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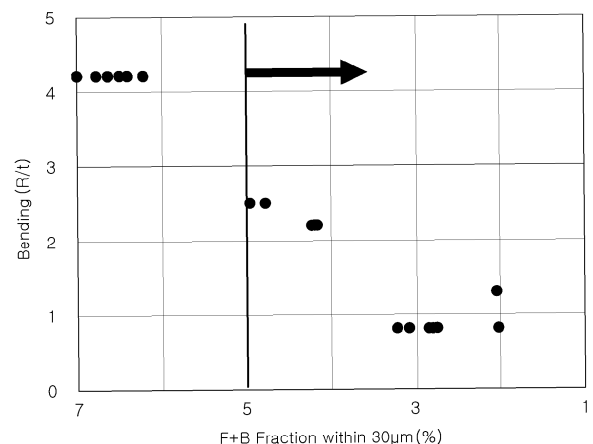
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(54) **COLD-ROLLED STEEL SHEET AND MANUFACTURING METHOD THEREOF**

(57) The present invention relates to a cold-rolled steel sheet and a manufacturing method thereof and, more specifically, to an ultra-high strength cold-rolled steel sheet having excellent bendability and hydrogen embrittlement resistance, and a manufacturing method thereof.

[FIG. 1]



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Description

Technical Field

[0001] The present disclosure relates to a cold-rolled steel sheet and a method for manufacturing the same, and more particularly, to an ultra-high strength cold-rolled steel sheet having excellent bendability and resistance to hydrogen embrittlement, and a method for manufacturing the same.

Background Art

[0002] Recently, there has been an increasing demand for higher strength in steel sheets applied to automotive frame parts. Furthermore, for some parts, the application of ultra-high strength steel sheets with a tensile strength exceeding 1500 MPa is underway.

[0003] To obtain such ultra-high strength, it is effective to use a steel structure mainly composed of a hard phase such as martensite or bainite. However, such a steel structure has lower elongation compared to dual-phase steels of ferrite and martensite, and due to crack formation during forming, its application is limited to parts formed by relatively simple bending processes.

[0004] Although the composition of the hardened structure is necessary to improve the strength of the steel sheet, its application as a suitable automotive part has been limited because not only do cracks occur during part forming, but impact properties during a collision are also degraded. Therefore, to achieve high strength in automotive parts with a steel structure mainly composed of martensite, in addition to securing the target strength, it is necessary to secure crashworthiness during a vehicle collision by developing a steel material with superior resistance to hydrogen embrittlement and fatigue properties, in order for it to be widely applied as a high-strength steel material for automotive parts.

[0005] Meanwhile, Hot Press Forming (HPF) steel is a material with superior part formability and crash properties. The HPF forming technique involves press forming a material in a hot state, where the required strength is secured through water cooling between the die and the material after forming the material at a high temperature. Therefore, it is widely used because it can secure higher strength for the same thickness and is also excellent in terms of formability.

[0006] However, due to problems in application arising from excessive facility investment costs and increased process costs, research on the development of materials for cold stamping with a tensile strength of 1500 MPa or higher has been actively conducted recently.

[0007] Meanwhile, Patent Document 1 discloses a technology for securing strength by adding hardenability elements such as C and Mn to secure strength, and then obtaining martensite at room temperature through water cooling after conventional annealing.

[0008] Furthermore, Patent Document 2 discloses a technology for securing a high-strength steel by optimizing cooling conditions during cooling.

[0009] However, in the case of Patent Documents 1 and 2, since strength is fundamentally secured using martensite, there are limitations in manufacturing a steel sheet with better shape due to limitations in formability and poor shape caused by quenching, which presents many problems during processing. Furthermore, there are also limitations in securing crashworthiness and fatigue properties.

(Patent Document 1) Japanese Unexamined Patent Application Publication No. 2010-215958

(Patent Document 2) Japanese Unexamined Patent Application Publication No. 2013-227657

Disclosure of Invention

Technical Problem

[0010] An aspect of the present disclosure is to provide a cold-rolled steel sheet and a method for manufacturing the same.

[0011] An aspect of the present disclosure is to provide an ultra-high strength cold-rolled steel sheet with excellent bendability and resistance to hydrogen embrittlement, and a method for manufacturing the same.

[0012] The objects of the present disclosure are not limited to the aforementioned contents. A person skilled in the art will have no difficulty in understanding additional objects of the present disclosure from the overall description herein.

Solution to Problem

[0013] According to an embodiment of the present disclosure, a cold-rolled steel sheet may comprise, by weight %,

carbon (C): 0.20-0.30%, silicon (Si): 0.5% or less, manganese (Mn): 1.5-3.5%, boron (B): 0.0005-0.0030%, phosphorus (P): 0.010% or less, sulfur (S): 0.010% or less, nitrogen (N): 0.010% or less, aluminum (Al): 0.010-0.100%, chromium (Cr): 0.20% or less, molybdenum (Mo): 0.10% or less, niobium (Nb): 0.010-0.100%, and titanium (Ti): 0.010-0.100%, with the balance being iron (Fe) and other unavoidable impurities,

wherein a ratio $a/b \times 100$ of a residual stress (a) at a 1/2 point in a thickness direction of the steel sheet to a residual stress (b) in a region up to 30 μm from a surface toward a center of the thickness is 95.0% or more.

[0014] The cold-rolled steel sheet may further comprise at least one of vanadium (V): 0.01-0.10% and antimony (Sb): 0.10% or less.

[0015] In the cold-rolled steel sheet, a microstructure in a region up to 30 μm from the surface toward the center of the thickness may mainly include at least one of martensite and tempered martensite, and may include, by area %, a sum of ferrite and bainite of 5.0% or less.

[0016] The cold-rolled steel sheet may have a tensile strength of 1500 MPa or more and a bendability (R/t) of 3.5 or less.

[0017] According to an embodiment of the present disclosure, a method for manufacturing a cold-rolled steel sheet comprises: reheating a steel slab comprising, by weight %, carbon (C): 0.20-0.30%, silicon (Si): 0.5% or less, manganese (Mn): 1.5-3.5%, boron (B): 0.0005-0.0030%, phosphorus (P): 0.010% or less, sulfur (S): 0.010% or less, nitrogen (N): 0.010% or less, aluminum (Al): 0.010-0.100%, chromium (Cr): 0.20% or less, molybdenum (Mo): 0.10% or less, niobium (Nb): 0.010-0.100%, and titanium (Ti): 0.010-0.100%, with the balance being iron (Fe) and other unavoidable impurities;

hot-rolling the reheated steel slab;

coiling the hot-rolled steel sheet in a temperature range of 400°C to 600°C;

cold-rolling the coiled steel sheet;

annealing the cold-rolled steel sheet in a temperature range of $A_{c3}+10^\circ\text{C}$ to $A_{c3}+80^\circ\text{C}$;

and primarily cooling the annealed steel sheet to a temperature range of 680°C to 750°C at an average cooling rate of 20°C/s or less.

