direction-crystal-orientation RD//<100> fraction (an area ratio of crystal having 20 degrees or less of an orientation difference between a <100> orientation and a rolling direction).

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Description

TECHNICAL FIELD

5 **[0001]** The present invention relates to a bar-shaped steel product.

BACKGROUND ART

10 **[0002]** Small-diameter wire rods made of a high purity ferrite stainless steel are conventionally used to produce cold forging parts. However, large-diameter wire rods, steel bars, and the like made of the high purity ferrite stainless may have restriction on cold forging. This is because in the large-diameter wire rods and steel bars made of the high purity ferrite stainless steel, coarse unrecrystallized crystal grains and the like in a steel structure are present to decrease toughness and promote brittle fracture during cold forging.

15 **[0003]** Patent Literatures 1 to 6 disclose steel wire rods and the like whose properties are improved by appropriately controlling chemical compositions, manufacturing conditions and the like.

CITATION LIST

PATENT LITERATURE(S)

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[0004]

Patent Literature 1: JP 2015-224358 A

Patent Literature 2: JP 2013-147705 A

25 Patent Literature 3: International Publication WO 2014/157231

Patent Literature 4: JP 2002-254103 A

Patent Literature 5: JP 2005-226147 A

Patent Literature 6: JP 2005-313207 A

Patent Literature 7: JP 05-329510 A

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SUMMARY OF THE INVENTION

PROBLEM(S) TO BE SOLVED BY THE INVENTION

35 **[0005]** However, no study has been made on a technique for improving toughness by controlling a chemical composition, micro structure and the like of a bar-shaped steel product.

[0006] In light of the above, an object of the invention is to solve the above problem and provide a bar-shaped steel product having an excellent toughness.

40 MEANS FOR SOLVING THE PROBLEM(S)

[0007] The invention has been made for solving the above problem and provides a bar-shaped steel product below as a gist.

45 (1) According to an aspect of the invention, a bar-shaped steel product extending unidirectionally has a chemical composition including: by mass%,

0.001 to 0.09 % of C;

0.01 to 3.0% of Si;

50 0.01 to 2.0 % of Mn;

0.01 to 5.0 % of Ni;

7.0 to 35.0% of Cr;

0.01 to 5.0% of Mo;

0.01 to 3.0 % of Cu;

55 0.001 to 0.10% of N;

0.2 to 2.0% of Nb;

0 to 2.0% of Ti;

0 to 2.0% of V;

0 to 0.1% of B;
 0 to 5.0% of Al;
 0 to 2.5 % of W;
 0 to 0.05 % of Ga;
 0 to 2.5% of Co;
 0 to 2.5 % of Sn;
 0 to 2.5% of Ta;
 0 to 0.05 % of Ca;
 0 to 0.012% of Mg;
 0 to 0.012% of Zr;
 0 to 0.05% of REM; and

a balance consisting of Fe and inevitable impurities, and

the bar-shaped steel product has 0.5 or less of a rolling-direction-crystal-orientation RD//<100> fraction, the rolling-direction-crystal-orientation RD//<100> fraction meaning an area ratio of crystal having 20 degrees or less of an orientation difference between a <100> orientation and a rolling direction.

(2) In the above aspect, the chemical composition further includes, by mass%, at least one selected from 0.001 to 2.0% of Ti, 0.001 to 2.0% of V, 0.0001 to 0.1% of B, 0.001 to 5.0% of Al, 0.05 to 2.5% of W, 0.0004 to 0.05% of Ga, 0.05 to 2.5% of Co, 0.01 to 2.5% of Sn, and 0.01 to 2.5% of Ta.

(3) In the above aspect, the chemical composition further includes, by mass%, at least one selected from 0.0002 to 0.05% of Ca, 0.0002 to 0.012% of Mg, 0.0002 to 0.012% of Zr, and 0.0002 to 0.05% of REM.

(4) According to another aspect of the invention, a bar-shaped steel product extending unidirectionally has the chemical composition according to the above aspect, and a transition temperature of 200 degrees C or less.

(5) The bar-shaped steel product according to the above aspect has a transition temperature of 200 degrees C or less.

(6) The bar-shaped steel product according to the above aspect has a cross section whose shape is a circle, in which a diameter of the circle is in a range from 15.0 to 200 mm.

[0008] The bar-shaped steel product according to the above aspects of the invention is exemplified by a steel wire rod, a steel wire, and a steel bar.

[0009] According to the above aspects of the invention, a bar-shaped steel product having an excellent toughness is obtainable.

DESCRIPTION OF EMBODIMENT(S)

[0010] Inventors have conducted various studies in order to obtain a bar-shaped steel product having an excellent toughness. As a result, the following findings (a) to (c) have been obtained.

[0011]

(a) For instance, in a bar-shaped steel product such as a high purity ferrite stainless steel wire rod, since transformation from delta ferrite to austenite does not occur, a micro structure tends to be coarse. In terms of toughness of the steel product, brittle fracture occurs due to such a coarse micro structure. Among the ferrite stainless steel wire rods, a large-diameter bar-shaped steel product tends to have a significantly coarse micro structure and decrease in toughness.

(b) It is effective to appropriately control an RD//<100> fraction in the micro structure in order to improve toughness of the large-diameter bar-shaped steel product.

(c) In order to control the above-mentioned RD//<100> fraction, it is desirable to adjust a chemical composition and manufacturing conditions, specifically, a temperature, time, and processing rate in the rolling, a roller diameter in rough rolling, and the like.

[0012] The invention has been made on a basis of the above findings. A preferable exemplary embodiment of the invention will be described in detail. In the following description, the preferable exemplary embodiment of the invention will be described as the invention. Requirements of the invention will be described in detail below.

1. Rolling-Direction-Crystal-Orientation RD//<100> Fraction

[0013] In a bar-shaped steel product according to the invention, a crystal orientation of a rolling direction (RD) is controlled. Specifically, a rolling-direction-crystal-orientation RD//<100> fraction (area ratio) (hereinafter, simply referred to as a "RD//<100> fraction") is preferably 0.5 or less. This is because the RD//<100> fraction exceeding 0.5 promotes

brittle fracture and decreases toughness. The RD//<100> fraction is more preferably 0.40 or less, further preferably 0.35 or less.

