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(54) **STEEL SHEET AND MANUFACTURING METHOD THEREFOR**

(57) An aspect of the present invention provides a steel sheet. The steel sheet comprises, in weight%, C: 0.25-0.55%, Si: 3.0% or less, Mn: 0.9-3.4%, Al: 3.0% or less, P: 0.15% or less, S: 0.03% or less, N: 0.03% or less, B: 0.0015-0.005%, and the balance being Fe and

inevitable impurities, wherein the microstructure includes tempered martensite, bainite, and retained austenite, and the value of W may be 0.08 or more as defined by Relational Expression 1.

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Description

Technical Field

5 **[0001]** The present disclosure relates to a steel sheet and a method for manufacturing the same.

Background Art

10 **[0002]** Recently, in the automotive industry, in order to protect the global environment, weight reduction of a material has been promoted, and measures to secure passenger stability have also received attention. In order to meet the requirements for stability and weight reduction, demand for a high-strength steel sheet is increasing.

[0003] In general, as the steel sheet has higher strength, its ductility and workability are reduced, and thus, in the steel sheet for automobile parts, a steel sheet having excellent ductility and workability as well as excellent strength is required.

15 **[0004]** As a technology to improve ductility of a steel sheet, a method of using tempered martensite is disclosed in Patent Documents 1 and 2. Tempered martensite made by tempering hard martensite is softened martensite and shows a difference in strength from previous untempered martensite (fresh martensite). When fresh martensite is suppressed and tempered martensite is formed, ductility and workability are increased.

20 **[0005]** However, the technologies disclosed in Patent Documents 1 and 2 suggest that the product of tensile strength and elongation rate (TSYEI) does not satisfy 22,000 MPa%, and it is difficult to secure a steel sheet having both excellent strength and ductility.

25 **[0006]** Meanwhile, a transformation induced plasticity (TRIP) steel using transformation induced plasticity of retained austenite has been developed in order to obtain all characteristics of high strength and excellent ductility and workability of a steel sheet for automobile parts. Patent Documents 3 and 4 disclose TRIP steels having excellent ductility and workability.

[0007] Patent Document 3 discloses a technology for improving ductility and workability by including polygonal ferrite with retained austenite and martensite. However, it was found that in Patent Document 3, since bainite was included as a main phase, high strength was not secured, and the product of tensile strength and elongation rate (TSYEI) did not satisfy 22,000 MPa% or more.

30 **[0008]** Patent Document 4 discloses a technology for improving ductility and workability by promoting ferrite formation and residual austenite refining and forming a composite structure including tempered martensite. However, Patent Document 4 has a problem in that it is difficult to secure high strength due to a large amount of soft ferrite inclusions.

[0009] Thus, demand for a steel sheet having excellent ductility while having high strength is not being met.

35 (Patent Document 1) Korean Patent Laid-Open Publication No. 10-2006-0118602

(Patent Document 2) Japanese Patent Laid-Open Publication No. 2009-019258

(Patent Document 3) Korean Patent Laid-Open Publication No. 10-2014-0012167

(Patent Document 4) Korean Patent Laid-Open Publication No. 10-2010-0092503

40 Summary of Invention

Technical Problem

45 **[0010]** An aspect of the present disclosure is to provide a steel sheet having excellent elongation rate and hole expandability, and a method for manufacturing the same.

[0011] An object of the present disclosure is not limited to the above description. Additional objects of the present disclosure are described throughout the specification, and any person with ordinary skill in the art to which the present disclosure pertains has no difficulty in understanding of the additional object of the present disclosure from the description in the specification of the present disclosure.

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Solution to Problem

55 **[0012]** According to an aspect of the present disclosure, a steel sheet is provided. The steel sheet may comprises, by weight: 0.25 to 0.55% of C, 3.0% or less (excluding 0%) of Si, 0.9 to 3.4% of Mn, 3.0% or less (excluding 0%) of Al, 0.15% or less (excluding 0%) of P, 0.03% or less (excluding 0%) of S, 0.03% or less (excluding 0%) of N, 0.0015 to 0.005% of B, a balance of Fe, and inevitable impurities, wherein the microstructure includes tempered martensite, bainite, and retained austenite, and a value of W defined by the following Relation 1 is 0.08 or more:

[Relation 1]

$$W = TTS \times 100 \times B$$

wherein TTS is a value calculated based on the following Relation 2 after measuring a thickness before rupture and a thickness after rupture of a specimen performed by a test method of the tensile test JIS 5 standard, and B is a content (wt%) of boron included in the steel sheet,

[Relation 2]

$$TTS = \ln(t_0/t_1)$$

wherein t_0 is a thickness before rupture of a specimen performed by a test method of the tensile test JIS 5 standard, and t_1 is a thickness after rupture of a specimen.

[0013] In addition, in the steel sheet described above, the sum of contents of Si and Al may be 1.0 to 6.0%.

[0014] In addition, in one of the steel sheets described above, the steel sheet may further comprise one or more selected from the following (1) to (3):

- (1) one or more of 0 to 0.5% of Ti, 0 to 0.5% of Nb, and 0 to 0.5% of V,
- (2) one or more of 0 to 3.0% of Cr and 0 to 3.0% of Mo,
- (3) one or more of 0 to 4.5% of Cu and 0 to 4.5% of Ni.