[0018] The method may further include: secondarily cooling the primarily cooled steel sheet to a temperature range of 100°C to M_f at an average cooling rate of 70-200°C/s;

over-aging the secondarily cooled steel sheet in a temperature range of 150°C to 240°C;

and temper rolling or tension leveling the over-aged steel sheet at a reduction ratio of 0.01-0.20%.

[0019] The steel slab may further include at least one of vanadium (V): 0.01-0.1% and antimony (Sb): 0.1% or less.

[0020] The reheating may be performed in a temperature range of 1100°C to 1300°C,

the hot-rolling may be performed in a temperature range of A_{r3} or higher,

and the cold-rolling may be performed at a reduction ratio of 30-80%.

[0021] The annealing may be performed for 30 seconds or more, and the over-aging treatment may be performed for 200 seconds or more.

Advantageous Effects of Invention

[0022] According to an embodiment of the present disclosure, a cold-rolled steel sheet and a method for manufacturing the same can be provided.

[0023] According to an embodiment of the present disclosure, an ultra-high strength cold-rolled steel sheet with excellent bendability and resistance to hydrogen embrittlement, and a method for manufacturing the same can be provided.

[0024] According to an embodiment of the present disclosure, an ultra-high strength cold-rolled steel sheet, a plated steel sheet, and a method for manufacturing the same, which have excellent resistance to hydrogen embrittlement, leading to excellent part performance, and excellent crashworthiness during a collision, making them suitable for use in automotive steel sheets, can be provided.

[0025] The various and beneficial advantages and effects of the present disclosure are not limited to the aforementioned contents and will be more easily understood in the course of describing specific embodiments of the present disclosure.

Brief Description of Drawings

[0026] FIG. 1 is a graph showing bendability values according to the sum of the fractions of ferrite and bainite (F+B) in a region up to 30 μm from the surface toward the center of the thickness.

Best Mode for the Invention

[0027] Hereinafter, preferred embodiments of the present disclosure will be described. The implementations of the present disclosure may be modified in various other 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 explain the present disclosure in more detail to those skilled in the art to which the present disclosure pertains.

[0028] Hereinafter, the present disclosure will be described in detail.

[0029] Hereinafter, the steel composition of the present disclosure will be described in detail.

[0030] Unless otherwise specified in the present disclosure, the % indicating the content of each element is based on weight.

[0031] The cold-rolled steel sheet according to an embodiment of the present disclosure may comprise, by weight %, carbon (C): 0.20-0.30%, silicon (Si): 0.5% or less, manganese (Mn): 1.5-3.5%, boron (B): 0.0005-0.0030%, phosphorus (P): 0.010% or less, sulfur (S): 0.010% or less, nitrogen (N): 0.010% or less, aluminum (Al): 0.010-0.100%, chromium (Cr): 0.20% or less, molybdenum (Mo): 0.10% or less, niobium (Nb): 0.010-0.100%, and titanium (Ti): 0.010-0.100%.

Carbon (C): 0.20-0.30%

[0032] Carbon (C) is necessary to improve hardenability and obtain a steel structure with a martensite area fraction of 95% or more at a 1/4 point in the thickness direction. In addition, carbon (C) is necessary from the viewpoint of increasing the strength of martensite and securing the target tensile strength. If the content of carbon (C) is less than 0.20%, a predetermined strength cannot be obtained. Therefore, according to an embodiment of the present disclosure, the carbon (C) content may be 0.20% or more. According to an embodiment of the present disclosure, the carbon (C) content may be 0.22% or more. On the other hand, if the content exceeds 0.30%, it may be difficult to obtain good weldability or delayed fracture resistance. Therefore, according to an embodiment of the present disclosure, the carbon (C) content may be 0.30% or less. According to an embodiment of the present disclosure, it may be 0.25% or less.

Silicon (Si): 0.5% or less

[0033] Silicon (Si) is a strengthening element through solid solution strengthening and can be included from the viewpoint of improving bendability by suppressing the formation of film-like carbides during the high-temperature tempering process. From the viewpoint of obtaining this effect, it is advantageous for the silicon (Si) content to be high, but if the content is excessive, weldability and liquid metal embrittlement (LME) properties may be deteriorated, so the upper limit is limited to 0.5%. According to an embodiment of the present disclosure, it may be 0.32% or less. However, the lower limit of the silicon (Si) content is not particularly limited, and 0% is excluded because it is added as an impurity element in the manufacturing process. On the other hand, according to an embodiment of the present disclosure, the lower limit of the silicon (Si) content may be 0.001%.

Manganese (Mn): 1.5-3.5%

[0034] Manganese (Mn) contributes to improving strength through an increase in hardenability, thereby increasing the martensite area fraction, or through solid solution strengthening. In addition, manganese (Mn) can be included to fix S in the steel as MnS and reduce hot shortness. If the manganese (Mn) content is less than 1.5%, the possibility of ferrite or bainite formation is higher than that of martensite formation during cooling, so the lower limit is limited to 1.5%. According to an embodiment of the present disclosure, it may be 1.7% or more. On the other hand, the manganese (Mn) content is limited to 3.5% or less from the viewpoint of welding stability. According to an embodiment of the present disclosure, it may be 3.0% or less. According to an embodiment of the present disclosure, it may be 2% or less.

Boron (B): 0.0005-0.0030%

[0035] Boron (B) is an element that suppresses the formation of ferrite, and accordingly, in the present disclosure, it

has the advantage of suppressing the formation of ferrite during cooling after annealing. However, if the content of boron (B) exceeds 0.0030%, ductility may be significantly reduced. According to an embodiment of the present disclosure, it may be 0.0020% or less. On the other hand, if the content of boron (B) is less than 0.0005%, the hardenability effect is completely absent, so not only can the target strength not be secured, but ferrite may also be formed on the surface layer, which tends to deteriorate bendability.

Phosphorus (P): 0.010% or less

[0036] Phosphorus (P) is an impurity element included in steel, and the lower the amount added to the steel, the more advantageous it is, but considering the case where it is inevitably included during the manufacturing process, the content is excluded from 0%. However, if the content exceeds 0.010%, weldability may be deteriorated and there is a risk of embrittlement of the steel, so the upper limit is limited to 0.010%. According to an embodiment of the present disclosure, it may be 0.003% or less.

