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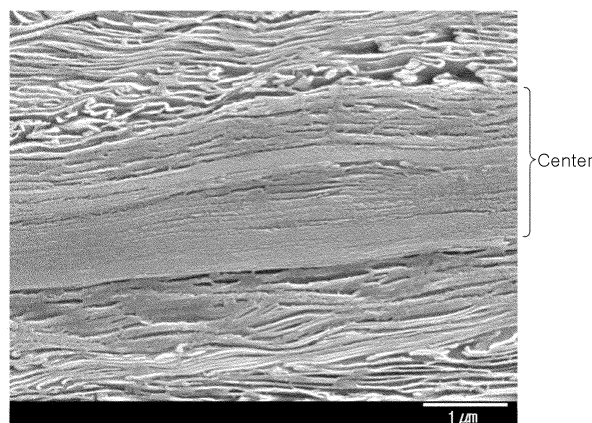
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(54) **STEEL SHEET HAVING HIGH STRENGTH AND HIGH TOUGHNESS, AND MANUFACTURING METHOD THEREFOR**

(57) The present invention relates to a steel sheet having high strength and high toughness, and a manufacturing method therefor, and, more specifically, to a

steel sheet, which has high strength and high toughness and can be used for a vehicle seat belt spring and the like, and a manufacturing method therefor.

FIG. 1



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Description

Technical Field

5 **[0001]** The present disclosure relates to a high-strength, high-toughness steel sheet and a manufacturing method thereof, and more particularly, to a high-strength, high-toughness steel sheet that may be used for automobile seat belt springs, or the like, and a manufacturing method thereof.

Background Art

10 **[0002]** Materials used for automobile seat belt springs generally have a final material thickness of about 0.1 to 0.3 mm and are used in the form of a spring with a width of about 3 to 25 mm, thus requiring high toughness. In addition, since rewinding performance, which is an important characteristic of the spring, needs to be excellent, tensile strength of a final cold rolled steel sheet should be high to secure a target restoring force and torque for each product.

15 **[0003]** The most widely used to secure the aforementioned characteristics of thin material and high strength is high carbon steel, which contains more carbon than eutectoid steel. High toughness and strength may be secured by controlling a shape of an elongated pearlite structure obtained after cold rolling by utilizing a pearlite structure of hyper-eutectoid high carbon steel. This is more economical than using expensive alloy elements or utilizing low-temperature transformation structures, such as bainite or tempered martensite, through an additional heat treatment process.

20 **[0004]** In order to use the spring for more than 300,000 rewinds without fracture or breakage during use, a homogeneous pearlite (fibrous pearlite) fraction in a microstructure of a final 0.2 tons of cold rolled material needs to be high.

[Related art document]

25 **[0005]** (Patent Document 1) Korean Application Publication No. 10-2018-0034885 (published on April 5, 2018)

Summary of Invention

Technical Problem

30 **[0006]** An aspect of the present disclosure is to provide a high-strength, high-toughness steel sheet and a manufacturing method thereof.

35 **[0007]** The object of the present disclosure is not limited to the contents described above. A person skilled in the art would have no difficulty in understanding additional problems of the present invention from the overall contents of the present disclosure.

Solution to Problem

40 **[0008]** According to an aspect of the present disclosure, a steel sheet includes: by wt%, carbon (C) : 0.70 to 1.20%, manganese (Mn) : 0.2 to 0.6%, silicon (Si) : 0.01 to 0.4%, phosphorus (P) : 0.005 to 0.02%, sulfur (S) : 0.01% or less, aluminum (Al) : 0.01 to 0.1%, chromium (Cr) : 0.1 to 0.8%, vanadium (V) : 0.02 to 0.25%, cobalt (Co) : 0.01 to 0.2 %, a balance of iron (Fe), and other inevitable impurities,

45 wherein the steel sheet has a microstructure including a pearlite structure as a main phase and less than 4 area% of remaining grain boundary proeutectoid cementite, and the pearlite structure includes, by area%, 40% or more of homogeneous pearlite (fibrous pearlite), 50% or less of zigzag pearlite (bent pearlite), and 10% or less of heterogeneous pearlite.

50 **[0009]** When a cross-section of the microstructure is observed in a thickness direction, an average thickness of the homogeneous pearlite may be 2.5 μm or less.

[0010] The steel sheet may have a value A of 1.2 or less in the following relational expression 1.

[Relational expression 1]

$$55 \quad A = [\text{Mn}] + [\text{Cr}] + [\text{V}]$$

[0011] (Here, [Mn], [Cr], and [V] are a wt% of each element.)

[0012] The steel sheet may have a tensile strength of 2100 MPa or more, an elongation of 2% or more, and bending properties (R/t) of 3.0 or less, where R is a bending radius at which cracks in a bending portion do not occur after a 180° bending test and t is a thickness of the steel sheet.

[0013] The steel sheet may have a tensile strength of 2200 to 2350 MPa.

[0014] A thickness of the steel sheet may be 0.1 to 0.6 mm.

[0015] According to another aspect of the present disclosure, a method of manufacturing a steel sheet includes: reheating a steel slab including, by wt%, carbon (C): 0.70 to 1.20%, manganese (Mn): 0.2 to 0.6%, silicon (Si): 0.01 to 0.4%, phosphorus (P): 0.005 to 0.02%, sulfur (S): 0.01% or less, aluminum (Al): 0.01 to 0.1%, chromium (Cr): 0.1 to 0.8%, vanadium (V): 0.02 to 0.25%, cobalt (Co): 0.01 to 0.2 %, a balance of iron (Fe), and other inevitable impurities,

rough rolling the reheated steel slab;

finish rolling the rough-rolled steel sheet to obtain a hot-rolled steel sheet;

cooling the hot-rolled steel sheet to a temperature within a range of 540-660°C at a cooling rate of 5-50°C/s and then coiling the cooled hot-rolled steel sheet;

performing heat treatment of heating the cooled and coiled steel sheet to a temperature within a range of 850 to 1,050°C, maintaining for 5 to 20 minutes, then cooling to a temperature within a range of 520 to 590°C at a cooling rate of 50 to 150°C/s, and then maintaining for 30 to 120 seconds; and

cold rolling the heat-treated steel sheet at a cumulative reduction rate of 80 to 96%.