[0015] In addition, in one of the steel sheets described above, an area fraction of the tempered martensite may be 30 to 85%, an area fraction of the bainite may be 10 to 50%, and an area fraction of the retained austenite may be 10 to 40%, of the total area fraction of the microstructure.

[0016] In addition, in one of the steel sheets described above, the microstructure may further include ferrite, and the area fraction of the ferrite may be 5% or less of the total area fraction of the microstructure.

[0017] In addition, in one of the steel sheets described above, the steel sheet may have a product of tensile strength and elongation rate ($TS \times El$) of 22,000 MPa% or more and a HER value of 20% or more.

[0018] According to another aspect of the present disclosure, a method for manufacturing a steel sheet is provided. The method may comprise: reheating a steel slab comprising, by weight: 0.25 to 0.55% of C, 3.0% or less (excluding 0%) of Si, 0.9 to 3.4% of Mn, 3.0% or less (excluding 0%) of Al, 0.15% or less (excluding 0%) of P, 0.03% or less (excluding 0%) of S, 0.03% or less (excluding 0%) of N, 0.0015 to 0.005% of B, a balance of Fe, and inevitable impurities; finish hot rolling the reheated steel slab; winding the finish hot rolled steel sheet; heat treating the wound steel sheet by hot rolling annealing in a temperature range of 500 to 850°C for 600 to 85000 seconds; cold rolling the steel sheet which is heat treated by hot rolling annealing; first heating the cold rolled steel sheet at a first heating temperature of A_{c1} or higher, and first maintaining the steel sheet for 120 seconds or more; first cooling the first heated steel sheet to a first cooling temperature of 100 to 300°C at an average cooling rate of 20°C/s or more; second heating the first cooled steel sheet to a second heating temperature of 300 to 500°C, and second maintaining the steel sheet for 300 to 90000 seconds; and second cooling the second heated steel sheet to room temperature.

[0019] In addition, in the method described above, in the reheating step, the sum of the contents of Si and Al of the steel slab may be 1.0 to 6.0%.

[0020] In addition, in one of the methods described above, in the reheating step, the steel slab may further comprise one or more selected from the following (1) to (3):

- (1) one or more of 0 to 0.5% of Ti, 0 to 0.5% of Nb, and 0 to 0.5% of V,
- (2) one or more of 0 to 3.0% of Cr and 0 to 3.0% of Mo,
- (3) one or more of 0 to 4.5% of Cu and 0 to 4.5% of Ni.

[0021] In addition, in one of the methods described above, the reheating step may be performed at 1000 to 1350°C, and the finish hot rolling step may be performed at 800 to 1000°C.

[0022] In addition, in one of the methods described above, in the winding step, the finish hot rolled steel sheet may

be cooled to 300 to 700°C at an average cooling rate of 10°C/s or more and then wound.

[0023] In addition, in one of the methods described above, the cold rolling step may be performed at a reduction rate of 20 to 90%.

[0024] In addition, in one of the methods described above, in the first maintaining step, the cold rolled steel sheet may be heated to the first heating temperature at an average heating rate of 10°C/s or more.

[0025] In addition, in one of the methods described above, in the second maintaining step, the first cooled steel sheet may be heated to the second heating temperature at an average heating rate of 15°C/s or more.

[0026] In addition, in one of the methods described above, in the second cooling step, the second heated steel sheet may be cooled to room temperature at an average cooling rate of 1°C/s or more.

Advantageous Effects of Invention

[0027] According to the present disclosure, a high-strength steel sheet having excellent elongation rate and hole expandability, and a method for manufacturing the same may be provided.

[0028] In addition, according to the present disclosure, since the steel sheet may secure excellent strength, ductility, and working characteristics, it may be appropriately used as a steel sheet for an automobile structure requiring both lightweight and stability.

[0029] Various and beneficial merits and effects of the present disclosure are not limited to the descriptions above and may be more easily understood in a process of describing specific example embodiments in the present disclosure.

Best Mode for Invention

[0030] Hereinafter, the preferred example embodiments in the present disclosure will now be described in detail. However, the example embodiments in the present disclosure may be modified in many different forms, and the terms used in the present specification are for describing the present disclosure and are not intended to limit the present disclosure. In addition, a singular form used in the present specification includes a plural form also, unless the relevant definition has a clearly opposite meaning thereto.

[0031] In the present specification, the term "comprising" is used to indicate further inclusion of other constituent elements rather than exclusion of other constituent elements, unless otherwise particularly stated.

[0032] In addition, unless otherwise defined in the specification of the present disclosure, % unit refers to wt%.

[0033] Unless otherwise defined, all terms including technical terms and scientific terms used in the present specification have the same meaning as commonly understood by a person with ordinary skill in the art to which the present disclosure pertains. Pre-defined terms are interpreted as being consistent with the relevant technical literature and the disclosure herein.

[0034] The inventors of the present disclosure recognized that strength, ductility, and workability may be adjusted by promoting stability of retained austenite and controlling the content, size, and the like of retained austenite, in transformation induced plasticity (TRIP) steel including bainite, tempered martensite, and retained austenite. Thus, the present inventors confirmed a method for improving the ductility and workability of a high-strength steel sheet, thereby completing the present disclosure.

[0035] First, an alloy composition of the steel sheet according to an example embodiment in the present disclosure will be described. The content of the alloy composition is wt%, unless otherwise stated.