Sulfur (S): 0.010% or less

[0037] Sulfur (S), like P, is an impurity inevitably included in steel, and since it is an element that impairs the ductility and weldability of the steel sheet, it is desirable to manage its content as low as possible. Therefore, in the present disclosure, the content of sulfur (S) is limited to 0.010% or less. According to an embodiment of the present disclosure, it may be 0.005% or less. According to an embodiment of the present disclosure, it can be controlled to 0.002% or less to minimize the precipitation of MnS in the steel and contribute more to the improvement of bendability. On the other hand, considering the case where it is inevitably included during the manufacturing process, 0% is excluded.

Nitrogen (N): 0.010% or less

[0038] Nitrogen (N) is an impurity element, and if its content exceeds 0.010%, the risk of crack formation during continuous casting due to the formation of AlN, etc. is greatly increased, so its upper limit is limited to 0.010%. According to an embodiment of the present disclosure, it may be 0.008% or less. According to an embodiment of the present disclosure, it may be 0.006% or less. On the other hand, considering the case where it is inevitably included during the manufacturing process, 0% is excluded.

Aluminum (Al): 0.010-0.100%

[0039] Aluminum (Al) can be added to deoxidize the molten steel, and like Si, it is an element that is effective in stabilizing residual austenite by suppressing the precipitation of cementite during the reheating and over-aging stages. If the content of aluminum (Al) is less than 0.010%, deoxidation of the steel is not sufficiently achieved, and the cleanliness of the steel may be impaired. On the other hand, if the content of aluminum (Al) exceeds 0.100%, not only does the castability of the slab deteriorate, but the temperature required for single-phase region heating during annealing becomes high, which may cause production and facility problems. According to an embodiment of the present disclosure, it may be 0.050% or less.

Chromium (Cr): 0.20% or less

[0040] Chromium (Cr) can be added to obtain the effect of improving the hardenability of steel. However, since the cost of the alloy element is high compared to other hardenability elements, it is advantageous to manage it as low as possible, so the lower limit is not particularly limited, but 0% is excluded in consideration of the level of impurities that are inevitably entrained. On the other hand, if the chromium (Cr) content exceeds 0.20%, it delays the dissolution rate of cementite during annealing, and deteriorates bendability by leaving undissolved cementite. Therefore, according to an embodiment of the present disclosure, the chromium (Cr) content can be controlled to 0.20% or less. According to an embodiment of the present disclosure, it may be 0.10% or less.

Molybdenum (Mo): 0.10% or less

[0041] Molybdenum (Mo) has the effects of improving the hardenability of steel, forming fine carbides including molybdenum (Mo) that become hydrogen trap sites, and improving the delayed fracture resistance by refining martensite. However, if the content of molybdenum (Mo) exceeds 0.10%, the effect is not significant compared to the increase in cost due to the addition of a high-cost alloy element, so the upper limit is limited to 0.10%. Since the cost is high compared to other hardenability elements, it is advantageous to manage it as low as possible, so the lower limit is not

particularly limited, but 0% is excluded in consideration of the level of impurities that are inevitably entrained.

Niobium (Nb): 0.010-0.100%

- 5 **[0042]** Niobium (Nb) is an element that segregates at austenite grain boundaries, suppresses the growth of austenite crystal grains during annealing heat treatment, and contributes to an increase in strength through a precipitation strengthening effect. However, if the content of niobium (Nb) exceeds 0.100%, the precipitation of carbonitrides, etc. increases, deteriorating the workability of the base material, and the cost increases as the amount of alloy input becomes excessive. According to an embodiment of the present disclosure, it may be 0.080% or less. On the other
10 hand, if the content is less than 0.010%, it may not contribute to the increase in strength at all. According to an embodiment of the present disclosure, it may be 0.020% or more.

Titanium (Ti): 0.010-0.100%

- 15 **[0043]** Titanium (Ti) is a nitride-forming element that scavenges N in steel by precipitating it as TiN. If titanium (Ti) is not added, there is a possibility of cracks occurring during continuous casting due to the formation of AlN. In addition, if the Ti content is less than 0.010%, it does not contribute to the increase in strength at all, similar to the Nb element, so the lower limit of the Ti content is limited to 0.010% in the present disclosure. According to an embodiment of the present disclosure, it may be 0.020% or more. However, if the content of titanium (Ti) exceeds 0.100%, the strength of
20 martensite may be reduced by additional carbide precipitation in addition to the removal of solute N, and hole expansion and bending workability may be impaired by the formation of carbonitrides such as TiC and TiN. According to an embodiment of the present disclosure, it may be 0.080% or less.

- [0044]** The steel material of the present disclosure may include the balance of iron (Fe) and unavoidable impurities in addition to the above-described composition. Since unavoidable impurities may be unintentionally incorporated from
25 a normal manufacturing process, they cannot be excluded. These impurities are known to any person skilled in the ordinary steel manufacturing field, and therefore, all of their contents are not specifically mentioned in this specification.

- [0045]** The cold-rolled steel sheet according to an embodiment of the present disclosure may further comprise at least one of vanadium (V): 0.01-0.10% and antimony (Sb): 0.10% or less.
30

Vanadium (V): 0.01-0.10%

- [0046]** Vanadium (V) is also a carbonitride-forming element, but it has a precipitation strengthening effect that increases the strength of the steel, which is advantageous for increasing strength. However, when added in excess,
35 not only does the cost increase, but the possibility of brittle fracture due to the formation of inclusions in the steel increases. If the content of vanadium (V) exceeds 0.10%, the hardenability is weakened by the removal of solute C, and the strength of martensite may be reduced. According to an embodiment of the present disclosure, it may be included at 0.08% or less. On the other hand, if the vanadium (V) content is less than 0.01%, it does not contribute to the increase in strength at all, similar to Nb, so in the present disclosure, the lower limit of its content is limited to
40 0.01%. According to an embodiment of the present disclosure, it may be included at 0.02% or more.

Antimony (Sb): 0.10% or less

- [0047]** Antimony (Sb) induces a uniform oxidation reaction in the surface layer region of the steel sheet and can selectively improve bending properties by suppressing the formation of C or B oxides in the surface layer. From the
45 viewpoint of obtaining this effect, if the antimony (Sb) content exceeds 0.10%, castability deteriorates, and antimony (Sb) segregates at the prior-austenite grain boundaries, which can deteriorate bendability. Therefore, according to an embodiment of the present disclosure, the content is limited to 0.10% or less. According to an embodiment of the present disclosure, it may be 0.06% or less. However, from the viewpoint of reducing the cost of alloy elements, it is advantageous for the added content to be low, and the lower limit is not particularly limited as long as the required
50 properties of the steel sheet are not impaired.