[0016] The steel slab may have value A of 1.2 or less in the following relational expression 1:

[Relational expression 1]

$$A = [\text{Mn}] + [\text{Cr}] + [\text{V}]$$

[0017] (Here, [Mn], [Cr], and [V] are wt% of each element.)

[0018] The reheating may be performed at a temperature within a range of 1100 to 1300°C,

the rough rolling may be performed at a temperature within a range of 1000 to 1100°C, and

the finish rolling may be performed at a temperature within a range of 860 to 940°C.

[0019] The method may further include: pickling the steel sheet at a temperature within a range of 200°C or less, after the coiling.

[0020] The method may further include: air cooling the steel sheet, after the heat treatment.

[0021] A microstructure of the heat-treated steel sheet may include a pearlite structure as a main phase and less than 4 area% of remaining grain boundary proeutectoid cementite.

[0022] After the finish rolling, a thickness of the hot-rolled steel sheet may be 1.5 to 2.6 mm.

[0023] After the cold rolling, a thickness of the cold rolled steel sheet may be 0.1 to 0.6 mm.

Advantageous Effects of Invention

[0024] According to an aspect of the present disclosure, the high-strength, high-toughness steel sheet and the manufacturing method thereof may be provided.

[0025] According to an aspect of the present disclosure, the high-strength, high-toughness steel sheet and the manufacturing method thereof may be used for high-end industry/tools, automobile seat belt springs, or the like.

Brief Description of Drawings

[0026]

FIG. 1 is a photograph of a shape of homogeneous pearlite (fibrous pearlite) observed with a scanning electron microscope (X 20,000).

FIG. 2 is a photograph showing a method of calculating a homogeneous pearlite (fibrous pearlite) fraction of Inventive Example 2.

Best Mode for Invention

[0027] Hereinafter, embodiments of the present disclosure will be described. Embodiments of the present disclosure may be modified in various forms, and the scope of the present disclosure should not be construed as being limited to the embodiments described below. These embodiments are provided to describe the present disclosure in more detail to those skilled in the art.

[0028] However, as described above, the materials of reel springs that have been manufactured so far have an insufficient homogeneous pearlite (fibrous pearlite) fraction, resulting in reduced durability and quality differences between materials, and thus, it may be difficult to secure a stable, homogeneous pearlite (fibrous pearlite) structure. In addition, a component system produced by cold rolling a pearlite single-phase structure of eutectoid steel or higher and process characteristics involve quality deterioration due to proeutectoid cementite, which, thus, needs to be improved.

[0029] The present inventor conducted in-depth research to manufacture cold-rolled steel sheets having excellent strength and toughness by controlling a steel composition and a manufacturing process.

[0030] As a result, it was confirmed that the aforementioned properties may be secured by optimizing an alloy composition and manufacturing conditions to control a grain boundary proeutectoid cementite of a steel sheet before cold rolling and by strictly controlling a homogeneous pearlite (fibrous pearlite) structure of a final steel sheet, based on which the present disclosure was completed.

[0031] Hereinafter, the present disclosure will be described in detail.

[0032] Hereinafter, a steel composition of the present disclosure will be described in detail.

[0033] In the present disclosure, unless otherwise specified, the % indicating the content of each element is based on weight.

[0034] A steel sheet according to an aspect of the present disclosure may include, by wt%, carbon (C): 0.70 to 1.20%, manganese (Mn): 0.2 to 0.6%, silicon (Si): 0.01 to 0.4%, phosphorus (P): 0.005 to 0.02%, sulfur (S): 0.01% or less, aluminum (Al): 0.01 to 0.1%, chromium (Cr): 0.1 to 0.8%, vanadium (V): 0.02 to 0.25%, cobalt (Co): 0.01 to 0.2 %, a balance of iron (Fe), and other inevitable impurities.

Carbon (C): 0.70 to 1.20%

[0035] Carbon (C) is an element that significantly affects strength and toughness of a pearlite structure, and carbon (C) is preferably added by 0.70% or more to secure homogeneous pearlite (fibrous pearlite) by 40% or more after cold rolling. However, if the carbon (C) content exceeds 1.20%, a grain boundary proeutectoid cementite fraction may increase after heat treatment, resulting in inferior toughness. A lower limit of the carbon (C) content is more preferably 0.75%, more preferably 0.76%, even more preferably 0.77%, and more preferably 0.78%. An upper limit of the carbon (C) content is more preferably 0.90%, more preferably 0.88%, even more preferably 0.87%, and more preferably 0.85%.

Manganese (Mn): 0.2 to 0.6%

[0036] Manganese (Mn) may be added in an amount of 0.2% or more to improve strength due to solid solution strengthening. However, if manganese (Mn) is added excessively, there may be a risk of deterioration of toughness due to carbide formation and there may be a risk of brittleness due to a low-temperature structure of a segregated portion due to center segregation, so an upper limit of the manganese (Mn) content may be limited to 0.6%. A lower limit of the manganese (Mn) content is more preferably 0.22%, more preferably 0.24%, and more preferably 0.25%. An upper limit of the manganese (Mn) content is more preferably 0.5%, more preferably 0.48%, more preferably 0.46%, and more preferably 0.45%.

Silicon (Si): 0.01 to 0.4%

[0037] Silicon (Si) may be added in an amount of 0.01% or more to strengthen the solid solution of a ferrite structure in pearlite. However, excessive addition of silicon (Si) may excessively form a primary scale occurring in a heating furnace to cause red scale defects impede a heat treatment and workability and have a risk of brittleness caused by residual cementite, so the silicon (Si) content may be limited to 0.4% or less. A lower limit of the silicon (Si) content is more preferably 0.05%, more preferably 0.06%, more preferably 0.08%, and more preferably 0.1%. An upper limit of the silicon (Si) content is more preferably 0.3%, more preferably 0.28%, more preferably 0.26%, and more preferably 0.25%.

Phosphorus (P): 0.005 to 0.02%

[0038] If phosphorus (P) exceeds 0.02%, there may be a risk of brittleness due to segregation. Therefore, it is preferable

that the phosphorus (P) content is 0.02% or less. An upper limit of the phosphorus (P) content is more preferably 0.015%, more preferably 0.014%, more preferably 0.013%, and more preferably 0.012%. Meanwhile, considering a case in which phosphorus (P) is inevitably included during the manufacturing process, a lower limit may be limited to 0.005%.