[0014] The RD//<100> fraction is calculated according to the following procedure. Specifically, the RD//<100> fraction is obtained by measuring at least one field of view among 200-fold fields of view in a surface layer portion, a center portion, and a 1/4-depth-position existing between the surface layer portion and the center portion in an L-cross section of a steel product (i.e., a cross section including a center of the steel product and being in parallel to the rolling direction (longitudinal direction) of the steel product). A crystal orientation of each of crystal grains in the observed field(s) of view is analyzed using FE-SEM/EBSD. The rolling direction is represented by RD. A crystal plane in the RD direction is analyzed. Components in a <100> orientation only in a clearance of 20 degrees or less are displayed and the RD//<100> fraction is measured. The surface layer portion refers to a position at a 1-mm depth in a central axial direction from a surface of the steel product. Specifically, the rolling-direction-crystal-orientation RD//<100> fraction means an area ratio of crystal having 20 degrees or less of an orientation difference between the <100> orientation and the rolling direction.

2. Chemical Composition

[0015] Reasons for limiting elements are as follows. It should be noted that an indication "%" for a content of each element means "mass%" in the following description.

C: 0.001 to 0.09%

[0016] C increases strength of the steel product. For this reason, a C content is defined at 0.001% or more, preferably 0.002% or more. However, an excessive C content increases the RD//<100> fraction. As a result, toughness is decreased. For this reason, the C content is defined at 0.09% or less. The C content is preferably 0.05% or less, more preferably 0.03% or less, further preferably 0.02% or less.

Si: 0.01 to 3.0%

[0017] Si is contained as a deoxidizing element to improve high-temperature oxidation properties. For this reason, an Si content is defined at 0.01% or more, preferably 0.05% or more. However, an excessive Si content increases the RD//<100> fraction. As a result, toughness is decreased. For this reason, the Si content is defined at 3.0% or less. The Si content is preferably 2.0% or less, more preferably 1.0% or less, further preferably 0.5% or less.

Mn: 0.01 to 2.0%

[0018] Mn improves strength of the steel product. For this reason, an Mn content is defined at 0.01% or more, preferably 0.05% or more. However, an excessive Mn content increases the RD//<100> fraction. As a result, toughness is decreased. Moreover, corrosion resistance is sometimes decreased. For this reason, the Mn content is defined at 2.0% or less. The Mn content is preferably 1.0% or less, more preferably 0.8% or less, further preferably 0.5% or less.

Ni: 0.01 to 5.0%

[0019] Ni improves the toughness of the steel product. For this reason, an Ni content is defined at 0.01% or more, preferably 0.05% or more. However, an excessive Ni content increases the RD//<100> fraction. As a result, the toughness is decreased. For this reason, the Ni content is defined at 5.0% or less. The Ni content is preferably 2.0% or less, more preferably 1.0% or less, further preferably 0.5% or less.

Cr: 7.0 to 35.0%

[0020] Cr improves corrosion resistance. For this reason, the Cr content is defined at 7.0% or more. The Cr content is preferably 10.0% or more, more preferably 15.0% or more. However, an excessive Cr content increases the RD//<100> fraction. As a result, the toughness is decreased. The Cr content is defined at 35.0% or less. The Cr content is preferably 27.0% or less, more preferably 25.0% or less, further preferably 21.0% or less.

Mo: 0.01 to 5.0%

[0021] Mo improves the corrosion resistance. For this reason, an Mo content is defined at 0.01% or more. However, an excessive Mo content increases the RD//<100> fraction. As a result, the toughness is decreased. For this reason, the Mo content is defined at 5.0% or less. The Mo content is preferably 2.0% or less, more preferably 1.0% or less,

further preferably 0.5% or less.

Cu: 0.01 to 3.0%

5 **[0022]** Cu improves the corrosion resistance. For this reason, a Cu content is defined at 0.01% or more, preferably 0.30% or more. However, an excessive Cu content increases the RD//<100> fraction. As a result, the toughness is decreased. For this reason, the Cu content is defined at 3.0% or less. The Cu content is preferably 2.0% or less, more preferably 1.0% or less, further preferably 0.5% or less.

10 N: 0.001 to 0.10%

[0023] N increases the strength of the steel product. For this reason, an N content is defined at 0.001% or more, preferably 0.004% or more. However, an excessive N content increases the RD//<100> fraction. As a result, the toughness is decreased. For this reason, the N content is defined at 0.10% or less. The N content is preferably 0.05% or less, more preferably 0.03% or less, further preferably 0.02% or less.

Nb: 0.2 to 2.0%

20 **[0024]** Nb has an effect of increasing the strength of the steel product. Moreover, since Nb forms carbonitrides, formation of Cr carbides is suppressed to suppress formation of Cr-deficient layers. As a result, Nb has an effect of preventing intergranular corrosion. In other words, since Nb is an effective element for improving the corrosion resistance, an Nb content to be added is 0.2% or more, preferably 0.3% or more. However, an excessive Nb content increases the RD//<100> fraction. As a result, the toughness is decreased. Moreover, coarse carbonitrides decrease the toughness. For this reason, the Nb content is defined at 2.0% or less. The Nb content is preferably 1.0% or less, more preferably 0.8% or less.

[0025] The bar-shaped steel product of the invention may contain at least one element selected from Ti, V, B, Al, W, Ga, Co, Sn, and Ta as needed, in addition to the aforementioned elements.

Ti: 0 to 2.0%

30 **[0026]** Ti has an effect of increasing the strength of the steel product. Moreover, since Ti forms carbonitrides, formation of Cr carbides is suppressed to suppress formation of Cr-deficient layers. As a result, Ti has an effect of preventing intergranular corrosion. In other words, since Ti has an effect of improving the corrosion resistance, Ti may be contained as needed.

35 **[0027]** However, an excessive Ti content increases the RD//<100> fraction. As a result, the toughness is decreased. Moreover, coarse carbonitrides decrease the toughness. For this reason, the Ti content is defined at 2.0% or less. The Ti content is preferably 1.0% or less, more preferably 0.5% or less, further preferably 0.05% or less. On the other hand, the Ti content is preferably 0.001% or more in order to obtain the aforementioned effects.