Carbon (C): 0.25 to 0.55%

[0036] Carbon (C) is an element for imparting strength of a steel sheet and may stabilize retained austenite which increases ductility of a steel sheet. When the content of C is less than 0.25%, it may be difficult to secure tensile strength to be desired. In addition, when the content of C is more than 0.55%, cold rolling may be difficult during manufacture of a steel sheet. That is, the content of C may be 0.25 to 0.55%, more specifically 0.28 to 0.45%, and still more specifically 0.30 to 0.40%.

Silicon (Si): 3.0% or less (excluding 0%)

[0037] Silicon (Si) is an element having an effect of improving strength by solid solution strengthening, and may strengthen ferrite, homogenize the structure, and improve workability. In addition, silicon (Si) may suppress cementite precipitation to contribute to production of retained austenite. When the content of Si is more than 3.0%, a problem in plating defects such as unplating may occur in a plating process, or weldability of a steel sheet may be deteriorated, during manufacture of a steel sheet. That is, the content of Si may be 3.0% or less, more specifically 2.8% or less, and

more specifically 2.5% or less. Though the lower limit of the content of Si does not need to be particularly limited, as a non-limiting example, the content of Si may be 0.5% or more, 0.7% or more, or 1.0% or more.

Manganese (Mn): 0.9 to 3.5%

[0038] Manganese (Mn) may improve strength and ductility together. When the content of Mn is less than 0.9%, it may be difficult to sufficiently secure the effect described above. In addition, when the content of Mn is more than 3.5%, a bainite transformation time is increased, and thus, C concentration in austenite is not sufficient, and it may be difficult to sufficiently secure the fraction of retained austenite. That is, the content of Mn may be 0.9 to 3.5%, more specifically 1.0 to 3.3%, and still more specifically 1.5 to 3.0%.

Aluminum (Al): 3.0% or less (excluding 0%)

[0039] Aluminum (Al) may be bonded to oxygen in steel to perform a deoxidizing function. In addition, aluminum (Al) may suppress cementite precipitation to stabilize retained austenite. When the content of Al is more than 3.0%, workability of a steel sheet is deteriorated, and inclusion may be increased. Though the lower limit of the content of Al does not need to be particularly limited, as a non-limiting example, the content of Al may be 0.015% or more, 0.020% or more, or 0.050% or more.

Phosphorus (P): 0.15% or less (excluding 0%)

[0040] Phosphorus (P) may be included as an impurity and deteriorate impact toughness. That is, the content of P may be 0.15% or less, more specifically 0.10% or less, and still more specifically 0.08% or less. Though the lower limit of the content of P does not need to be particularly limited, as a non-limiting example, the content of P may be 0.0001% or more, 0.0003% or more, or 0.0005% or more.

Sulfur (S): 0.03% or less (excluding 0%)

[0041] Sulfur (S) may be included as an impurity, and form MnS in a steel sheet and deteriorate ductility. That is, the content of S may be 0.03% or less, more specifically 0.01% or less, and still more specifically 0.008% or less. Though the lower limit of the content of S does not need to be particularly limited, as a non-limiting example, the content of S may be 0.001% or more, 0.002% or more, or 0.003% or more.

Nitrogen (N): 0.03% or less (excluding 0%)

[0042] Nitrogen (N) may be included as an impurity and form a nitride during continuous casting to cause cracks of a slab. That is, the content of N may be 0.03% or less, more specifically 0.01% or less, and still more specifically 0.008% or less. Though the lower limit of the content of N does not need to be particularly limited, as a non-limiting example, the content of N may be 0.001% or more, 0.002% or more, or 0.003% or more.

Boron (B): 0.0015 to 0.005%

[0043] Boron (B) may strengthen a particle boundary to have crack resistance of LME and hydrogen embrittlement, and also suppress ferrite transformation during cooling after annealing. In addition, boron (B) may improve a hole expansion ratio (HER) value through resistance to intergranular fracture. When the content of B is less than 0.0015%, it may be difficult to sufficiently secure the effect described above. In addition, when the content of B is more than 0.005%, hot rollability may be deteriorated, and B may be excessively accumulated on the surface to deteriorate platability. That is, the content of B may be 0.0015 to 0.005%, specifically 0.0015 to 0.0050%, more specifically 0.0016 to 0.0040%, and still more specifically 0.0018 to 0.0035%.

[0044] The steel sheet for hot forming according to an example embodiment in the present disclosure may comprise iron (Fe) as a remaining component, while including the components. In addition, since in a common manufacturing process, unintended impurities may be inevitably incorporated from raw materials or the surrounding environment, it may not be excluded. Since these impurities are known to any person skilled in the common manufacturing process, the entire description thereof is not particularly mentioned in the present specification.

[0045] As an example, the sum of Si and Al of the steel sheet may be 1.0 to 6.0%. Si and Al are components which affect microstructure formation to affect ductility and bending workability. When the sum of the contents of Si and Al is within the above range, excellent ductility and bending workability may be secured.

[0046] When the sum of the contents of Si and Al is less than 1.0%, it may be difficult to sufficiently secure the effect

described above. In addition, when the sum of the contents of Si and Al is more than 6.0%, an oxide is excessively formed during hot rolling to deteriorate operability and also lower continuous castability. That is, the sum of the contents of Si and Al may be sum 1.0 to 6.0%, more specifically 1.2 to 5.0%, and still more specifically 1.5 to 4.0%.