[0048] Hereinafter, the microstructure of the steel of the present disclosure will be described in detail.

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

- 55 **[0050]** According to an embodiment of the present disclosure, the microstructure in a region up to 30 μm from the surface of the cold-rolled steel sheet toward the center of the thickness mainly includes at least one of martensite and tempered martensite, and may include, by area %, a sum of ferrite and bainite of 5.0% or less.

[0051] In the present disclosure, the microstructure in a region up to 30 μm from the surface of the steel sheet

toward the center of the thickness is limited in order to strictly limit bendability.

[0052] According to an embodiment of the present disclosure, at least one of martensite and tempered martensite may be included as a primary phase to improve bendability and suppress hydrogen embrittlement.

[0053] In addition, the higher the amount of mixed phases of ferrite or bainite in addition to the primary phase of martensite or tempered martensite in the surface layer of the steel sheet, the higher the residual stress between the phases, which may increase the possibility of crack formation. In particular, since hydrogen adsorbed on the interface between phases cannot easily escape to the outside, it is disadvantageous for hydrogen embrittlement. Therefore, according to an embodiment of the present disclosure, the primary phase may be at least one of martensite and tempered martensite. According to an embodiment of the present disclosure, the primary phase may be 90.0% or more.

[0054] On the other hand, if the sum of the fractions of ferrite and bainite exceeds 5.0%, there is a concern that bendability may be rapidly deteriorated, and it is also disadvantageous from the viewpoint of hydrogen embrittlement. Therefore, the sum of the fractions is limited to 5% or less. According to an embodiment of the present disclosure, it may be limited to 3% or less. In the present disclosure, it is advantageous for the sum of the fractions of ferrite and bainite to be low, and the lower limit is not particularly limited.

[0055] According to an embodiment of the present disclosure, the cold-rolled steel sheet may further include a plating layer on at least one surface, as needed.

[0056] The plating layer is not particularly limited, and not only its type, such as zinc-based plating and aluminum-based plating, but also its method, such as hot-dip plating and electroplating, are not limited. That is, anything that can be used in the technical field to which the present disclosure pertains is sufficient. According to an embodiment of the present disclosure, the plating layer may be a zinc-based plating layer.

[0057] The cold-rolled steel sheet according to an embodiment of the present disclosure has a tensile strength of 1500 MPa or more and a bendability (R/t) of 3.5 or less, and a ratio $a/b \times 100$ of a residual stress (a) at a 1/2 point in a thickness direction of the steel sheet to a residual stress (b) in a region up to 30 μm from a surface toward a center of the thickness is 95.0% or more.

[0058] The bendability (R/t, where R is the bending die radius and t is the steel sheet thickness) was performed using a jig with a tip inner angle of 90°. The limit bending radius (R/t) was calculated by changing the radius of curvature of the tip inner angle of the jig, finding the minimum jig tip inner angle at which no cracks were observed on the surface of the test piece, and dividing the obtained radius (R) by the sheet thickness (t).

[0059] If the residual stress ratio $a/b \times 100$ is less than 95.0%, the work hardening rate of the steel sheet surface increases, deteriorating bendability, and the hardenability of the surface layer increases, which may increase the risk of crack formation during part forming. According to an embodiment of the present disclosure, it may be 97.0% or more. According to an embodiment of the present disclosure, the ratio may be 100.0%. A ratio of 100.0% means that the work hardening of the surface layer is at almost the same level as that of the central part.

[0060] Hereinafter, the method for manufacturing the steel of the present disclosure will be described in detail.

[0061] The cold-rolled steel sheet according to an embodiment of the present disclosure can be manufactured by reheating, hot-rolling, coiling, cold-rolling, annealing, primary cooling, secondary cooling, and over-aging a steel slab that satisfies the above-described alloy composition.

Reheating

[0062] The steel slab satisfying the alloy composition according to an embodiment of the present disclosure can be reheated in a temperature range of 1100-1300°C.

[0063] This process can be performed to smoothly carry out the subsequent hot-rolling process and to sufficiently obtain the properties of the target steel sheet. If the reheating temperature is less than 1100°C, a problem of a sharp increase in the hot-rolling load may occur. On the other hand, if the reheating temperature exceeds 1300°C, there is a concern that the amount of surface scale may increase and the yield of the material may decrease.

Hot-rolling

[0064] The reheated steel slab can be hot-rolled in a temperature range of Ar3 or higher.

[0065] During hot-rolling, if the finish rolling temperature is lower than Ar3 (the temperature at which ferrite starts to appear when austenite is cooled), a mixed structure may be formed due to rolling in the two-phase region of ferrite and austenite or in the ferrite region, and there is a concern of operational errors due to fluctuations in the hot-rolling load. According to an embodiment of the present disclosure, the upper limit of the hot-rolling temperature is not particularly limited, but it may be limited to 1000°C or less.

$$\text{Ar3} = 910 - 310[\text{C}] - 80[\text{Mn}] - 20[\text{Cu}] - 15[\text{Cr}] - 55[\text{Ni}] - 80[\text{Mo}]$$

[Formula]

(In the formula, [C], [Mn], [Cu], [Cr], [Ni], and [Mo] are the weight % of each element.)

Coiling

[0066] The hot-rolled steel sheet can be coiled in a temperature range of 400-600°C.

[0067] If the coiling temperature exceeds 600°C, an excessive oxide film may be formed on the surface of the steel sheet, causing defects, which may deteriorate the surface properties of the plated material. The structure of the steel sheet after hot-rolling is limited to maintain a low coiling temperature to form a single-phase structure rather than a composite structure as much as possible, thereby securing material uniformity in the longitudinal and transverse directions. According to an embodiment of the present disclosure, the coiling temperature may be 500°C or less. However, as the temperature decreases, the strength of the hot-rolled steel sheet increases, which is a disadvantage in that the rolling load increases during the subsequent cold-rolling process, and there may be a factor that makes actual production impossible, so the lower limit is limited to 400°C. According to an embodiment of the present disclosure, the coiling temperature may be 420°C or higher.

[0068] According to an embodiment of the present disclosure, cooling can be performed by water cooling after coiling. In addition, according to an embodiment of the present disclosure, a pickling process for removing the oxide layer formed on the surface of the steel sheet after coiling may be further performed as needed.

Cold-rolling

[0069] The coiled steel sheet can be cold-rolled at a reduction ratio of 30-80%.