40 V: 0 to 2.0%

[0028] Since V has the effect of improving the corrosion resistance, V may be contained as needed. However, an excessive V content increases the RD//<100> fraction. As a result, the toughness is decreased. Moreover, coarse carbonitrides decrease the toughness. For this reason, the V content is defined at 2.0% or less. The V content is preferably 1.0% or less, more preferably 0.5% or less, further preferably 0.1% or less. On the other hand, the V content is preferably 0.001% or more in order to obtain the aforementioned effects.

B: 0 to 0.1%

50 **[0029]** B has effects of improving hot workability and corrosion resistance. Accordingly, B may be contained as needed. However, an excessive B content increases the RD//<100> fraction. As a result, the toughness is decreased. For this reason, the B content is defined at 0.1% or less. The B content is preferably 0.02% or less, more preferably 0.01% or less. On the other hand, the B content is preferably 0.0001% or more in order to obtain the aforementioned effects.

55 Al: 0 to 5.0%

[0030] Since Al has an effect of promoting deoxidation to improve a cleanliness level of inclusions, Al may be contained as needed. However, an excessive Al content saturates this effect and increases the RD//<100> fraction. As a result,

the toughness is decreased. Moreover, coarse inclusions decrease the toughness. For this reason, the Al content is defined at 5.0% or less. The Al content is preferably 1.0% or less, more preferably 0.1% or less, further preferably 0.01% or less. On the other hand, the Al content is preferably 0.001% or more in order to obtain the aforementioned effects.

5 W: 0 to 2.5%

[0031] Since W has the effect of improving the corrosion resistance, W may be contained as needed. However, an excessive W content increases the RD//<100> fraction. As a result, the toughness is decreased. Moreover, coarse carbonitrides decrease the toughness. For this reason, the W content is defined at 2.5% or less. The W content is preferably 2.0% or less, more preferably 1.5% or less. On the other hand, in order to obtain the aforementioned effects, the W content is preferably 0.05% or more, more preferably 0.10% or more.

Ga: 0 to 0.05%

15 **[0032]** Since Ga has the effect of improving the corrosion resistance, Ga may be contained as needed. However, an excessive Ga content decreases the hot workability. Accordingly, the Ga content is defined at 0.05% or less. On the other hand, the Ga content is preferably 0.0004% or more in order to obtain the aforementioned effects.

Co: 0 to 2.5%

20 **[0033]** Since Co has the effect of improving the strength of the steel product, Co may be contained as needed. However, an excessive Co content increases the RD//<100> fraction. As a result, the toughness is decreased. For this reason, the Co content is defined at 2.5% or less. The Co content is preferably 1.0% or less, more preferably 0.8% or less. On the other hand, in order to obtain the aforementioned effects, the Co content is preferably 0.05% or more, more preferably 0.10% or more.

Sn: 0 to 2.5%

30 **[0034]** Since Sn has the effect of improving the corrosion resistance, Sn may be contained as needed. However, an excessive Sn content increases the RD//<100> fraction. As a result, the toughness is decreased. Moreover, the toughness is decreased by grain boundary segregation of Sn. For this reason, the Sn content is defined at 2.5% or less. The Sn content is preferably 1.0% or less, more preferably 0.2% or less. On the other hand, in order to obtain the aforementioned effects, the Sn content is preferably 0.01% or more, more preferably 0.05% or more.

35 Ta: 0 to 2.5%

[0035] Since Ta has the effect of improving the corrosion resistance, Ta may be contained as needed. However, an excessive Ta content increases the RD//<100> fraction. As a result, the toughness is decreased. For this reason, the Ta content is defined at 2.5% or less. The Ta content is preferably 1.5% or less, more preferably 0.9% or less. On the other hand, in order to obtain the aforementioned effects, the Ta content is preferably 0.01% or more, more preferably 0.04% or more, further preferably 0.08% or more.

[0036] The bar-shaped steel product of the invention may contain at least one element selected from Ca, Mg, Zr, and REM as needed, in addition to the aforementioned elements.

45 Ca: 0 to 0.05%

Mg: 0 to 0.012%

Zr: 0 to 0.012%

50 REM: 0 to 0.05%

[0037] Ca, Mg, Zr, and REM may be contained for deoxidation, as needed. However, an excessive content of each of Ca, Mg, Zr, and REM increases the RD//<100> fraction. As a result, the toughness is decreased. Moreover, coarse inclusions decrease the toughness. For this reason, Ca of 0.05% or less, Mg of 0.012% or less, Zr of 0.012% or less, and REM of 0.05% or less are defined. The Ca content is preferably 0.010% or less, more preferably 0.005% or less. The Mg content is preferably 0.010% or less, more preferably 0.005% or less. The Zr content is preferably 0.010% or less, more preferably 0.005% or less. REM is preferably 0.010% or less.

[0038] On the other hand, in order to obtain the aforementioned effects, Ca of 0.0002% or more, Mg of 0.0002% or more, Zr of 0.0002% or more, and REM of 0.0002% or more are preferable. The Ca content is more preferably 0.0004% or more, further preferably 0.001% or more. The Mg content is more preferably 0.0004% or more, further preferably 0.001% or more. The Zr content is more preferably 0.0004% or more, further preferably 0.001% or more. The REM content is more preferably 0.0004% or more, further preferably 0.001% or more.

[0039] It should be noted that REM is a general term for 17 elements including Y, Sc, and 15 elements of lanthanoids. One or more of the 17 elements can be contained in steel. The REM content means a total content of these elements.

[0040] In a chemical composition of a steel sheet of the invention, a balance consists of Fe and inevitable impurities. The "inevitable impurities" herein mean substances in raw materials such as ore and scrap as well as components mixed in the manufacturing process due to various factors when the steel sheet is industrially manufactured, the substances and the components being allowable within a range that does not adversely affect the invention.

[0041] Examples of the inevitable impurities include S, P, O, Zn, Bi, Pb, Se, Sb, H, and Te. The inevitable impurities are preferably reduced, however, when being contained, Zn, Bi, Pb, Se, and H are desirably 0.01% or less. Sb and Te are desirably 0.05% or less.