5 Sulfur (S): 0.01% or less

[0039] Sulfur (S) is an element that forms non-metallic inclusions to reduce toughness, so it is necessary to keep the sulfur (S) content as low as possible. Therefore, it is preferable that the sulfur (S) content is 0.01% or less. Meanwhile, in the present disclosure, as the sulfur (S) content is lower, the risk of brittleness due to segregation/inclusions is lower, which is advantageous in securing toughness, so a lower limit is not particularly limited. The sulfur (S) content is more preferably 0.008% or less, more preferably 0.006% or less, and more preferably 0.005% or less.

Aluminum (Al): 0.01 to 0.1%

15 **[0040]** Aluminum (Al) may be added to refine the pearlite structure by refining austenite grains through AlN formation. If the aluminum (Al) content is less than 0.01%, it may be difficult to sufficiently obtain the above effect. Meanwhile, if the aluminum (Al) content exceeds 0.1%, there may be a risk of brittleness due to inclusions due to oxide formation. A lower limit of the aluminum (Al) content is more preferably 0.012%, more preferably 0.014%, and more preferably 0.015%. An upper limit of the aluminum (Al) content is more preferably 0.06%, more preferably 0.05%, more preferably 0.04%, and more preferably 0.03%.

Chromium (Cr): 0.1 to 0.8%

25 **[0041]** Chromium (Cr) is preferably added in an amount of 0.1% or more to ensure strength and refine the pearlite layer spacing. Meanwhile, if the chromium (Cr) content exceeds 0.8%, there may be a risk of toughness deterioration due to excessive carbide formation. A lower limit of the chromium (Cr) content is more preferably 0.12%, more preferably 0.14%, and more preferably 0.15%. An upper limit of the chromium (Cr) content is more preferably 0.4%, more preferably 0.35%, even more preferably 0.33%, and more preferably 0.30%.

30 Vanadium (V): 0.02 to 0.25%

[0042] Vanadium (V) is an element necessary to refine pearlite grains and secure strength through work hardening after cold rolling. In order to ensure the above effect, in the present disclosure, 0.02% or more of vanadium (V) may be added. Meanwhile, if the content is excessive, coarse carbon/nitride may be formed and there may be a risk of brittleness, so an upper limit may be limited to 0.25%. A lower limit of vanadium (V) is more preferably 0.03%, more preferably 0.04%, and more preferably 0.05%. An upper limit of vanadium (V) is more preferably 0.22%, more preferably 0.20%, and more preferably 0.18%.

Cobalt (Co): 0.01 to 0.2%

40 **[0043]** Cobalt (Co) is an element necessary to promote the formation of homogeneous pearlite and increase the degree of orientation of pearlite to secure homogeneous pearlite (fibrous pearlite) after cold rolling and may be included in an amount of 0.01% or more. Meanwhile, if the content is excessive, there may be a risk of reducing heat treatability as it reduces hardenability and requires a faster cooling rate. Therefore, an upper limit of the cobalt (Co) content may be limited to 0.2%. A lower limit of cobalt (Co) is more preferably 0.02%, more preferably 0.03%, and more preferably 0.05%. An upper limit of cobalt (Co) is more preferably 0.18%, more preferably 0.16%, and more preferably 0.15%.

[0044] The steel sheet of the present disclosure may include a balance of iron (Fe) and inevitable impurities in addition to the composition described above. Since inevitable impurities may be unintentionally introduced during a general manufacturing process, they cannot be excluded. Since these impurities are known to any one skilled in the art of steel manufacturing, all of them are not specifically mentioned in this specification.

[0045] The steel sheet according to an aspect of the present disclosure may have a value A which is 1.2 or less in relational expression 1 below.

55 **[0046]** In the present disclosure, it is desired to prevent poor bending properties and excessive carbide formation due to segregation through the following relational expression 1. Excessive addition of Mn, Cr, and V may cause macro and micro segregation during a continuous casting process and form a large amount of carbides during a heat treatment process, which may reduce toughness and bending properties of a final product. Therefore, in the present disclosure, in order to prevent the above problem, the value A may be controlled to 1.2 or less. A lower limit of the value A may be the sum of the lower limits of the contents of each element Mn, Cr, and V.

[Relational expression 1]

$$A = [\text{Mn}] + [\text{Cr}] + [\text{V}]$$

5

[0047] (Here, [Mn], [Cr], and [V] are the wt% of each element.)

[0048] A steel microstructure of the present disclosure will be described in detail hereinafter.

[0049] In the present disclosure, unless specifically stated otherwise, the % indicating a fraction of a microstructure is based on area.

10 **[0050]** A steel sheet according to an aspect of the present disclosure may have a microstructure including a pearlite structure as a main phase and a remaining 4 area% or less of grain boundary proeutectoid cementite. In addition, the pearlite includes 40% or more of homogeneous pearlite (fibrous pearlite), 50% or less of zigzag pearlite (bent pearlite), and 10% or less of heterogeneous pearlite in terms of area%, and an average thickness of the homogeneous pearlite may be 2.5 μm or less.

15 **[0051]** A sheet having a pearlite structure before cold rolling finally has three types of pearlite structures due to compression deformation in a thickness direction through cold rolling. Fibrous pearlite is stretched in a state in which a lamella structure is placed to be parallel to a rolling direction and has a shape such as the center of FIG. 1. Bent pearlite is one that is bent more than once in a vertical direction of rolling, resulting in a zig-zag lamella structure of pearlite. Heterogeneous pearlite is one in which a lamella structure of pearlite is bent, curved, and broken at μm intervals after
20 cold rolling, showing a form in which fibrous or bent pearlite is difficult to clearly observe. The form of the final pearlite structure after such cold rolling may vary in proportion depending on a component system and manufacturing conditions.

[0052] Meanwhile, in the overall microstructure, if the grain boundary proeutectoid cementite fraction exceeds 4 area%, there may be a problem of brittle fracture due to grain boundary proeutectoid cementite.