[0047] As an example, the steel sheet may further comprise one or more selected from the following (1) to (3):

(1) one or more of titanium (Ti): 0 to 0.5%, niobium (Nb): 0 to 0.5%, and vanadium (V): 0 to 0.5%

[0048] Titanium (Ti), niobium (Nb), and/or vanadium (V) may form a precipitate to refine crystal grains. In addition, Titanium (Ti), niobium (Nb), and/or vanadium (V) may improve strength and impact toughness of a steel sheet. When the content of Ti, Nb, or V is more than 0.5%, an excessive precipitate is formed, so that impact toughness may be lowered, and also an increase in manufacturing costs may be caused. That is, the content of Ti, Nb, or V may be 0.5% or less, more specifically 0.4% or less, and still more specifically 0.3% or less.

(2) One or more of chromium (Cr): 0 to 3.0% and molybdenum (Mo): 0 to 3.0%

[0049] Chromium (Cr) and/or molybdenum (Mo) may suppress austenite decomposition and stabilize austenite in an alloying process during manufacture of a steel sheet. When the content of Cr or Mo is more than 3.0%, a bainite transformation time is increased, and thus, C concentration in austenite is not sufficient, and it may be difficult to sufficiently secure the fraction of retained austenite. That is, the content of Cr or Mo may be 3.0% or less, more specifically 2.5% or less, and still more specifically 2.0% or less.

(3) One or more of copper (Cu): 0 to 4.5% and nickel (Ni): 0 to 4.5%

[0050] Copper (Cu) and/or nickel (Ni) may stabilize austenite and suppress corrosion. In addition, copper (Cu) and/or nickel (Ni) may be concentrated on the surface of a steel sheet and prevent intrusion of hydrogen moving into the steel sheet to suppress hydrogen delayed fracture. When the content of Cu or Ni is more than 4.5%, the characteristic effect may be excessively shown, and also an increase in manufacturing costs may be caused. That is, the content of Cu or Ni may be 4.5% or less, more specifically 3.0% or less, and still more specifically 2.0% or less.

[0051] Hereinafter, the microstructure of the steel sheet according to an example embodiment in the present disclosure will be described. The fraction of the microstructure refers to % by area unless otherwise stated. In addition, the fraction of the microstructure may be measured by analyzing a matrix structure at a 1/4 point of the thickness of the steel sheet, and specifically, the fraction of the microstructure may be measured using FE-SEM, Image analyzer, and XRD.

[0052] The microstructure of the steel sheet may include tempered martensite, bainite, and retained austenite.

[0053] Tempered martensite may improve strength of the steel sheet. Specifically, both untempered martensite (fresh martensite) and tempered martensite may improve the strength of the steel sheet. Of the two, since tempered martensite is not softened by a tempering heat treatment, fresh martensite may lower the ductility of the steel sheet, as compared with the tempered martensite. That is, a steel sheet having an improved balance of strength and ductility and having excellent workability may be provided, using the tempered martensite.

[0054] As an example, an area fraction of the tempered martensite may be 30 to 85% of the total area fraction of the microstructure. When the area fraction of the tempered martensite is less than 30%, it may be difficult to secure the product of tensile strength and elongation rate (TS×EI) of 22,000 MPa% or more. In addition, when the area fraction of tempered martensite is more than 85%, ductility and workability may be lowered, and the product of tensile strength and elongation rate (TS×EI) may be less than 22,000 MPa% or a HER value may be less than 20%. That is, the area fraction of tempered martensite may be 30 to 85%, and more specifically 35 to 80%, and still more specifically 40 to 75%.

[0055] Bainite may improve a balance of strength and ductility of the steel sheet and improve workability of the steel sheet. For example, the area fraction of bainite may be 10 to 50% of the total area fraction of the microstructure. When the area fraction of bainite is less than 10%, the product of tensile strength and elongation rate (TS×EI) may be less than 22,000 MPa% or the HER value may be less than 20%. In addition, the area fraction of bainite is more than 50%, the area fraction of tempered martensite is relatively decreased, and thus, it may be difficult to sufficiently secure the product of tensile strength and elongation rate (TS×EI). That is, the area fraction of bainite may be 10 to 50%, more specifically 15 to 45%, and still more specifically 20 to 40%.

[0056] Retained austenite produces transformation induced plasticity in transformation from austenite to martensite during steel sheet working, and thus, may improve ductility and workability. For example, the area fraction of retained austenite may be 10 to 40% of the total area fraction of the microstructure. When the area fraction of retained austenite is within the range, a balance of strength and ductility of the steel sheet is improved, and the workability of the steel sheet may also be improved.

[0057] When the area fraction of retained austenite is less than 10%, the product of tensile strength and elongation rate (TS×EI) may be less than 22,000 MPa% or the HER value may be less than 20%. In addition, the area fraction of retained austenite is more than 40%, a local elongation rate may be lowered. That is, the area fraction of retained austenite may be 10 to 40%, more specifically 12 to 35%, and still more specifically 15 to 30%.

[0058] As an example, the microstructure of the steel sheet may further include ferrite. For example, the area fraction of ferrite may be 5% or less of the total area fraction of the microstructure. When the area fraction of ferrite is more than 5%, a soft phase is introduced to increase an interphase hardness difference, and thus, it may be difficult to sufficiently secure hole expandability.