3. Shape and Size

[0042] As described above, in the bar-shaped steel product according to the invention, a cross section perpendicular to a length direction is not particularly limited. For instance, the cross section is not limited only to a general circular cross section. The bar-shaped steel product can be exemplified by a deformed bar as well as a flat steel bar and a square steel bar whose cross sections are rectangular.

[0043] When the bar-shaped steel product according to the invention is a round steel bar (i.e., the cross section is circular), a diameter of the cross section is preferably in a range from 15.0 to 200 mm. When the diameter of the cross section is less than 15.0 mm, the bar-shaped steel product cannot meet a large-component size currently required. Accordingly, the diameter of the cross section is preferably 15.0 mm or more, more preferably 20.0 mm or more, further preferably 30.0 mm or more.

[0044] However, the diameter of the cross section exceeding 200 mm increases the RD//<100> fraction. As a result, the toughness is decreased. For this reason, the diameter of the cross section is preferably 200 mm or less. The diameter of the cross section is more preferably 150 mm or less, further preferably 100 mm or less, particularly preferably 70 mm or less.

4. Evaluation of Properties

[0045] The bar-shaped steel product according to the invention is evaluated in terms of toughness using a ductile-brittle transition temperature according to Charpy impact test. The toughness is evaluated as being favorable when the transition temperature is 200 degrees C or less. For the toughness, the transition temperature is preferably 150 degrees C or less, more preferably 100 degrees C or less, further preferably 80 degrees C or less, still further preferably 30 degrees C or less. A favorable lower limit of the transition temperature is defined as -150 degrees C due to components used for controlling a texture, and costs caused by manufacturing restriction.

5. Manufacturing Method

[0046] A favorable manufacturing method of the bar-shaped steel product according to the invention will be described. In the following description, a steel wire rod having a circular cross section will be described as an example. The bar-shaped steel product according to the invention can provide the effects as long as having the aforementioned structure irrespective of the manufacturing method. However, the bar-shaped steel product according to the invention is stably obtainable according to, for instance, a manufacturing method below.

[0047] For the bar-shaped steel product according to the invention, it is preferable to melt steel having the aforementioned chemical composition, cast the molten steel into a cast piece having a predetermined diameter, and then subject the cast piece to hot rolling or warm rolling for a wire rod. Subsequently, it is preferable to appropriately perform a solution treatment and pickling as needed.

5-1. Heating Step

[0048] A heating temperature of the cast piece is related to a processing temperature and contributes to cumulative strain and recrystallization behavior of the bar-shaped steel product, and eventually changes a RD//<100> fraction, which is related to toughness. Therefore, it is preferable to heat the cast piece, which is obtained by melting and casting, at a temperature in a range from 450 to 1300 degrees C. An excessively low heating temperature of the cast piece

embrittles the bar-shaped steel product. Therefore, the heating temperature of the cast piece is preferably 450 degrees C or more, more preferably 700 degrees C or more, further preferably 800 degrees C or more.

[0049] However, an excessively high heating temperature of the cast piece increases the RD//<100> fraction. As a result, the toughness is decreased. Therefore, the heating temperature of the cast piece is preferably 1300 degrees C or less, more preferably 1200 degrees C or less, further preferably 1100 degrees C or less.

5-2. Skew Rolling Step

[0050] It is preferable that the heated cast piece is subjected to hot working by using skew rolling. The hot working is not limited to the skew rolling. Any method of hot working going through the same or similar heat processing history is usable. For instance, blooming (breakdown) is usable as long as going through the same or similar heat processing history.

[0051] In the skew rolling, for instance, as disclosed in Patent Literature 7, three work rolls are arranged on respective roll shafts that are twisted and inclined in the same direction around a target material to be rolled, and each work roll revolves around the target material while rotating, whereby the target material is rolled into a spiral shape while advancing.

[0052] A reduction of area in the skew rolling changes the RD//<100> fraction. Therefore, the reduction of area affects toughness. The reduction of area of less than 20.0% increases the RD//<100> fraction. As a result, the toughness is decreased. Therefore, the reduction of area is preferably 20.0% or more, more preferably 40.0% or more, further preferably 50.0% or more, still further preferably 80.0% or more.

[0053] A processing temperature in the skew rolling (i.e., a temperature of the steel product after the skew rolling) changes the RD//<100> fraction. Since the processing temperature in the skew rolling thus affects the toughness, the processing temperature is preferably in a range from 450 to 1200 degrees C. When the processing temperature in the skew rolling is less than 450 degrees C, the steel product is embrittled. Therefore, the processing temperature in the skew rolling is preferably 450 degrees C or more, more preferably 700 degrees C or more. However, the processing temperature exceeding 1200 degrees C in the skew rolling increases the RD//<100> fraction. As a result, the toughness is decreased. Therefore, the processing temperature in the skew rolling is preferably 1200 degrees C or less, more preferably 1100 degrees C or less, further preferably 1000 degrees C or less.

[0054] Subsequent to the completion of the skew rolling, the steel product is preferably subjected to intermediate annealing. A time from the completion of the skew rolling to the start of the intermediate annealing changes the RD//<100> fraction. Therefore, the time from the completion of the skew rolling to start of the intermediate annealing affects the toughness. The time from the completion of the skew rolling to the start of the intermediate annealing is preferably in a range from 0.01 to 100 s.

[0055] When the time from the completion of the skew rolling to start of the intermediate annealing is less than 0.01 s, the RD//<100> fraction is increased in the later-described manufacturing step. As a result, the toughness is decreased. Therefore, the time from the completion of the skew rolling to start of the intermediate annealing is preferably 0.01 s or more, more preferably 0.1 s or more, further preferably 1 s or more.

[0056] However, when the time from the completion of the skew rolling to start of the intermediate annealing exceeds 100 s, the RD//<100> fraction is increased. As a result, the toughness is decreased. Therefore, the time from the completion of the skew rolling to start of the intermediate annealing is preferably 100 s or less, more preferably 50 s or less, further preferably 10 s or less.