25 **[0053]** In the present disclosure, in order to secure high strength and high toughness, when a pearlite structure before cold rolling is formed into homogeneous pearlite (fibrous pearlite), zigzag pearlite (bent pearlite), and heterogeneous pearlite by cold rolling, the fraction of each pearlite being formed is controlled. Specifically, in the present disclosure, the pearlite, after cold rolling, includes 40% or more of homogeneous pearlite (fibrous pearlite), 50% or less of zigzag pearlite (bent pearlite), and 10% or less of heterogeneous pearlite in terms of area%. Fibrous pearlite is preferably
30 included in an amount of 40% or more by area% in order to secure bending properties for high toughness, and bent pearlite and heterogeneous pearlite are preferably limited to 50% or less and 10% or less, respectively, in order to secure physical properties desired in the present disclosure. More preferably, homogeneous pearlite may be included in an amount of 50% or more. In the present disclosure, the fibrous pearlite fraction may include 100%, and the bent pearlite and heterogeneous pearlite fractions may each include 0%. Meanwhile, in the present disclosure, the fraction of the pearlite phases may be expressed by averaging the microstructure fractions measured when observing 10 to 15 arbitrary
35 points in a cross-section of the entire steel sheet in a thickness direction, and the thickness of the fibrous pearlite may also be expressed by calculating the average.

[0054] If an average thickness of homogeneous pearlite exceeds 2.5 μm , a desired level of strength may not be secured due to the formation of coarse homogeneous pearlite based on the principle that the strength decreases as the grains become larger, and bending properties may also not be secured due to increased brittleness.

40 **[0055]** A method of manufacturing a steel sheet of the present disclosure will be described in detail hereinafter.

[0056] A steel sheet according to an aspect of the present disclosure may be manufactured by reheating, rolling, cooling, coiling, heat treatment, and cold rolling a steel slab satisfying the aforementioned alloy composition.

Reheating

45 **[0057]** The steel slab satisfying the alloy composition of the present disclosure may be reheated to a temperature within a range of 1100 to 1300°C.

[0058] If the reheating temperature is less than 1100°C, it may be difficult to sufficiently secure the temperature of the slab required for whole plate. On the other hand, if the temperature exceeds 1300°C, abnormal austenite growth and
50 surface defects due to excessive scale may occur.

Rough rolling

[0059] The reheated steel slab may be roughly rolled at a temperature within a range of 1000 to 1100°C.

55 **[0060]** If the rough rolling temperature is less than 1000°C, there may be a disadvantage in that a rolling load may increase and threading may be deteriorated. Meanwhile, if the temperature exceeds 1100°C, excessive scale may be formed, resulting in very poor surface quality.

Finish rolling

[0061] The rough-rolled steel sheet may be finish-rolled at a temperature within a range of 860 to 940°C to obtain a hot-rolled steel sheet.

[0062] If the finish rolling temperature is less than 860°C, hot rolling properties may be significantly reduced due to an excessive rolling load. Meanwhile, if the temperature exceeds 940°C, the austenite grain size may become very coarse and there may be a risk of brittleness. In the present disclosure, a thickness of the hot-rolled steel sheet after finish rolling may be 1.5 to 2.6 mm. A more preferable upper limit of the thickness of the hot-rolled steel sheet may be 2.5 mm, and a more preferable lower limit of the thickness may be 1.6 mm.

Cooling and coiling

[0063] The hot-rolled steel sheet may be cooled to a temperature within a range of 540-680°C at a cooling rate of 5-50°C/s and then coiled.

[0064] During the cooling, if the cooling rate is less than 5°C/s, the pearlite structure may become coarse and there may be a risk of brittleness. Meanwhile, if the cooling rate exceeds 50°C/s, the shape may be deteriorated due to material deviation in a width direction due to supercooling of an edge portion in the width direction, making coiling difficult.

[0065] If the coiling temperature is less than 540°C, it may be difficult to obtain a uniform hot-rolled structure because a bainite or martensite structure, which is a low-temperature transformation structure, is formed. Meanwhile, an upper limit of the coiling temperature may be limited to 680°C. However, since surface defects may be caused by forming an internal oxidation layer and a decarburization layer on a surface portion, the temperature may be more preferably limited to 660°C or less.

[0066] After the coiling, the present disclosure may further include a process of pickling the hot-rolled steel sheet. The pickling may be performed after the coiled steel sheet is naturally cooled to 200°C or less, and a scale formed on a surface of the steel sheet may be removed through the pickling.

Heat treatment

[0067] The cooled and coiled steel sheet is heated to a temperature within a range of 850 to 1,050°C, maintained for 5 to 20 minutes, cooled to a temperature within a range of 500 to 650°C at a cooling rate of 50 to 250°C/s, and then subjected to a heat treatment maintained for 30 to 180 seconds. More preferably, an upper limit of the cooling rate may be 150°C/s, and a lower limit of the cooling temperature within a range may be 520°C and an upper limit thereof may be 590°C. More preferably, an upper limit of the holding time may be 120 seconds.

[0068] If the heating temperature, that is, an austenizing heating temperature, is less than 850°C, undissolved carbide may remain due to insufficient austenizing, causing brittleness. Meanwhile, if the temperature exceeds 1,050°C, the austenite grains may become coarse and there may be a risk of decreasing toughness and work hardenability of the pearlite structure may be reduced, making it difficult to secure a homogeneous pearlite (fibrous pearlite) structure thereafter. In the present disclosure, the heating method is not particularly limited, but methods, such as highfrequency induction heating or a BOX type heating furnace, may be used.

[0069] If the holding time after heating is less than 5 minutes, complete austenizing may be difficult, and if the time exceeds 20 minutes, the grains may become excessively coarse.

[0070] If the cooling rate is less than 50°C/s during cooling after heating and maintaining, the proportion of grain boundary proeutectoid cementite may increase excessively, causing brittleness and making it difficult to form a homogeneous pearlite (fibrous pearlite) structure. Meanwhile, an upper limit of the cooling rate may be limited to 250°C/s. However, since the cooling rate is not easy to control, there may be a risk of forming low-temperature structures other than pearlite, so a more preferable upper limit of the cooling rate may be 150°C/s.