[0059] As an example, the microstructure of the steel sheet may further include an inevitable structure. In an embodiment in the present disclosure, the inevitable structure may include fresh martensite, pearlite, martensite austenite constituent (M-A), and the like. For example, the area fraction of the inevitable structure may be 20% or less of the total area fraction of the microstructure. When the area fraction of the inevitable structure is more than 20%, the ductility and workability of the steel sheet may be deteriorated, or the area fraction of the retained austenite may be decreased.

[0060] The steel sheet according to an example embodiment in the present disclosure may stabilize retained austenite to secure excellent ductility and workability as well as high strength. In general, C and Mn may be concentrated into austenite in ferrite, bainite, and tempered martensite of the steel sheet, thereby stabilizing retained austenite. However, when C is concentrated into austenite using ferrite, the strength of the steel sheet may be lowered due to the low strength characteristic of ferrite.

[0061] In an example embodiment in the present disclosure, since C and Mn are concentrated into austenite in bainite and tempered martensite of the steel sheet to stabilize retained austenite, the problem described above may be solved. When the concentration of C and Mn into retained austenite is not sufficient, retained austenite is unstable to tensile deformation to cause deterioration of ductility and workability, and the product of tensile strength and elongation rate (TS×EI) may be less than 22,000 MPa% or the HER value may be less than 20%.

[0062] The steel sheet according to an example embodiment in the present disclosure may have the product of tensile strength and elongation rate (TS×EI) of 22,000 MPa% or more. Additionally, the steel sheet may have the HER value of 20% or more. Herein, the HER value may be calculated by the formula of [(maximum diameter - initial diameter)/initial diameter × 100], after punching a hole having an initial diameter of 10 mm in the center of rolled steel material of 120 mm×120 mm, pushing it up in a conical shape, and measuring a maximum diameter having no crack observed by the naked eye. Since the product of tensile strength and elongation rate (TS×EI) and the HER value of the steel sheet satisfy the ranges, a steel sheet having an excellent balance of strength and ductility may be provided.

[0063] The steel sheet according to an example embodiment in the present disclosure may have a W value defined by the following Relation 1 of 0.08 or more:

[Relation 1]

$$W = TTS \times 100 \times B$$

wherein TTS is a value calculated based on the following Relation 2 after measuring a thickness before rupture and a thickness after rupture of a specimen performed by a test method of the tensile test JIS 5 standard, and B is a content (wt%) of boron included in the steel sheet,

[Relation 2]

$$TTS = \ln(t_0/t_1)$$

wherein t_0 is a thickness before rupture of a specimen performed by a test method of the tensile test JIS 5 standard, and t_1 is a thickness after rupture of a specimen.

[0064] The W value defined in Relation 1 is an equation which quantitatively expresses that the strength of a steel sheet and the content of B may contribute to the physical properties (for example, ductility, hole expandability, workability, and the like) of the steel sheet. When the W value is less than 0.08, the strength of the steel sheet and/or the content of B is/are low, and thus, resistance to intergranular fracture is insufficient, so that it may be difficult to

sufficiently secure hole expandability. That is, the W value may be 0.08 or more, specifically 0.080 or more, more specifically 0.085 or more, and still more specifically 0.090 or more.

[0065] Hereinafter, a method for manufacturing a steel sheet according to an example embodiment in the present disclosure will be described in detail. However, it does not mean that the steel sheet according to an example embodiment in the present disclosure should be necessarily manufactured by the following manufacturing method.

[Steel slab reheating]

[0066] A steel slab having the composition described above may be reheated. Herein, the composition of the steel slab is the same as the composition of the steel sheet described above, and the above description of the steel sheet may be identically applied to the reason for adding each component and the reason for limiting the content in the slab.

[0067] As an example, the reheating step may be performed at 1000 to 1350°C. When a reheating temperature is lower than 1000°C, hot rolling is performed at or below the finish hot rolling temperature section. When the reheating temperature is higher than 1350°C, it may reach the melting point of steel to cause fusion. That is, the reheating temperature may be 1000 to 1350°C, more specifically 1050 to 1300°C, and still more specifically 1100 to 1280°C.

[Finish hot rolling]

[0068] The reheated steel slab may be finish hot rolled. For example, the finish hot rolling may be performed at 800 to 1000°C. When the finish hot rolling temperature is lower than 800°C, a load may occur in a roller due to the high strength of steel. In addition, when the finish hot rolling temperature is higher than 1000°C, crystal grains of the steel sheet may be coarsened after hot rolling to deteriorate physical properties of the steel sheet. That is, the finish hot rolling temperature may be 800 to 1000°C, more specifically 830 to 980°C, and still more specifically 850 to 960°C.

[Cooling and winding]

[0069] The finish hot rolled steel sheet may be wound. For example, the winding step may be performed at 300 to 700°C. When the winding temperature is lower than 300°C, a winding process may not be easily performed. In addition, the winding temperature is higher than 700°C, scale produced on the surface of the hot rolled steel sheet is formed into the steel sheet, and thus, a pickling process becomes difficult. That is, the winding temperature may be 300 to 700°C, more specifically 350 to 680°C, and still more specifically 400 to 650°C.