5-3. Intermediate Annealing Step

[0057] The subsequent intermediate annealing step is performed in order to recrystallize a coarse solidified texture formed by casting. In the intermediate annealing, it is preferably to anneal the steel product in a temperature range from 700 to 1300 degrees C. Recrystallization of the steel product in the intermediate annealing step decreases the RD//<100> fraction. As a result, the toughness is improved. When a temperature in the intermediate annealing (hereinafter, referred to as a "intermediate annealing temperature") is less than 700 degrees C, the RD//<100> fraction is increased. As a result, the toughness is decreased. Therefore, the intermediate annealing temperature is preferably 700 degrees C or more, more preferably 800 degrees C or more.

[0058] However, the intermediate annealing temperature exceeding 1300 degrees C increases the RD//<100> fraction. As a result, the toughness is decreased. Therefore, the intermediate annealing temperature is preferably 1300 degrees C or less, more preferably 1200 degrees C or less, further preferably 1100 degrees C or less.

[0059] An annealing time in the intermediate annealing (hereinafter, referred to as an "intermediate annealing time") is preferably in a range from 1 to 480 min. The intermediate annealing time of less than 1 min increases the RD//<100> fraction. As a result, the toughness is decreased. Therefore, the intermediate annealing time is preferably 1 min or more, more preferably 30 min or more.

[0060] However, the intermediate annealing time exceeding 480 min increases the RD//<100> fraction. As a result, the toughness is decreased. Therefore, the intermediate annealing time is preferably 480 min or less, more preferably

180 min or less.

5-4. Total Reduction of area

[0061] The rolling is performed using a skew rolling mill, rough rolling mill, intermediate rolling mill, finish rolling mill and/or the like. A total reduction of area by the rolling including the above skew rolling, and the like refers to a reduction of area until an entire processing is completed. The total reduction of area changes the RD//<100> fraction. Therefore, the total reduction of area affects the toughness. The total reduction of area of less than 30.0% increases the RD//<100> fraction. As a result, the toughness is decreased. Therefore, the total reduction of area is preferably 30.0% or more, more preferably 50.0% or more, further preferably 80.0% or more, still further preferably 90.0% or more.

5-5. Roller Diameter of Rough Rolling Mill

[0062] Since a roller diameter of a rough rolling mill affects the hot-worked structure and is particularly related to the RD//<100> fraction, the roller diameter of the rough rolling mill is preferably in a range from 200 to 2500 mm. When the roller diameter of the rough rolling mill is less than 200 mm, shear deformation is promoted in the steel product to form an orientation other than RD//<110> that is a priority orientation of the deformed texture of BCC crystal structure, thereby increasing the RD//<100> fraction. Since a plane perpendicular to the <100> orientation is a cleavage plane, the increase of the RD//<100> fraction decreases the toughness. Accordingly, the roller diameter of the rough rolling mill is 200 mm or more, preferably 400 mm or more. On the other hand, when the roller diameter of the rough rolling mill exceeds 2500 mm, rolling equipment becomes large, which is uneconomical. Accordingly, the roller diameter of the rough rolling mill is defined at 2500 mm or less, <ret> preferably 2000 mm or less, further preferably 1500 mm or less.

[0063] The invention is more specifically described below by means of Examples, however, is not limited to these Examples.

Example 1

[0064] Steels having chemical compositions shown in Tables 1 and 2 were molten. When melting each steel, assuming AOD melting that was an inexpensive melting process for stainless steel, each steel was molten in a 100-kg vacuum melting furnace and cast into a cast piece with a diameter of 180 mm. Subsequently, the cast piece was formed into a bar-shaped steel product with a diameter of 47.0 mm under the following manufacturing conditions. In each of Tables below, values falling out of the scope of the invention are underlined.

[0065] The conditions are described below. Specifically, the cast piece was heated at a heating temperature of 1030 degrees C, was subjected to the skew rolling at a reduction of area of 80.0% and a processing temperature of 805 degrees C, and, subsequently, was subjected to the intermediate annealing at an annealing temperature of 960 degrees C for an annealing time of 3.5 min. In this operation, a time between the skew rolling and the intermediate annealing was 5.4 s. Subsequently, the steel was rolled. For the rolling, a roller diameter for rough rolling was 940 mm, a rolling temperature was 750 degrees C, a rolling finish temperature was 730 degrees C, and a time between rolling passes was 0.5 s. The total reduction of area was 93.2%. The rolled steel was cooled at a cooling rate of 11 degrees C/s, was subjected to final annealing at a final annealing temperature of 750 degrees C for a final annealing time of 0.8 min, and was cooled at a cooling rate of 14 degrees C/s.