[0070] During cold-rolling, if the reduction ratio is less than 30%, it is difficult to secure the target thickness, and there is a concern that the residual hot-rolled crystal grains may affect the formation of austenite and the final properties during annealing. On the other hand, if the reduction ratio exceeds 80%, there is a problem that the material deviation of the final steel sheet may occur due to the non-uniformity of the reduction amount rolled in the longitudinal and transverse directions due to the work hardening that occurs during cold-rolling, and it is difficult to secure the target thickness due to the rolling load.

Annealing

[0071] The cold-rolled steel sheet can be annealed in a temperature range of Ac3+10°C to Ac3+80°C.

[0072] In the present disclosure, the temperature of Ac3 varies depending on the composition, so it can be determined by the following formula.

[0073] If the annealing temperature is less than Ac3+10°C, a mixed structure may be formed by two-phase region annealing instead of single-phase region annealing over the entire length of the coil, which may have a negative effect on the material. On the other hand, if the annealing temperature exceeds Ac3+80°C, facility trouble may occur due to an overload of the annealing furnace.

[0074] According to an embodiment of the present disclosure, annealing may be performed for 30 seconds or more in the above temperature range.

[0075] If the annealing time is less than 30 seconds, there is a problem that the fine carbides formed during hot-rolling are not re-dissolved, and bendability deteriorates. In addition, during annealing, if it does not sufficiently transform into a single-phase austenite and a mixed phase exists, there is a possibility that martensite will not be sufficiently formed during final cooling, and the tensile strength will not reach the standard. On the other hand, in the present disclosure, the upper limit of the annealing time is not particularly limited.

$$Ac3 = 910 - 203\sqrt{([C]) - 15.2[Ni] + 44.7[Si] + 104[V] + 31.5[Mo] + 13.1[W]}$$

[Formula]

(In the formula, [C], [Ni], [Si], [V], [Mo], and [W] are the weight % of each element.)

Primary Cooling

[0076] The annealed steel sheet can be primarily cooled to a temperature range of 680-750°C at an average cooling rate of 20°C/s or less.

[0077] During primary cooling, if the cooling end temperature is less than 680°C, the bendability (R/t) evaluation value may exceed the proposed range, resulting in poor formability. According to an embodiment of the present disclosure, it may be 700°C or more. On the other hand, if the temperature exceeds 750°C, not only can it not be reproduced due to facility configuration, but a phenomenon in which the structure is coarsened and the strength deteriorates may occur. According to an embodiment of the present disclosure, it may be 730°C or less. According to

an embodiment of the present disclosure, it may be 720°C or less. According to an embodiment of the present disclosure, it may be 710°C or less.

[0078] During primary cooling, if the average cooling rate exceeds 20°C/s, a problem may occur in the shape of the sheet. On the other hand, the lower limit of the cooling rate is not particularly limited as long as it is within a range possible with the facility configuration. According to an embodiment of the present disclosure, the lower limit of the average cooling rate during primary cooling may be 1°C/s.

Secondary Cooling

[0079] The primarily cooled steel sheet can be secondarily cooled to a temperature range of 100°C to Mf at an average cooling rate of 70-200°C/s.

[0080] The Mf refers to the martensite transformation finish temperature, and since it can be obtained by a method generally known in the art, it is not particularly defined in the present disclosure and can be measured using a dilatometer.

[0081] During secondary cooling, if the cooling end temperature exceeds the Mf temperature, the martensite transformation is not sufficiently performed, and it may be difficult to secure the microstructure that the present disclosure intends to obtain. According to an embodiment of the present disclosure, the cooling end temperature during secondary cooling may be 160°C or less. According to an embodiment of the present disclosure, the cooling end temperature during secondary cooling may be 150°C or less. On the other hand, if the temperature is less than 100°C, it is not only disadvantageous in terms of shape due to the too low temperature, but it may also exceed the manufacturing process range of the facility. According to an embodiment of the present disclosure, the cooling end temperature during secondary cooling may be 120°C or more.

[0082] According to an embodiment of the present disclosure, a quenching condition can be applied during secondary cooling to secure a target level of strength. If the average cooling rate during secondary cooling is less than 70°C/s, some bainite may be formed during cooling, making it difficult to secure the target strength. According to an embodiment of the present disclosure, the average cooling rate during secondary cooling may be 80°C/s or more. On the other hand, if the average cooling rate during secondary cooling exceeds 200°C/s, a problem of material deviation in the transverse direction and poor shape of the steel sheet may occur due to the rapid martensite transformation rate. According to an embodiment of the present disclosure, the average cooling rate during secondary cooling may be 180°C/s or less.

Over-aging Treatment

[0083] The secondarily cooled steel sheet can be over-aged in a temperature range of 150-240°C.

[0084] According to an embodiment of the present disclosure, the yield strength can be increased by transforming the martensite obtained through the quenching process by the aforementioned secondary cooling into tempered martensite through this process.

[0085] If the over-aging treatment temperature is less than 150°C, tempering is not sufficiently performed, and not only is the yield strength low, but sufficient toughness cannot be secured. In addition, the lower the temperature, the more advantageous it is for bendability, but considering the facility characteristics, the lower limit is limited to 150°C. According to an embodiment of the present disclosure, the over-aging treatment may be performed at 160°C or higher. On the other hand, if the temperature exceeds 240°C, the bendability may be deteriorated by the abundant precipitation and coarsening of carbides. According to an embodiment of the present disclosure, it may be 200°C or less. According to an embodiment of the present disclosure, it may be 180°C or less.

[0086] According to an embodiment of the present disclosure, the over-aging treatment may be performed for 200 seconds or more in the above temperature range.

[0087] If the heat treatment time is less than 200 seconds, there is a problem that the yield strength is lowered because tempering is not sufficiently performed. According to an embodiment of the present disclosure, it may be 300 seconds or more. According to an embodiment of the present disclosure, it may be 400 seconds or more. On the other hand, according to an embodiment of the present disclosure, the upper limit of the over-aging treatment time is not particularly limited, but it is difficult to exceed 1000 seconds due to the characteristics of the continuous annealing facility, so the upper limit may be 1000 seconds. According to an embodiment of the present disclosure, it may be 900 seconds or less. According to an embodiment of the present disclosure, it may be 800 seconds or less.

Temper Rolling or Tension Leveling

[0088] The over-aged steel sheet can be temper rolled or tension leveled at a reduction ratio of 0.01-0.20%.

[0089] According to an embodiment of the present disclosure, the temper rolling or tension leveling process can be

performed to improve the sheet shape.