[0071] A lower limit of a cooling end temperature may be 500°C. However, in order to prevent the risk of forming low-temperature structures, such as bainite other than pearlite, a more preferable lower limit may be 520°C. In addition, an upper limit of the cooling end temperature may be 650°C. However, considering that it may be difficult to form homogeneous pearlite (fibrous pearlite) after cold rolling due to coarse grains in the structure, a more preferable upper limit of the cooling end temperature may be 590°C.

[0072] If the holding time after cooling is less than 30 seconds, the pearlite structure may not be sufficiently formed, and an upper limit of the time may be limited to 180 seconds. Meanwhile, since it may be difficult to secure sufficient strength through work hardening after cold rolling due to a decrease in strength, a more preferable upper limit of the holding time may be 120 seconds. In the present disclosure, the heat treatment method may use hydrogen gas, a salt bath, a lead bath, or the like, and may not be particularly limited. In addition, in the present disclosure, the steel sheet may be air-cooled after heat treatment.

[0073] In the present disclosure, it is preferable that, after heat treatment, the microstructure of the steel sheet includes

a main phase pearlite structure and a remaining 4 area% or less of grain boundary proeutectoid cementite. At this time, in the present disclosure, by appropriately controlling the grain boundary proeutectoid cementite fraction, the amount of cementite having very high strength may be minimized, thereby facilitating stretching during cold rolling of pearlite and ensuring a homogeneous pearlite thickness of 2.5 μm or less. Meanwhile, if the grain boundary proeutectoid cementite fraction exceeds 4 area%, there may be a problem of brittle fracture due to grain boundary proeutectoid cementite during cold rolling.

Cold rolling

[0074] The heat-treated steel sheet may be cold rolled at a cumulative reduction rate of 75 to 96 %. A more preferable lower limit of the cumulative reduction rate may be 80 %, and a more preferable upper limit of the cumulative reduction rate may be 95 %.

[0075] In the present disclosure, cold rolling may be performed by applying a certain reduction ratio to manufacture a cold rolled steel sheet having a desired thickness. A lower limit of the reduction rate may be limited to 75 %. However, it may be difficult to secure a homogeneous pearlite (fibrous pearlite) fraction, and thus, a more preferable lower limit may be 80 %. Meanwhile, if the reduction ratio exceeds 96 %, there may be a risk of cracking due to excessive work hardening. A more preferable lower limit of reduction ratio may be 95 %. Detailed rolling pass schedules, such as the reduction rate, speed, and width size per individual pass may vary depending on equipment and use, and are not specified in the present disclosure. In the present disclosure, a thickness of the cold rolled steel sheet may be more preferably 0.1 to 0.6 mm. More preferably, the thickness may be 0.3 mm or less.

[0076] As described above, through the cold rolling, the pearlite structure, which is the main phase forming the microstructure of the sheet material, may have three final types of pearlite structures due to compression deformation in the thickness direction.

[0077] Therefore, the steel sheet of the present disclosure may have a microstructure including a pearlite structure as the main phase and a remaining 4 area% or less of grain boundary proeutectoid cementite, and through the aforementioned cold rolling, the pearlite structure may be formed as a structure including, by area%, more than 40% of homogeneous pearlite (fibrous pearlite), 50% or less of zigzag pearlite (bent pearlite), and 10% or less of heterogeneous pearlite.

[0078] The steel sheet of the present disclosure manufactured in this manner has a thickness of 0.1 to 0.6 mm, a tensile strength of 2100 MPa or more, an elongation of 2% or more, and bending properties (R/t) of 3.0 or less (R is a bending radius at which cracks in a bending portion do not occur after a 180° bending test and t is a thickness of the steel sheet), thereby obtaining high strength and excellent toughness characteristics. A more preferable upper limit of the thickness of the steel sheet may be 0.3 mm. More preferably, the tensile strength value may be 2200 MPa or more, and a more preferable upper limit of the tensile strength value may be 2350 MPa.

[0079] Hereinafter, the present disclosure will be described in more detail through examples. However, it should be appreciated that the examples below are only for illustrating and explaining the present disclosure in more detail and are not desired to limit the scope of the present disclosure.

Mode for invention

(Example)

[0080] A steel slab having the alloy composition of Table 1 below was heated to 1200°C for 2 hours, and then a cold rolled steel sheet was manufactured under the conditions of Table 2 below. At this time, a rough rolling temperature was 1080°C and a finish rolling temperature was 900°C. In addition, a cooling rate to coiling after hot rolling was 20°C/s, and coiling was performed under the coiling temperature conditions of Table 2. The manufactured hot-rolled steel sheet was pickled, heated at 950°C for 10 minutes, cooled at a cooling rate of 70°C/s, and then cold-rolled under the conditions of Table 2.

[Table 1]

Steel species	Alloy composition (wt%)								
	C	Mn	Cr	Si	Al	P	S	V	Co
A	0.82	0.35	0.27	0.23	0.035	0.011	0.002	0.06	0.07
B	0.63	0.36	0.23	0.21	0.037	0.010	0.003	0.07	0.11
C	0.83	0.11	0.26	0.22	0.033	0.011	0.002	0.09	0.09

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(continued)

Steel species	Alloy composition (wt%)								
	C	Mn	Cr	Si	Al	P	S	V	Co
D	0.83	0.64	0.28	0.24	0.034	0.010	0.003	0.07	0.08

[Table 2]

Specimen No.	Steel species	Coiling	Heat treatment		Cold rolling	Thickness of steel sheet (mm)	
		Temperature (°C)	Cooling and holding temperature (°C)	Time (sec.)	Cumulative reduction rate (%)	After hot rolling	After cold rolling
1	A	600	560	70	90.5	2.1	0.20
2	A	620	550	60	93.2	2.2	0.15
3	A	620	545	80	86.1	1.8	0.25
4	A	500	560	60	90.0	2.2	0.18
5	A	720	560	60	90.0	2.2	0.18
6	A	600	490	70	89.0	2.0	0.22
7	A	600	630	70	89.0	2.0	0.22
8	A	620	550	16	91.7	1.8	0.15
9	A	620	550	150	91.7	1.8	0.15
10	A	600	560	65	75	1.6	0.40
11	A	600	560	65	96.9	3.5	0.11
12	B	620	550	70	91.0	2.0	0.18
13	C	620	550	70	91.0	2.0	0.18
14	D	620	550	70	91.0	2.0	0.18