Table 1

Sort	Steel Type	Chemical Components (mass%)										
		C	Si	Mn	Ni	Cr	Mo	Cu	N	Nb	Ti	Others
Invention	A	0.001	0.2	0.1	0.04	18.3	0.5	0.3	0.020	0.80	-	
	B	0.017	2.9	0.3	0.2	15.9	0.1	0.5	0.005	0.79	-	
	C	0.011	0.1	2.0	0.2	19.0	0.1	0.02	0.008	0.36	-	
	D	0.013	0.2	0.2	4.8	18.8	0.03	0.5	0.018	0.35	-	
	E	0.013	0.1	0.3	0.2	34.0	0.01	0.3	0.005	0.49	-	
	F	0.010	0.4	0.5	0.3	10.0	0.5	0.1	0.018	0.37	-	
	G	0.015	0.5	0.3	0.4	19.9	4.8	0.3	0.004	0.51	-	
	H	0.014	0.5	0.1	0.2	16.2	0.2	3.0	0.019	0.72	-	
	I	0.004	0.03	0.1	0.1	19.2	0.2	0.1	0.001	0.51	-	
	J	0.018	0.4	0.4	0.5	15.4	0.5	0.2	0.100	0.25	-	
	K	0.002	0.2	0.02	0.5	15.9	0.3	0.3	0.003	2.00	-	
	L	0.019	0.3	0.4	0.1	16.1	0.3	0.1	0.019	1.10	-	
	M	0.019	0.2	0.3	0.05	15.6	0.3	0.5	0.020	0.73	2.00	
	N	0.013	0.5	0.4	0.5	16.9	0.3	0.3	0.014	0.26	1.05	
	O	0.010	0.1	0.4	0.3	19.9	0.1	0.4	0.018	0.79	0.03	
	P	0.032	0.8	0.5	1.0	24.3	0.5	0.7	0.022	0.71	0.06	
	Q	0.081	1.7	0.9	1.9	26.5	1.0	1.8	0.047	0.95	0.96	
	R	0.007	0.3	0.2	0.4	16.9	0.2	0.2	0.008	0.41	0.02	
	S	0.016	0.3	0.04	0.3	19.9	0.4	0.1	0.019	0.33	0.04	
	T	0.020	0.1	0.04	0.2	18.0	0.3	0.1	0.010	0.40	0.02	
	U	0.017	0.1	0.03	0.2	20.6	0.2	0.4	0.003	0.50	-	Al:0.12
	V	0.010	0.4	0.5	0.4	15.1	0.2	0.3	0.017	0.28	-	V:1.0
	W	0.012	0.2	0.1	0.1	16.5	0.01	0.4	0.003	0.49	-	B:0.01
	X	0.008	0.3	0.1	0.1	17.1	0.4	0.3	0.016	0.29	-	Ca:0.01
	Y	0.003	0.1	0.2	0.4	18.9	0.1	0.4	0.007	0.29	-	Co:0.2
	Z	0.003	0.5	0.4	0.2	15.5	0.4	0.3	0.019	0.22	-	V:0.01
	A A	0.004	0.5	0.1	0.5	16.1	0.4	0.4	0.001	0.57	-	W:1.0
	A B	0.012	0.5	0.4	0.3	16.4	0.2	0.4	0.014	0.57	-	Al:0.02
	A C	0.002	0.2	0.5	0.5	16.2	0.3	0.3	0.009	0.53	-	Sn:0.5
	A D	0.016	0.3	0.2	0.1	20.6	0.3	0.4	0.007	0.32	-	Sn:0.06
	A E	0.010	0.5	0.3	0.6	19.7	0.8	0.8	0.015	0.30	-	W:0.07
	A F	0.032	0.8	0.7	0.5	23.6	0.7	0.8	0.024	0.44	-	Ta:0.07
	A G	0.012	0.5	0.1	0.05	18.0	0.1	0.1	0.003	0.40	-	Zr:0.007
	A H	0.016	0.1	0.4	0.2	17.3	0.2	0.2	0.003	0.65	-	Mg:0.008
	A I	0.011	0.2	0.4	0.4	20.4	0.3	0.1	0.008	0.50	-	REM:0.002
	A J	0.010	0.05	0.4	0.1	20.5	0.02	0.2	0.017	0.52	-	Ga:0.01
	A K	0.019	0.02	0.4	0.5	15.3	0.2	0.3	0.003	0.34	-	Al:3.0

Table 2

Sort	Steel Type	Chemical Components (mass%)										
		C	Si	Mn	Ni	Cr	Mo	Cu	N	Nb	Ti	Others
Comparatives	A L	<u>0.220</u>	0.4	0.4	0.3	15.5	0.3	0.5	0.014	0.74	-	
	A M	0.008	<u>3.5</u>	0.5	0.5	15.6	0.4	0.4	0.020	0.49	-	
	A N	0.018	0.1	<u>2.3</u>	0.4	16.4	0.4	0.4	0.001	0.45	-	
	A O	0.019	0.4	0.2	<u>5.4</u>	18.3	0.4	0.04	0.012	0.54	-	
	A P	0.009	0.2	0.4	0.1	<u>6.0</u>	0.4	0.2	0.012	0.28	-	
	A Q	0.015	0.2	0.1	0.2	<u>40.0</u>	0.02	0.07	0.017	0.58	-	
	A R	0.014	0.1	0.1	0.3	19.1	<u>5.3</u>	0.3	0.008	0.62	-	
	A S	0.017	0.2	0.2	0.4	15.1	0.2	<u>3.3</u>	0.014	0.54	-	
	A T	0.003	0.4	0.3	0.04	19.63	0.43	0.20	<u>0.150</u>	0.65	-	
	A U	0.018	0.05	0.08	0.07	17.03	0.10	0.12	0.015	<u>2.50</u>	-	
	A V	0.007	0.15	0.06	0.29	16.94	0.21	0.38	0.005	0.64	<u>2.40</u>	
	A W	0.012	0.14	0.31	0.17	15.80	0.50	0.20	0.019	0.73	0.05	<u>V:3.0</u>
	A X	0.008	0.13	0.21	0.02	15.87	0.40	0.19	0.016	0.30	0.01	<u>Al:6.0</u>
	A Y	0.015	0.13	0.34	0.31	19.65	0.48	0.14	0.014	0.23	0.01	<u>Ca:0.10</u>
	A Z	0.013	0.34	0.07	0.02	20.00	0.28	0.13	0.017	0.71	0.02	<u>B:0.20</u>

[0066] The obtained steel wire rod was measured in terms of the RD//<100> fraction and a transition temperature. Results are collectively shown in Tables 3 and 4 below. The measurements were performed according to the following procedure.

[0067] The RD//<100> fraction was obtained by measuring at least one field of view among 200-fold fields of view in a surface layer portion, a center portion, and a 1/4-depth-position existing between the surface layer portion and the center portion in an L-cross section of a steel product. A crystal orientation of each of crystal grains in the observed field(s) of view was analyzed using FE-SEM/EBSD. A rolling direction was represented by RD. A crystal plane in the RD direction was analyzed. Components in a <001> orientation only in a clearance of 20 degrees or less were displayed and the RD//<100> fraction was measured.

[0068] A transition temperature was a ductile-brittle transition temperature in Charpy impact test in accordance with JIS Z 2242. A test piece in the Charpy impact test was a standard test piece. A length direction of the test piece was a rolling direction of the bar-shaped steel product. A notch of the test piece was U-notch. An energy transition temperature was used as the ductile-brittle transition temperature. The toughness was judged as being favorable when the transition temperature was 200 degrees C or less.