[0090] On the other hand, if the reduction ratio exceeds 0.20%, work hardening on the surface layer increases, and bendability may be very poor. That is, cracks occur due to acting as a notch during part processing, and a phenomenon in which bendability (R/t , where R is the bending die radius and t is the steel sheet thickness) deteriorates may occur. According to an embodiment of the present disclosure, it may be 0.15% or less. On the other hand, if the reduction ratio is less than 0.01%, it is advantageous for poor bendability, but it may not be helpful at all in terms of improving the sheet shape. According to an embodiment of the present disclosure, it may be 0.03% or more.

[0091] According to an embodiment of the present disclosure, a plating layer can be formed on the cold-rolled steel sheet as needed.

[0092] According to an embodiment of the present disclosure, the manufactured cold-rolled steel sheet can be plated by a hot-dip plating method of dipping it in a molten plating solution and an electroplating method of electroplating in an electrolyte. A plating layer can be formed. The plating conditions are not particularly limited as long as they are generally known in the technical field to which the present disclosure pertains.

Mode for the Invention

[0093] Hereinafter, the present disclosure will be described in more detail through examples. However, it should be noted that the following examples are for illustrating the present disclosure and are not intended to limit the scope of the present disclosure.

(Example)

[0094] A steel slab was manufactured by casting molten steel having the alloy composition shown in Table 1 into an ingot and then sizing rolling. The steel slab was reheated to a temperature of 1200°C, held for 1 hour, and then finish hot-rolled at 900°C. Hot-rolled coiling was simulated by charging it into a heating furnace set under various conditions, holding it for 1 hour, and then furnace cooling. Subsequently, after pickling the hot-rolled steel sheet, it was cold-rolled at a cold reduction ratio of 50%, and then a cold-rolled steel sheet was manufactured by performing annealing, primary cooling, secondary cooling, over-aging treatment, and tension leveling under the conditions shown in Table 2.

[Table 1]

Steel Type	Alloy Composition (wt%)													
	C	Si	Mn	Cr	Mo	B	P	S	N	S.Al	Nb	Ti	Sb	V
A	0.24	0.1	1.7	0.10	0.08	0.0025	0.008	0.002	0.003	0.042	0.003	0.031	-	-
B	0.24	0.1	1.9	0.10	0.05	0.0018	0.006	0.003	0.004	0.031	0.025	0.032	-	0.02
C	0.22	0.2	1.8	0.15	0.06	0.0023	0.007	0.005	0.002	0.025	0.031	0.028	-	-
D	0.25	0.2	2.5	0.12	0.06	0.0009	0.006	0.004	0.005	0.040	0.041	0.027	0.05	-
E	0.28	0.3	2.6	0.11	0.05	0.0018	0.008	0.006	0.006	0.020	0.029	0.026	0.04	-
F	0.26	0.3	2.8	0.16	0.08	0.0018	0.006	0.004	0.006	0.030	0.029	0.025	-	-
G	0.24	0.8	3.5	0.05	0.06	0.0003	0.005	0.005	0.004	0.040	-	-	-	-
H	0.25	0.9	3.6	0.06	0.08	0.0004	0.009	0.003	0.005	0.030	-	-	-	-

[Table 2]

Specimen No.	Steel Type	Coiling	Ac3 (°C)	Annealing	1st Cooling		2nd Cooling		Over-aging Treatment		Tension Leveling
		Temp. (°C)		Temp. (°C)	End Temp. (°C)	Speed (°C/s)	End Temp. (°C)	Speed (°C/s)	Temp. (°C)	Time (sec)	Reduction (%)
1	A	420	818	852	692	12	122	102	185	520	0.10
2	A	423	818	862	695	8	120	103	192	515	0.11
3	B	670	817	856	700	17	121	78	275	515	0.08
4	B	450	817	790	650	16	123	56	210	520	0.07

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(continued)

Specimen No .	Steel Type	Coiling	Ac3 (°C)	Annealing	1st Cooling		2nd Cooling		Over-aging Treatment		Tension Leveling
		Temp. (°C)		Temp. (°C)	End Temp. (°C)	Speed (°C/s)	End Temp. (°C)	Speed (°C/s)	Temp. (°C)	Time (sec)	Reduction (%)
5	C	550	826	858	703	12	122	152	205	530	0.12
10	C	580	826	856	698	11	131	145	204	515	0.11
	D	450	819	859	695	8	128	131	203	505	0.15
	D	490	819	862	670	7	350	55	195	520	0.35
15	E	470	818	863	700	9	125	128	187	490	0.13
	E	465	818	810	702	22	126	85	192	485	0.09
	F	490	822	859	703	13	122	86	178	512	0.08
	F	480	822	849	701	11	121	88	182	516	0.07
20	G	550	848	865	706	10	145	45	352	540	0.32
	G	560	848	864	700	8	146	50	326	535	0.33
	H	700	851	842	703	6	151	120	182	580	0.35
	H	715	851	835	701	7	142	115	198	560	0.36
25	H	470	851	856	695	8	105	123	178	523	0.11

$$Ac3 = 910 - 203\sqrt{[C]} - 15.2[Ni] + 44.7[Si] + 104[V] + 31.5[Mo] + 13.1[W]$$

[Formula]

(In the formula, [C], [Ni], [Si], [V], [Mo], and [W] are the weight % of each element.)

[0095] Table 3 shows the observation of the microstructure and mechanical properties of the manufactured steel sheets.

[0096] First, the fractions of ferrite and bainite were measured and shown in the microstructure in a region up to 30 μm from the surface of the steel sheet toward the center of the thickness. A cross-section parallel to the rolling direction was mechanically polished and nital etched, and the ferrite and bainite in a region up to 30 μm from the surface of the steel sheet toward the center of the thickness were observed with a scanning electron microscope (SEM) at 4 fields of view (i.e., measured at 4 points in the thickness direction for a region up to 30 μm from the surface). That is, the area fraction of each structure was obtained by image analysis of SEM images at a magnification of 2000x, and the average area fraction was obtained by calculating the arithmetic mean of the area fractions obtained from each of the 4 fields of view. In addition to ferrite and bainite, martensite or tempered martensite was observed.

[0097] In addition, the yield strength (YS), tensile strength (TS), and elongation (El) were measured and shown by a tensile test. The tensile test was performed by cutting a JIS No. 5 tensile test piece at a 1/4 point in the width direction of the steel sheet so that the direction perpendicular to the rolling direction on the surface of the steel sheet became the longitudinal direction, and performing a tensile test (JIS Z2241).