[0081] Table 3 below shows the measured microstructure and physical properties of the manufactured steel sheets. The microstructure was observed and shown after heat treatment and cold rolling, respectively. First, the area fraction of grain boundary proeutectoid cementite was measured and shown using an electron microscope photograph of a steel sheet heat-treated before cold rolling at a magnification of x3000. In the microstructure of the steel sheet before cold rolling in Table 3 below, all fractions other than the grain boundary proeutectoid cementite include pearlite. 10 to 15 images of a cross-section of the steel sheet after cold rolling in the thickness direction was captured multiple times using an electron microscope at x4300, and after measuring a thickness length occupied by the microstructure, the thickness was expressed as a ratio and an average value was calculated as a microstructure fraction. In addition, each thickness was measured for the homogeneous pearlite (fibrous pearlite) structure, and average values thereof are shown in Table 3 below. At this time, the fractions of homogeneous pearlite, zigzag pearlite, and heterogeneous pearlite represent the fraction with respect to the total pearlite fraction.

[0082] In addition, a tensile test and a bending test were performed on the manufactured cold-rolled steel sheets to show physical properties and whether cracks existed. The tensile test was performed at room temperature according to the JIS No. 5 standard to measure the tensile strength and elongation. The presence or absence of cracks was determined to be O when R/t was 3.0 or less after a 180° bending test (R is a bending radius in which no cracks occur in a bending portion after the 180° bending test, and t is the thickness of the steel sheet), or otherwise, X.

[Table 3]

Specimen No.	Steel specimen	Microstructure						Physical properties			Classification
		Pearlite					Fraction of grain boundary proeutectoid cementite (%)				
		Fraction (%)	(based on entire pearlite 100 fraction)								
			Fibrous pearlite		Bent pearlite	Heterogeneous pearlite					
			Average thickness (μm)	Fraction (%)	Fraction (%)	Fraction (%)					
1	A	98	2.2	49	46	5	2	2287	3.5	X	Inventive Example 1
2	A	99	2.1	48	48	4	1	2276	3.4	X	Inventive Example 2
3	A	97	2.3	51	45	4	3	2311	3.8	X	Inventive Example 3
4	A	96	2.0	31	50	19	4	1982	5.6	X	Comparative Example 1
5	A	96	3.1	29	38	33	4	2139	4.2	○	Comparative Example 2
6	A	99	1.2	32	13	55	1	2614	0.8	X	Comparative Example 3
7	A	94	3.2	25	39	36	6	1898	6.9	○	Comparative Example 4
8	A	95	1.9	19	25	56	5	2013	4.8	○	Comparative Example 5
9	A	96	1.8	28	64	8	4	1899	6.1	○	Comparative Example 6
10	A	97	3.4	27	55	18	3	1985	6.4	○	Comparative Example 7
11	A	95	2.1	25	56	19	5	2529	1.1	X	Comparative Example 8
12	B	99	3.4	29	48	23	1	2013	6.7	○	Comparative Example 9
13	C	98	3.2	35	44	21	2	1957	6.6	X	Comparative Example 10
14	D	94	2.6	44	51	5	6	2493	1.2	X	Comparative Example 11

[0083] As shown in Table 3, in the case of the invention example that satisfies the alloy composition and manufacturing conditions of the present disclosure, the microstructure characteristics proposed in the present disclosure were satisfied and the physical properties desired in the present disclosure were secured.

[0084] FIG. 2 is a photograph showing a method of calculating a microstructure fraction and homogeneous pearlite (fibrous pearlite) thickness of Inventive Example 2. When the microstructure is imaged in the thickness direction of the

steel sheet, homogeneous pearlite (fibrous pearlite) appears to have a lamella structure without bends or segments and may be indicated by the dotted line as shown in FIG. 2. In addition, zigzag pearlite (bent pearlite) has a zigzag shape in which the lamella structure is bent more than once, as indicated by the solid line in FIG. 2, and a thickness may be measured by distinguishing from the homogeneous pearlite (fibrous pearlite) by mixing zigzag and wave shapes. The portion excluding the solid and dotted lines in FIG. 2 represents heterogeneous pearlite. After measuring the thickness of each microstructure, the sum thereof may be calculated and expressed as a fraction, and the homogeneous pearlite (fibrous pearlite) thickness may be expressed as an average value of the measured thickness values.

[0085] Meanwhile, Comparative Example 1 satisfied the alloy composition of the present disclosure, but the coiling temperature was too low and strength cannot be sufficiently secured by work hardening during cold rolling due to the formation of a low-temperature structure, so the tensile strength does not satisfy the level desired in the present disclosure.

[0086] Comparative Example 2 satisfied the alloy composition of the present disclosure, but the coiling temperature was too high, so a coarse pearlite structure was formed. This coarse pearlite structure interferes with the formation of a homogeneous pearlite (fibrous pearlite) structure during cold rolling, resulting in a homogeneous pearlite (fibrous fraction) did not satisfy the level desired in the present disclosure. As a result, the desired strength was not secured.

[0087] Comparative Example 3 satisfied the alloy composition of the present disclosure, but the heat treatment temperature was too low and a low-temperature structure was partially formed, so the tensile strength did not meet the level desired in the present disclosure.

[0088] Comparative Example 4 satisfied the alloy composition of the present disclosure, but the heat treatment temperature was too high to form a coarse pearlite structure, and the homogeneous pearlite (fibrous pearlite) fraction did not satisfy the level desired in the present disclosure. As a result, the strength was inferior.

[0089] Comparative Example 5 is a case in which the holding time after cooling during heat treatment did not fall within the range of the present disclosure, and sufficient homogeneous pearlite (fibrous pearlite) was not formed due to insufficient time. As a result, the strength due to work hardening during cold rolling was insufficient.

[0090] Comparative Example 6 is a case in which the holding time after cooling during heat treatment exceeded the range of the present disclosure, and homogeneous pearlite (fibrous pearlite) was not sufficiently formed, and after the pearlite was formed, the pearlite was softened to lower the strength, thereby failing to meet the level of strength desired by the present disclosure.