Table 3

No	Sort	Steel Type	RD//<100> fraction	Transition Temp. (°C)	Remarks
1	Invention	A	0.32	77	
2		B	0.26	79	
3		C	0.24	55	
4		D	0.25	75	
5		E	0.23	71	
6		F	0.25	72	
7		G	0.27	35	
8		H	0.23	45	
9		I	0.28	53	
10		J	0.22	59	
11		K	0.27	32	
12		L	0.30	46	
13		M	0.23	61	
14		N	0.34	55	
15		O	0.24	50	
16		P	0.38	88	
17		Q	0.41	130	
18		R	0.35	26	
19		S	0.22	-43	
20		T	0.26	-37	
21		U	0.34	61	
22		V	0.26	30	
23		W	0.30	40	
24		X	0.26	39	
25		Y	0.33	37	
26		Z	0.30	63	
27		A A	0.34	49	
28		A B	0.29	66	
29		A C	0.23	35	
30		A D	0.34	74	
31		A E	0.31	40	
32		A F	0.40	98	
33		A G	0.22	44	
34		A H	0.27	76	
35		A I	0.33	71	
36		A J	0.31	78	
37		A K	0.24	65	

Table 4

No	Sort	Steel Type	RD//<100> fraction	Transition Temp. (°C)	Remarks
38	Comparatives	A L	<u>0.92</u>	266	
39		A M	<u>0.84</u>	242	
40		A N	<u>0.84</u>	224	
41		A O	<u>0.94</u>	283	
42		A P	not evaluated		poor corrosion resistance
43		A Q	<u>0.94</u>	294	
44		A R	<u>0.88</u>	210	
45		A S	<u>1.00</u>	248	
46		A T	<u>0.88</u>	269	
47		A U	<u>0.92</u>	290	
48		A V	<u>0.89</u>	256	
49		A W	<u>0.83</u>	269	
50		A X	<u>0.91</u>	295	
51		A Y	<u>0.90</u>	247	
52		A Z	<u>0.96</u>	246	

[0069] Nos. 1 to 37 satisfied the requirement of the invention, exhibiting a favorable toughness. In contrast, Nos. 38 to 52 not satisfying the requirement of the invention exhibited a poor toughness and a poor corrosion resistance.

Example 2

[0070] Subsequently, steel types O and V shown in Table 1 were molten in the same manner and casted into cast pieces having various diameters. Subsequently, the cast pieces were heated at a heating temperature of 1053 degrees C, was subjected to the skew rolling at a reduction of area of 63.2% and a processing temperature of 948 degrees C, and then was annealed at an annealing temperature of 1032 degrees C for an annealing time of 1.6 min. In this operation, a time between the skew rolling and the annealing was 3 s. Subsequently, the steels were rolled. For the rolling, a roller diameter for rough rolling was 880 mm, a rolling temperature was 940 degrees C, a rolling finish temperature was 835 degrees C, and a time between rolling passes was 6 s. The total reduction of area by the rolling was 83.0%. The rolled steels were cooled at a cooling rate of 12 degrees C/s, were subjected to final annealing at a final annealing temperature of 1040 degrees C for a final annealing time of 1.4 min, and were cooled at a cooling rate of 12 degrees C/s. The obtained bar-shaped steel products were measured according to the above-mentioned method in terms of the RD//<100> fraction and the transition temperature. Results are collectively shown in Table 5 below. As described above in Example 1, the toughness was judged as being favorable when the transition temperature was 200 degrees C or less.

Table 5

No.	Sort	Steel Mark	Wire Diameter (mm)	RD//<100> fraction	Transition Temp. (°C)	Remarks
53	Examples of Invention	O	54.7	0.30	-29	
54			90.0	0.39	95	
55			105.7	0.47	105	
56			21.8	0.29	24	
57			61.3	0.28	25	
58			58.0	0.27	53	
59			20.8	0.34	36	
60			25.8	0.32	77	
61			69.2	0.23	39	
62			78.4	0.36	80	
63			133.2	0.40	118	
64		V	36.6	0.34	17	
65			15.4	0.22	-21	
66			87.0	0.38	95	
67			102.7	0.44	110	
68			47.0	0.26	49	
69			25.6	0.28	59	
70			68.2	0.34	76	
71			40.9	0.27	32	
72			25.7	0.30	63	
73			34.3	0.23	53	
74			94.0	0.39	87	
75			145.0	0.44	116	

[0071] Nos.53 to 75 satisfied the requirement of the invention, exhibiting a favorable toughness.

Example 3

[0072] A steel type Q shown in Table 1 was used to provide cast pieces having various diameters, from which bar-shaped steel products each having a diameter of 15 mm were manufactured under conditions shown in Tables 6 and 7. The manufactured bar-shaped steel products were measured according to the above-mentioned method in terms of the RD//<100> fraction and the transition temperature. Results are collectively shown in Tables 6 and 7 below. As described above in Example 1, the toughness was judged as being favorable when the transition temperature was 200 degrees C or less.

Table 6

No	Sort	Steel Type	Heating Temp. °C	Inclined Rolling		Time from completion of inclined rolling to start of intermediate annealing s	Intermediate Annealing		Roller diameter in rough rolling mm	Total cross-section reduction rate by rolling %	Quality											
				Cross-section reduction rate %	Processing Temp. °C		Annealing Temp. °C	Annealing Time min			RD//<100> fraction –	Transition Temp. °C										
76	Invention Q																					
77													450	84.3	728	5	1051	101	410	96.4	0.21	77
78													1300	85.6	956	3	1096	115	1478	97.6	0.21	52
79													887	20.0	744	4	918	37	787	94.9	0.21	58
80													821	98.0	873	4	1089	70	523	98.4	0.28	60
81													879	92.1	450	4	942	79	1311	96.8	0.26	80
82													902	89.2	1200	2.3	814	95	1110	92.7	0.25	42
83													894	85.9	722	0.01	892	139	1485	96.2	0.27	77
84													950	86.3	879	100	819	144	988	93.4	0.29	69
85													905	94.1	727	6	700	52	1455	95.0	0.22	56
86													955	80.7	779	4	1300	129	420	95.8	0.35	75
87													827	93.1	818	7	894	1	1086	95.8	0.30	79
88													1089	92.6	953	8	1056	480	1105	99.6	0.34	50
89													1014	80.8	945	2.8	969	177	210	96.1	0.30	40
90													910	91.7	946	3	1014	102	2400	98.3	0.31	47
91													821	28.0	992	4	926	162	1058	30.0	0.21	30
92	970	93.7	947	6	1090	142	1143	99.9	0.32	39												
93	950	91.6	747	9	990	39	731	93.9	0.29	–10												
94	926	66.2	746	17	1188	7	1804	88.1	0.37	82												
95	1143	40.3	1184	12	1196	28	1656	52.4	0.48	135												
		1100	43.0	1080	14	1100	20	1934	58.0	0.43	124											