[0070] As an example, the winding step may be performed by cooling the finish hot rolled steel sheet to the winding temperature range at an average cooling rate of 10°C/s or more and then winding. When the average cooling rate is less than 10°C/s, productivity of hot rolling may be lowered, or a cooling medium having poor cooling ability should be used during production.

[Heat treatment by hot rolling annealing]

[0071] The wound steel sheet may be heat treated by hot rolling annealing. Pickling and cold rolling after winding may be easily performed through the step of heat treatment by hot rolling annealing. For example, a temperature of heat treatment by hot rolling annealing may be 500 to 850°C. When the temperature of heat treatment by hot rolling annealing is lower than 500°C, strength of the steel sheet which is heat treated by hot rolling annealing is excessively increased, so that cold rolling may not be easily performed. In addition, when the temperature of heat treatment by hot rolling annealing is higher than 850°C, scale is formed deep into the steel sheet, and thus, the pickling process may become difficult. That is, the temperature of heat treatment by hot rolling annealing may be 500 to 850°C, more specifically 530 to 800°C, and still more specifically 550 to 750°C.

[0072] As an example, the heat treatment step by hot rolling annealing may be performed for 600 to 85000 seconds. When a time required for heat treatment by hot rolling annealing is less than 600 seconds, the strength of the steel sheet which is heat treated by hot rolling annealing is excessively increased, so that cold rolling may not be easily performed. When a time required for heat treatment by hot rolling annealing is more than 85000 seconds, scale is formed deep into the steel sheet, and thus, the pickling process may become difficult. That is, the time required for heat treatment by hot rolling annealing may be 600 to 85000 seconds, more specifically 3000 to 85000 seconds, and still more specifically 6000 to 85000 seconds.

[Cold rolling]

[0073] The steel sheet which is heat treated by hot rolling annealing may be cold rolled. For example, the cold rolling step may be performed at a reduction rate of 20 to 90%. When the reduction rate is less than 20%, it is difficult to

secure a target thickness, and shape correction of the steel sheet may be difficult. In addition, the reduction rate is more than 90%, strength of the steel sheet is excessively increased, and thus, it may be difficult to perform cold rolling within a short time. That is, the reduction rate may be 20 to 90%, more specifically 25 to 80%, and still more specifically 30 to 70%.

[0074] As an example, before the cold rolling step, a step of pickling the steel sheet which has been heat treated by hot rolling annealing may be further included. Through the pickling treatment, scale formed on the surface of the steel sheet may be removed. The pickling method is not particularly limited, and a method commonly used in the art (for example, adding a steel sheet into a hydrochloric acid bath) may be applied.

[0075] The method for manufacturing a steel sheet according to an example embodiment in the present disclosure may secure excellent strength, ductility, and workability, by performing a continuous annealing process after the cold rolling step. Hereinafter, a continuous annealing process will be described in detail.

[First heating and maintaining]

[0076] The cold rolled steel sheet is first heated at a first heating temperature of A_{c1} or higher and then first maintained at the first heating temperature. When the first heating temperature (or first maintaining temperature) is lower than A_{c1} , bainite, retained austenite, and tempered martensite are not sufficiently formed, and excessive ferrite is formed, so that it may be difficult to secure strength, ductility, hole expandability, and workability of the steel sheet. That is, the first heating temperature (or first maintaining temperature) may be A_{c1} or higher, more specifically $A_{c1}+10^{\circ}\text{C}$ or higher, and more specifically $A_{c1}+20^{\circ}\text{C}$ or higher. In addition, though the upper limit of the first heating temperature (or first maintaining temperature) is not particularly limited, in order to minimize a decrease in toughness due to crystal grain coarsening, the first heating temperature (or first maintaining temperature) may be 950°C or lower.

[0077] As an example, the cold rolled steel sheet may be first heated to the first heating temperature at an average heating rate of 10°C/s or more. When the average heating rate is less than 10°C/s , productivity may be decreased. Though the upper limit of the average heating rate is not particularly limited, the average heating rate may be 500°C/s or less.

[0078] As an example, the cold rolled steel sheet may be first maintained at the first heating temperature for 120 seconds or more. When the first maintenance time is less than 120 seconds, the structure is not sufficiently homogenized, thereby deteriorating the physical properties of the steel sheet. That is, the first maintenance time may be 120 seconds or more, more specifically 150 seconds or more, and still more specifically 180 seconds or more. Though the upper limit of the first maintenance time is not particularly limited, in order to minimize a decrease in toughness due to crystal grain coarsening, the first maintenance time may be 1200 seconds or less.

[First cooling]

[0079] The first heated and maintained steel sheet may be first cooled to the first cooling temperature of 100 to 300°C . When the first cooling temperature is lower than 100°C , tempered martensite is excessively formed, retained austenite is insufficient, and the product of tensile strength and elongation rate ($TS \times EI$) and the HER value of the steel sheet may be decreased. In addition, the first cooling temperature is higher than 300°C , bainite is excessively formed, tempered martensite is insufficient, and the product of tensile strength and elongation rate ($TS \times EI$) of the steel sheet may be decreased. That is, the first cooling temperature may be 100 to 300°C , more specifically 110 to 290°C , and still more specifically 120 to 280°C .

[0080] As an example, the first heated and maintained steel sheet may be first cooled to the first cooling temperature at the average cooling rate of 20°C/s or more. When the average cooling rate is less than 20°C/s , productivity may be decreased. Though the upper limit of the average cooling rate is not particularly limited, it may be 100°C/s or less.