[0091] Comparative Example 7 is a case in which the reduction rate during cold rolling is outside the range of the present disclosure, and the desired homogeneous pearlite (fibrous pearlite) fraction and tensile strength were not secured due to the low reduction rate.

[0092] In Comparative Example 8, the cold rolling reduction ratio was excessive, and the strength increased excessively, so the tensile strength did not satisfy the range desired by the present disclosure.

[0093] Comparative Example 9 is a case in which the C content was below the range of the present disclosure, and the homogeneous pearlite (fibrous pearlite) fraction falls below the desired range due to the formation of coarse pearlite, and the strength also did not fall within the desired range of the present disclosure.

[0094] Comparative Example 10 was a case in which the Mn content was below the range of the present disclosure, the homogeneous pearlite (fibrous pearlite) fraction did not meet the level desired in the present disclosure, and there was difficulty in securing the desired level of strength.

[0095] Comparative Example 11 is a case in which the Mn content exceeded the range of the present disclosure, and the strength was excessively increased, exceeding the desired range of the present disclosure.

[0096] Although the present disclosure has been described in detail through examples above, other forms of embodiments are also possible. Therefore, the technical spirit and scope of the claims set forth below are not limited to the embodiments.

Claims

1. A steel sheet comprising, by wt%, carbon (C) : 0.70 to 1.20%, manganese (Mn): 0.2 to 0.6%, silicon (Si): 0.01 to 0.4%, phosphorus (P): 0.005 to 0.02%, sulfur (S): 0.01% or less, aluminum (Al): 0.01 to 0.1%, chromium (Cr): 0.1 to 0.8%, vanadium (V): 0.02 to 0.25%, cobalt (Co): 0.01 to 0.2 %, a balance of iron (Fe), and other inevitable impurities,

wherein the steel sheet has a microstructure including a pearlite structure as a main phase and 4 area% or less of remaining grain boundary proeutectoid cementite, and the pearlite structure includes, by area%, 40% or more of homogeneous pearlite (fibrous pearlite), 50% or less of zigzag pearlite (bent pearlite), and 10% or less of heterogeneous pearlite.

2. The steel sheet of claim 1, wherein, when a cross-section of the microstructure is observed in a thickness direction, an average thickness of the homogeneous pearlite is 2.5 μm or less.

3. The steel sheet of claim 1, wherein the steel sheet has a value A of 1.2 or less in the following relational expression 1,

[Relational expression 1]

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$$A = [\text{Mn}] + [\text{Cr}] + [\text{V}]$$

where [Mn], [Cr], and [V] are a wt% of each element.

- 10 4. The steel sheet of claim 1, wherein the steel sheet has a tensile strength of 2100 MPa or more, an elongation of 2% or more, and bending properties (R/t) of 3.0 or less, where R is a bending radius at which cracks in a bending portion do not occur after a 180° bending test and t is a thickness of the steel sheet.

- 15 5. The steel sheet of claim 1, wherein the steel sheet has a tensile strength of 2200 to 2350 MPa.

6. The steel sheet of claim 1, wherein a thickness of the steel sheet is 0.1 to 0.6 mm.

7. A method of manufacturing a steel sheet, the method comprising:

20 reheating a steel slab including, by wt%, carbon (C): 0.70 to 1.20%, manganese (Mn) : 0.2 to 0.6%, silicon (Si): 0.01 to 0.4%, phosphorus (P) : 0.005 to 0.02%, sulfur (S): 0.01% or less, aluminum (Al): 0.01 to 0.1%, chromium (Cr): 0.1 to 0.8%, vanadium (V): 0.02 to 0.25%, cobalt (Co): 0.01 to 0.2 %, a balance of iron (Fe), and other inevitable impurities,
rough rolling the reheated steel slab;
25 finish rolling the rough-rolled steel sheet to obtain a hot-rolled steel sheet;
cooling the hot-rolled steel sheet to a temperature within a range of 540-660°C at a cooling rate of 5-50°C/s and then coiling the cooled hot-rolled steel sheet;
performing heat treatment of heating the cooled and coiled steel sheet to a temperature within a range of 850 to 1,050°C, maintaining for 5 to 20 minutes, then cooling to a temperature within a range of 520 to 590°C at a
30 cooling rate of 50 to 150°C/s, and then maintaining for 30 to 120 seconds; and
cold rolling the heat-treated steel sheet at a cumulative reduction rate of 80 to 96%.

8. The method of claim 7, wherein the steel slab has value A of 1.2 or less in the following relational expression 1:

35

[Relational expression 1]

$$A = [\text{Mn}] + [\text{Cr}] + [\text{V}]$$

40

where [Mn], [Cr], and [V] are wt% of each element.

9. The method of claim 7, wherein

45 the reheating is performed at a temperature within a range of 1100 to 1300°C,
the rough rolling is performed at a temperature within a range of 1000 to 1100°C, and
the finish rolling is performed at a temperature within a range of 860 to 940°C.

10. The method of claim 7, further comprising pickling the steel sheet at a temperature within a range of 200°C or less, after the coiling.

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11. The method of claim 7, further comprising air cooling the steel sheet, after the heat treatment.

12. The method of claim 7, wherein a microstructure of the heat-treated steel sheet includes a pearlite structure as a main phase and less than 4 area% of remaining grain boundary proeutectoid cementite.

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13. The method of claim 7, wherein, after the finish rolling, a thickness of the hot-rolled steel sheet is 1.5 to 2.6 mm.