[0098] The bendability (R/t) value was measured through a bending test. The bending test was performed by cutting a strip-shaped test piece of 100 mm in the direction perpendicular to the rolling direction and 35 mm in the rolling direction at a 1/4 point in the width direction of the steel sheet, on the surface of the steel sheet, and using a jig with a tip inner angle of 90°. The limit bending radius (R/t) was calculated by changing the radius of curvature of the tip inner angle of the jig, finding the minimum jig tip inner angle at which no cracks were observed on the surface of the test piece, and dividing the obtained radius (R) by the sheet thickness (t). The smaller this value, the better the bendability. The determination of cracks was performed by observing with a stereomicroscope at a maximum magnification of 20x and measuring the length of the cracks. A minute crack of less than 0.1 mm was difficult to distinguish from surface irregularities with a stereomicroscope, so a crack of 0.1 mm or more was judged as a fracture.

[0099] Residual stress was measured and analyzed by utilizing the principle of measuring and calculating the lattice spacing by X-ray diffraction on the surface of a polycrystalline material by irradiating characteristic X-rays and X-ray diffraction according to Bragg's law. The residual stress at the 1/2 point in the thickness direction of the steel sheet was measured by grinding and removing up to the 1/2 point in the thickness direction, and then heat-treating at 200°C for 1 hour to completely remove the residual stress, and then measuring it as a representative value.

[0100] The presence or absence of hydrogen embrittlement was evaluated by preparing a test piece of 10 mm in the direction perpendicular to the rolling direction and 35 mm in the rolling direction, performing V-bending, fixing both sides using a jig, and then immersing it in 0.1N hydrochloric acid (HCl) for 300 hours to determine the presence or absence of cracks.

[Table 3]

Specimen No.	Steel Type	Microstructure	Mechanical Properties						Classification
		F+B Fraction (area%)	YS (MPa)	TS (MPa)	El (%)	Bendability (R/t)	Residual Stress Ratio a/b*100 (%)	Hydrogen Embrittlement Occurrence	
1	A	3.5	1218	1532	8.2	3.1	96.5	X	Invention Ex. 1
2	A	3.5	1215	1526	8.1	3.1	95.6	X	Invention Ex. 2
3	B	8.5	1225	1526	7.8	4.5	85.0	X	Comparative Ex. 1
4	B	9.2	1220	1535	7.6	3.7	82.0	○	Comparative Ex. 2
5	C	2.8	1225	1541	7.3	3.2	96.1	X	Invention Ex. 3
6	C	3.6	1226	1539	7.2	3.2	96.2	X	Invention Ex. 4
7	D	3.7	1285	1595	7.6	3.1	95.8	X	Invention Ex. 5
8	D	9.5	1286	1596	7.5	4.5	88.0	X	Comparative Ex. 3
9	E	3.5	1275	1585	6.8	3.3	96.3	X	Invention Ex. 6
10	E	4.8	1281	1586	6.5	3.9	92.0	○	Comparative Ex. 4
11	F	3.4	1276	1593	6.8	3.2	95.8	X	Invention Ex. 7
12	F	2.9	1301	1601	6.7	2.8	97.2	X	Invention Ex. 8
13	G	4.5	1312	1602	5.9	4.6	87.0	X	Comparative Ex. 5
14	G	3.8	1302	1612	5.8	4.5	88.0	○	Comparative Ex. 6
15	H	7.2	1286	1596	5.9	4.9	78.0	X	Comparative Ex. 7
16	H	7.6	1283	1589	5.9	4.9	77.0	○	Comparative Ex. 8
17	H	2.8	1295	1601	6.2	4.8	87.0	○	Comparative Ex. 9

[0101] * F: Ferrite, B: Bainite, Residual stress ratio a/b*100: Ratio of residual stress (a) at 1/2 point in the thickness direction of the steel sheet to residual stress (b) in a region from the surface toward the center of the thickness up to 30μm. As shown in Table 3, in the case of the invention examples that satisfied the alloy composition and manufactur-

ing conditions of the present disclosure, the microstructure characteristics proposed in the present disclosure were satisfied, and the target properties in the present disclosure could also be secured.

[0102] FIG. 1 is a graph showing the bendability value according to the sum of the fractions of ferrite and bainite (F+B) in a region up to 30 μm from the surface toward the center of the thickness. As shown in FIG. 1, it was confirmed that when the fraction of ferrite and bainite exceeds 5%, the bendability deteriorates.

[0103] On the other hand, Comparative Examples 1 to 9 are examples that did not satisfy the alloy composition or manufacturing conditions proposed in the present disclosure. As a result, the microstructure proposed in the region from the surface of the steel sheet to 30 μm toward the center of the thickness was not secured, and all of the target properties such as bendability, residual stress, and resistance to hydrogen embrittlement were not secured.

[0104] Although the present disclosure has been described in detail through the above examples, other forms of embodiments are also possible. Therefore, the technical spirit and scope of the claims described below are not limited to the examples.

Claims

1. A cold-rolled steel sheet, comprising, by weight %:

carbon (C): 0.20 to 0.30%;

silicon (Si): 0.5% or less;

manganese (Mn): 1.5 to 3.5%;

boron (B): 0.0005 to 0.0030%;

phosphorus (P): 0.010% or less;

sulfur (S): 0.010% or less;

nitrogen (N): 0.010% or less;

aluminum (Al): 0.010 to 0.100%;

chromium (Cr): 0.20% or less;

molybdenum (Mo): 0.10% or less;

niobium (Nb): 0.010 to 0.100%; and

titanium (Ti): 0.010 to 0.100%,

with a balance being iron (Fe) and other unavoidable impurities,

wherein a ratio $a/b \times 100$ of a residual stress (a) at a 1/2 point in a thickness direction of the steel sheet to a residual stress (b) in a region up to 30 μm from a surface toward a center of the thickness is 95.0% or more.

2. The cold-rolled steel sheet of claim 1, further comprising at least one of vanadium (V): 0.01 to 0.10% and antimony (Sb): 0.10% or less.

3. The cold-rolled steel sheet of claim 1, wherein a microstructure in a region up to 30 μm from the surface toward the center of the thickness mainly comprises at least one of martensite and tempered martensite, and comprises, by area %, a sum of ferrite and bainite of 5.0% or less.

4. The cold-rolled steel sheet of claim 1, wherein the cold-rolled steel sheet has a tensile strength of 1500 MPa or more and a bendability (R/t) of 3.5 or less.