[Second heating and maintaining]

[0081] First cooled steel sheet may be second heated to a second heating temperature of 300 to 500°C , and then second maintained at the second heating temperature. When the second heating temperature (or second maintaining temperature) is lower than 300°C , tempered martensite is excessively formed, control of the contents of Si and Al in the retained austenite is insufficient, it may be difficult to secure the area fraction of retained austenite, and thus, the product of tensile strength and elongation rate ($TS \times EI$) and the HER value of the steel sheet may be decreased. In addition, when the second heating temperature (or second maintaining temperature) is higher than 500°C , control of the Si content in the retained austenite is insufficient, and it may be difficult to secure the area fraction of retained austenite. That is, the second heating temperature (or second maintaining temperature) may be 300 to 500°C , more specifically 310 to 480°C , and still more specifically 320 to 460°C .

[0082] As an example, the steel sheet which is first cooled to the second heating temperature at the average heating

rate of 15°C/s or more may be second heated. When the average heating rate is less than 15°C/s, productivity may be decreased. Though the upper limit of the average heating rate is not particularly limited, the average heating rate may be 100°C/s or less.

[0083] As an example, the first cooled steel sheet may be second maintained at the second heating temperature for 300 seconds. When the second maintenance time is less than 300 seconds, tempered martensite is excessively formed, control of the contents of Si and Al in the retained austenite is insufficient, it may be difficult to secure the area fraction of retained austenite, and thus, the product of tensile strength and elongation rate (TS×EI) and the HER value of the steel sheet may be decreased. That is, the second maintenance time may be 300 seconds or more, more specifically 350 seconds or more, and still more specifically 400 seconds or more. In addition, when the second maintenance time is excessively high, control of the Si content in the retained austenite is insufficient, and it may be difficult to secure the area fraction of retained austenite. As a non-limiting example, the second maintenance time may be 90000 seconds or less.

[Second cooling]

[0084] The second heated and maintained steel sheet may be second cooled to room temperature. Herein, the room temperature may refer to a temperature range of 15 to 25°C. For example, the second heated and maintained steel sheet may be second cooled to room temperature at the average cooling rate of 1°C/s or more. When the average cooling rate is less than 1°C/s, productivity may be decreased. Though the upper limit of the average cooling rate is not particularly limited, it may be 100°C/s or less.

[0085] As an example, in a continuous annealing process including first heating and maintaining, first cooling, second heating and maintaining, and second cooling, the internal oxidation of the steel sheet may be performed by adjusting a gas atmosphere and dew point in a continuous annealing furnace. Platability may be secured through the internal oxidation and improve liquid metal embrittlement (LME). In addition, a ferrite soft phase may be introduced to an extreme surface layer of the steel sheet through internal oxidation, and thus, may improve hole expandability. In addition to this, micro-voids are formed on the extreme surface layer of the steel sheet through the internal oxidation, and the micro-voids act as a trap site of hydrogen to improve resistance to hydrogen embrittlement.

[0086] As an example, the gas atmosphere in the continuous annealing furnace may be adjusted by gas including 80 to 99% by volume of nitrogen and a balance of hydrogen. In addition, for example, the dew point in the continuous annealing furnace may be adjusted to 5°C or higher.

[0087] As an example, after the second cooling step, plating the second cooled steel sheet may be further included. For example, a plating method commonly used in the art such as hot-dip galvanizing, electro-galvanizing, and hot-dip aluminum plating may be applied to the plating step, and the method and conditions are not particularly limited.

Mode for Invention

[0088] Hereinafter, the present disclosure will be specifically described through the following Examples. However, it should be noted that the following Examples are only for describing the present disclosure in detail by illustration and are not intended to limit the right scope of the present disclosure. The reason is that the right scope of the present disclosure is determined by the matters described in the claims and reasonably inferred therefrom.

(Examples)

[0089] A steel slab (thickness: 100 mm) having the composition listed in the following Table 1 (remaining components of the alloy composition: Fe and inevitable impurities, and in Table 1, the unit of P is ppm, and the remaining components are indicated as the unit of wt%) was manufactured, and then reheated at 1200°C. Thereafter, the reheated steel slab was finish hot rolled at 900°C, cooled at an average cooling rate of 30°C/s, and wound in the conditions listed in Table 2, thereby manufacturing a hot rolled steel sheet having a thickness of 3 mm. The hot rolled steel sheet was heat treated by hot rolling annealing in the conditions listed in Table 2, pickled to remove surface scale, and then cold rolled to the thickness of 1.5 mm. Thereafter, the steel sheet which was cold rolled in the conditions listed in Table 2 was first heated and maintained, and first cooled, second heated and maintained, and then second cooled in the conditions listed in Table 3.