Table 7

No	Sort	Steel Type	Heating Temp. °C	Inclined Rolling		Time from completion of inclined rolling to start of intermediate annealing s	Intermediate Annealing		Roller diameter in rough rolling mm	Total cross-section reduction rate by rolling %	Quality	
				Cross-section reduction rate %	Processing Temp. °C		Annealing Temp. °C	Annealing Time min			RD//<100> fraction	Transition Temp. °C
96	Comparatives	Q	400	93.3	782	5	873	79	764	95.0	0.90	241.7
97			1400	86.1	901	5	936	83	440	90.8	0.98	215.9
98			954	10.0	741	7	943	63	522	91.2	0.96	202.9
99			1073	91.8	400	9	822	35	1222	94.9	0.90	235.4
100			899	93.7	1300	5	959	43	1007	95.4	0.82	234.9
101			880	93.8	968	0.001	1060	92	1449	98.3	0.82	207.1
102			1098	83.9	701	200	941	111	769	93.2	0.84	238.2
103			956	93.5	935	3	600	86	1025	94.7	0.93	255.5
104			930	86.6	719	8	1400	50	1248	90.4	0.93	293.1
105			931	80.6	764	4	916	0.1	460	94.5	0.90	273.2
106			842	88.5	899	2	1078	600	849	98.3	0.96	281.1
107			833	87.4	919	6	887	33	120	99.6	0.94	217.5
108			1005	23.0	765	6	825	81	1395	25.0	0.88	298.9

[0073] Nos. 76 to 95 satisfied the requirement of the invention, exhibiting a favorable toughness. In contrast, Nos.96 to 108 did not satisfy the requirement of the invention, exhibiting a poor toughness.

INDUSTRIAL APPLICABILITY

[0074] According to the invention, a bar-shaped steel product having an excellent toughness is obtainable and extremely useful in industry.

Claims

1. A bar-shaped steel product extending unidirectionally and comprising a chemical composition comprising: by mass%,

0.001 to 0.09% of C;

0.01 to 3.0% of Si;

0.01 to 2.0% of Mn;

0.01 to 5.0% of Ni;

7.0 to 35.0% of Cr;

0.01 to 5.0% of Mo;

0.01 to 3.0% of Cu;

0.001 to 0.10% of N;

0.2 to 2.0% of Nb;

0 to 2.0% of Ti;

0 to 2.0% of V;

0 to 0.1% of B;

0 to 5.0% of Al;

0 to 2.5 % of W;

0 to 0.05 % of Ga;

0 to 2.5% of Co;

0 to 2.5 % of Sn;

0 to 2.5% of Ta;

0 to 0.05 % of Ca;

0 to 0.012% of Mg;

0 to 0.012% of Zr;

0 to 0.05% of REM; and

a balance consisting of Fe and inevitable impurities,

the bar-shaped steel product comprising 0.5 or less of a rolling-direction-crystal-orientation RD//<100> fraction, the rolling-direction-crystal-orientation RD//<100> fraction meaning an area ratio of crystal having 20 degrees or less of an orientation difference between a <100> orientation and a rolling direction.

2. The bar-shaped steel product according to claim 1, wherein

the chemical composition further comprises, by mass%, at least one selected from 0.001 to 2.0% of Ti, 0.001 to 2.0% of V, 0.0001 to 0.1% of B, 0.001 to 5.0% of Al, 0.05 to 2.5% of W, 0.0004 to 0.05% of Ga, 0.05 to 2.5% of Co, 0.01 to 2.5% of Sn, and 0.01 to 2.5% of Ta.

3. The bar-shaped steel product according to claim 1 or 2, wherein

the chemical composition further comprises, by mass%, at least one selected from 0.0002 to 0.05% of Ca, 0.0002 to 0.012% of Mg, 0.0002 to 0.012% of Zr, and 0.0002 to 0.05% of REM.

4. A bar-shaped steel product extending unidirectionally,

and comprising the chemical composition according to any one of claims 1 to 3, and a transition temperature of 200 degrees C or less.

5. The bar-shaped steel product according to any one of claims 1 to 3, comprising a transition temperature of 200 degrees C or less.

6. The bar-shaped steel product according to any one of claims 1 to 5, comprising a cross section whose shape is a

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circle, wherein
a diameter of the circle is in a range from 15.0 to 200 mm.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2020/013242

A. CLASSIFICATION OF SUBJECT MATTER

C21D 8/06 (2006.01)i; C22C 38/00 (2006.01)i; C22C 38/58 (2006.01)i
 FI: C22C38/00 302Z; C22C38/58; C21D8/06 B

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)

C22C38/00-38/60; C21D7/00-8/10

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

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2020
Registered utility model specifications of Japan	1996-2020
Published registered utility model applications of Japan	1994-2020

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2015/190422 A1 (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORPORATION) 17.12.2015 (2015-12-17) paragraphs [0011]-[0015], steel grade Q	1-6
A	JP 2018-119174 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORPORATION) 02.08.2018 (2018-08-02) entire text	1-6
A	JP 2014-080684 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORPORATION) 08.05.2014 (2014-05-08) entire text, all drawings	1-6
A	JP 2007-107073 A (SANYO SPECIAL STEEL CO., LTD.) 26.04.2007 (2007-04-26) entire text, all drawings	1-6
A	JP 2005-068490 A (SUMITOMO METAL INDUSTRIES, LTD.) 17.03.2005 (2005-03-17) entire text, all drawings	1-6
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☒ Further documents are listed in the continuation of Box C.

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Date of the actual completion of the international search
08 June 2020 (08.06.2020)

Date of mailing of the international search report
16 June 2020 (16.06.2020)

Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

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