14. The method of claim 7, wherein, after the cold rolling, a thickness of the cold rolled steel sheet is 0.1 to 0.6 mm.

FIG. 1

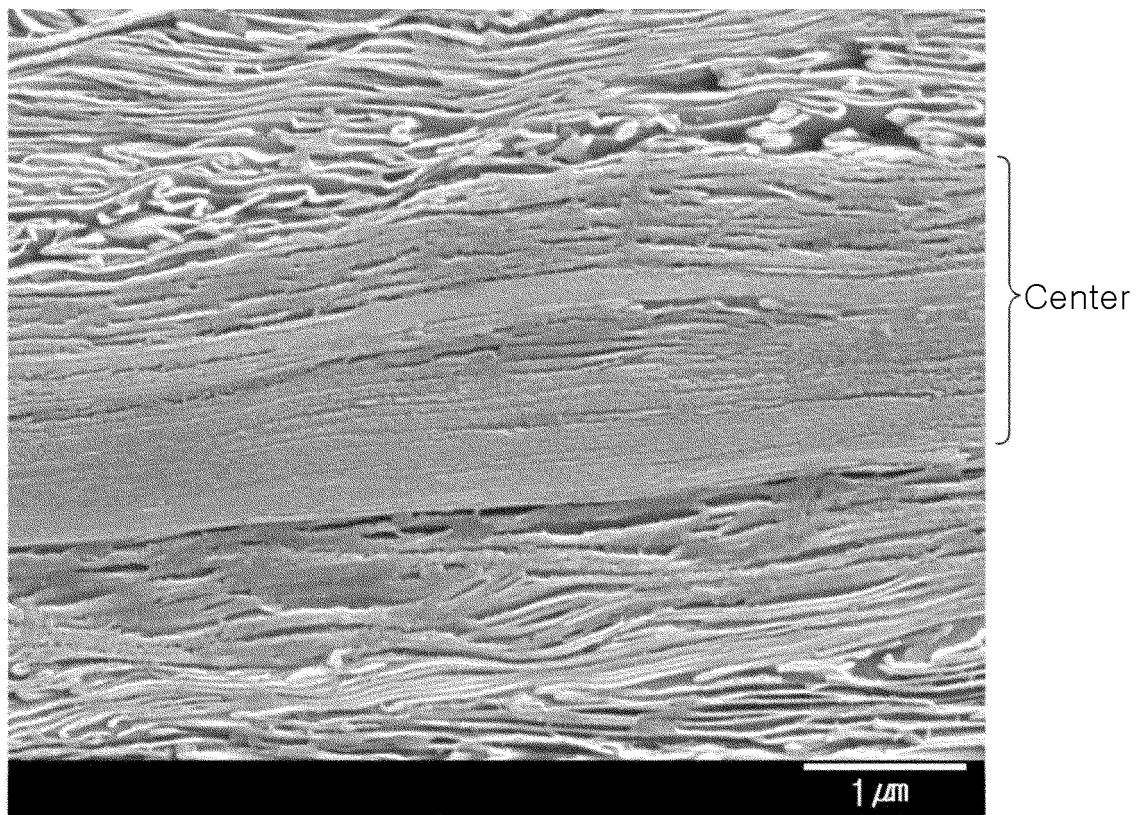
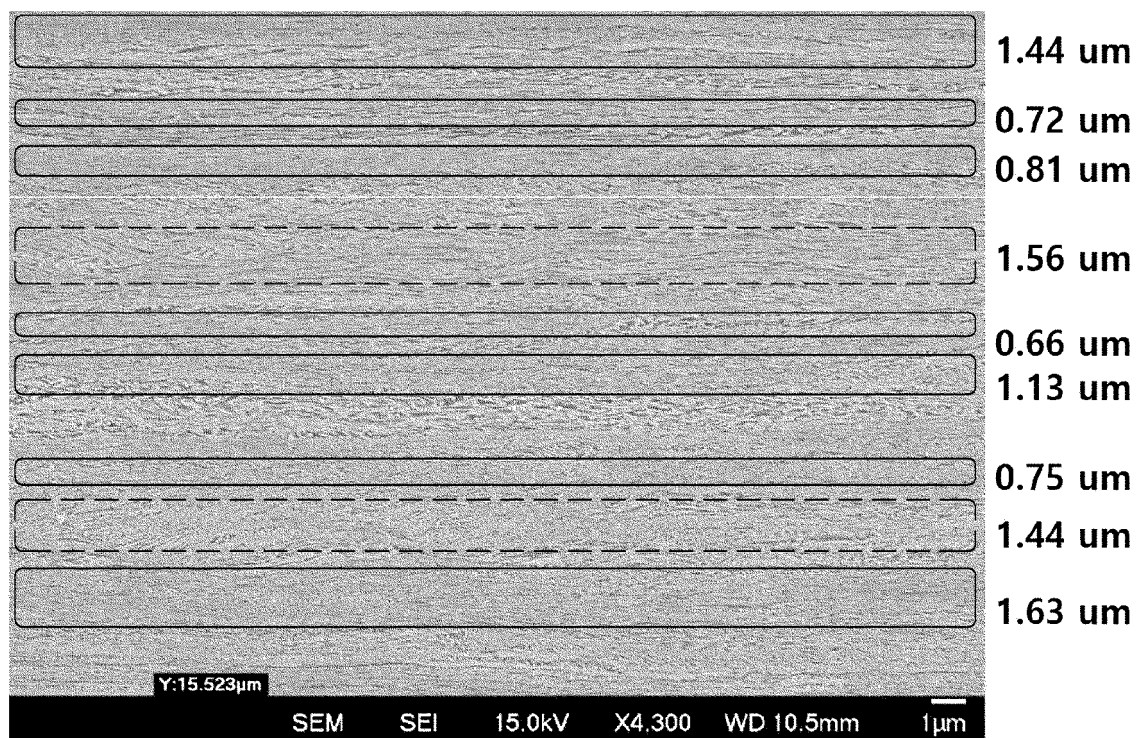


FIG. 2



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2022/012063

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/24(2006.01)i; C22C 38/30(2006.01)i; C21D 8/02(2006.01)i; B21C 47/02(2006.01)i; C23G 1/02(2006.01)i;
C21D 9/46(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)

C22C 38/24(2006.01); C21D 8/02(2006.01); C21D 8/06(2006.01); C22C 38/00(2006.01); C22C 38/14(2006.01);
C22C 38/18(2006.01); C22C 38/58(2006.01)

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

Korean utility models and applications for utility models: IPC as above
Japanese utility models and applications for utility models: IPC as above

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

eKOMPASS (KIPO internal) & keywords: 펄라이트(pearlite), 세멘타이트(cementite), 냉각(cooling), 가열(heating), 크롬(chromium), 바나듐(vanadium), 코발트(cobalt)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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

* Special categories of cited documents:

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“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

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Date of the actual completion of the international search

10 November 2022

Date of mailing of the international search report

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Name and mailing address of the ISA/KR

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Information on patent family members

International application No.

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International application No.

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