5. A method for manufacturing a cold-rolled steel sheet, the method comprising:

reheating a steel slab comprising, by weight %: carbon (C): 0.20 to 0.30%, silicon (Si): 0.5% or less, manganese (Mn): 1.5 to 3.5%, boron (B): 0.0005 to 0.0030%, phosphorus (P): 0.010% or less, sulfur (S): 0.010% or less, nitrogen (N): 0.010% or less, aluminum (Al): 0.010 to 0.100%, chromium (Cr): 0.20% or less, molybdenum (Mo): 0.10% or less, niobium (Nb): 0.010 to 0.100%, and titanium (Ti): 0.010 to 0.100%, with a balance being iron (Fe) and other unavoidable impurities;

hot-rolling the reheated steel slab;

coiling the hot-rolled steel sheet in a temperature range of 400°C to 600°C;

cold-rolling the coiled steel sheet;

annealing the cold-rolled steel sheet in a temperature range of $\text{Ac}_3 + 10^\circ\text{C}$ to $\text{Ac}_3 + 80^\circ\text{C}$;

primarily cooling the annealed steel sheet to a temperature range of 680°C to 750°C at an average cooling

rate of 20°C/s or less;

secondarily cooling the primarily cooled steel sheet to a temperature range of 100°C to Mf at an average cooling rate of 70 to 200°C/s;

over-aging the secondarily cooled steel sheet in a temperature range of 150°C to 240°C; and temper rolling or tension leveling the over-aged steel sheet at a reduction ratio of 0.01 to 0.20%.

6. The method of claim 5,
wherein the steel slab further comprises at least one of vanadium (V): 0.01 to 0.1% and antimony (Sb): 0.1% or less.

7. The method of claim 5,

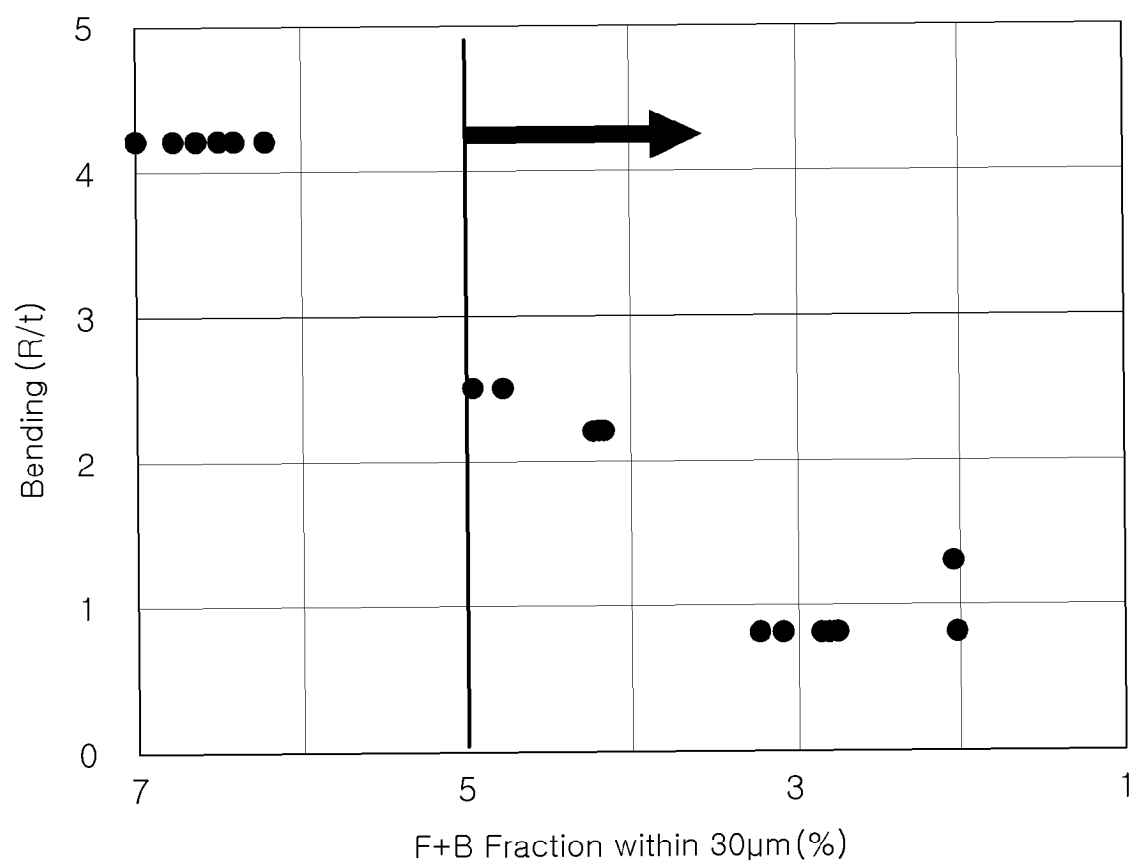
wherein the reheating is performed in a temperature range of 1100°C to 1300°C,

the hot-rolling is performed in a temperature range of Ar3 or higher, and

the cold-rolling is performed at a reduction ratio of 30 to 80%.

8. The method of claim 5,
wherein the annealing is performed for 30 seconds or more, and the over-aging is performed for 200 seconds or more.

[FIG. 1]



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/020397

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/38(2006.01)i; C22C 38/22(2006.01)i; C22C 38/32(2006.01)i; C22C 38/06(2006.01)i; C22C 38/00(2006.01)i;
C22C 38/26(2006.01)i; C22C 38/28(2006.01)i; C22C 38/24(2006.01)i; C21D 8/02(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/38(2006.01); B21C 47/02(2006.01); C21D 1/30(2006.01); C21D 8/02(2006.01); C21D 9/46(2006.01);
C22C 38/00(2006.01); C22C 38/04(2006.01); C22C 38/14(2006.01); C22C 38/32(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: 조질압연(skin pass), 텐션 레벨링(tension leveling), 굽힘성지수(R/t), 소둔
(annealing), 인장강도(tensile strength), 탄소(carbon), 망간(Mn), 마르텐사이트(martensite)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	KR 10-2021-0149841 A (JFE STEEL CORPORATION) 09 December 2021 (2021-12-09) See paragraphs [0068], [0110]-[0112] and [0149]-[0161], claims 1-14 and table 5.	1-8
Y	KR 10-2023-0056822 A (POSCO) 28 April 2023 (2023-04-28) See claims 7-10.	1-8
A	KR 10-2403767 B1 (HYUNDAI STEEL COMPANY) 30 May 2022 (2022-05-30) See claims 4-11.	1-8
A	JP 5810499 B2 (JFE STEEL CORP.) 11 November 2015 (2015-11-11) See paragraphs [0048]-[0054].	1-8
A	KR 10-1758485 B1 (POSCO) 17 July 2017 (2017-07-17) See claims 1-6 and 8.	1-8

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

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

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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

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2024/020397

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