[Table 1]

Steel type	Alloy composition									
	C	Si	Mn	P	S	Al	N	Mo	Nb	B
A	0.39	2.04	2.13	2.09	0.0008	0.02	0.0032	-	-	0.0026

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(continued)

Steel type	Alloy composition									
	C	Si	Mn	P	S	Al	N	Mo	Nb	B
B	0.38	2.09	2.21	2.17	0.0013	0.02	0.0028	-	-	0.0038
C	0.37	2.01	1.88	1.84	0.001	0.02	0.0029	0.11	-	0.003
D	0.33	2.38	3.35	3.87	0.0012	0.03	0.003	0.23	-	0.0021
E	0.41	1.91	2.06	2.02	0.0009	0.03	0.0031	-	0.03	0.0018
F	0.52	1.73	2.33	2.28	0.0008	0.02	0.0027	-	0.05	0.0041
G	0.72	1.69	2.41	2.36	0.0011	0.02	0.0034	-	-	0.0006
H	0.38	0.90	2.11	2.07	0.001	1.93	0.0033	0.1	-	0.0002
I	0.36	1.11	2.07	2.03	0.0013	2.35	0.0031	-	0.04	0.0004
J	0.35	0.02	1.95	1.91	0.001	4.67	0.003	-	-	0.0001
K	0.36	0.89	2.15	2.12	0.001	1.92	0.0032	-	-	0.0031
L	0.33	0.02	1.94	1.92	0.001	2.23	0.004	-	-	0.0027

[Table 2]

Classification	Steel type	Winding temperature (°C)	Hot rolling annealing heat treatment temperature (°C)	Hot rolling annealing heat treatment time (s)	First average heating rate (°C)	First heating temperature (°C)	First maintenance time (s)
Inventive Example 1	A	500	750	1200	10	880	120
Comparative Example 1	A	500	900	1000	Poor pickling		
Comparative Example 2	A	500	600	1300	Rupture occurrence during cold rolling		
Comparative Example 3	A	450	750	92000	Poor pickling		
Comparative Example 4	A	500	750	500	Rupture occurrence during cold rolling		
Comparative Example 5	A	500	750	1500	10	730	120
Comparative Example 6	A	550	750	1200	10	880	1
Comparative Example 7	A	500	750	1200	10	880	120
Inventive Example 2	B	500	700	1300	10	880	120
Inventive Example 3	B	500	750	1000	10	880	120
Inventive Example 4	B	550	750	800	10	880	120
Inventive Example 5	C	500	800	1000	10	880	120

(continued)

5	Classification	Steel type	Winding temperature (°C)	Hot rolling annealing heat treatment temperature (°C)	Hot rolling annealing heat treatment time (s)	First average heating rate (°C)	First heating temperature (°C)	First maintenance time (s)
10	Comparative Example 8	C	500	750	1200	10	880	120
	Comparative Example 9	C	450	750	1100	10	880	120
15	Comparative Example 10	C	500	700	1100	10	880	120
	Comparative Example 11	C	550	750	1000	10	880	120
20	Comparative Example 12	C	500	800	1300	10	880	120
	Comparative Example 13	C	500	750	1500	10	880	120
25	Inventive Example 6	D	500	750	1600	10	880	120
	Inventive Example 7	E	500	650	900	10	880	120
	Inventive Example 8	F	550	850	1000	10	880	120
30	Comparative Example 14	G	450	750	1700	10	880	120
	Comparative Example 15	H	500	800	1200	10	880	120
35	Comparative Example 16	I	450	750	600	10	880	120
	Comparative Example 17	J	500	750	1400	10	880	120
40	Inventive Example 9	K	500	750	1000	10	880	120
	Inventive Example 10	L	500	750	1200	10	880	120

[Table 3]

50	Classification	Steel type	First average cooling rate (°C)	First cooling temperature (°C)	Second average heating rate (°C)	Second heating temperature (°C)	Second maintenance time (s)	Second average cooling rate (°C)
	Inventive Example 1	A	20	180	15	400	300	10
55	Comparative Example 1	A	Poor pickling					
	Comparative Example 2	A	Rupture occurrence during cold rolling					

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(continued)

5	Classification	Steel type	First average cooling rate (°C)	First cooling temperature (°C)	Second average heating rate (°C)	Second heating temperature (°C)	Second maintenance time (s)	Second average cooling rate (°C)
	Comparative Example 3	A	Poor pickling					
10	Comparative Example 4	A	Rupture occurrence during cold rolling					
	Comparative Example 5	A	20	220	15	400	300	10
15	Comparative Example 6	A	20	200	15	400	300	10
	Comparative Example 7	A	0.5	200	15	400	300	10
20	Inventive Example 2	B	20	250	15	400	300	10
	Inventive Example 3	B	20	130	15	350	600	10
25	Inventive Example 4	B	20	270	15	450	300	10
	Inventive Example 5	C	20	220	15	400	300	10
30	Comparative Example 8	C	20	70	15	400	300	10
	Comparative Example 9	C	20	330	15	400	300	10
35	Comparative Example 10	C	20	210	15	270	300	10
	Comparative Example 11	C	20	210	15	530	300	10
40	Comparative Example 12	C	20	180	15	400	40	10
	Comparative Example 13	C	20	180	15	400	172,800	10
45	Inventive Example 6	D	20	180	15	400	300	10
	Inventive Example 7	E	20	180	15	400	300	10
50	Inventive Example 8	F	20	200	15	400	300	10
	Comparative Example 14	G	20	200	15	350	300	10
	Comparative Example 15	H	20	200	15	400	600	10
55	Comparative Example 16	I	20	200	15	400	300	10

(continued)

Classification	Steel type	First average cooling rate (°C)	First cooling temperature (°C)	Second average heating rate (°C)	Second heating temperature (°C)	Second maintenance time (s)	Second average cooling rate (°C)
Comparative Example 17	J	20	220	15	400	300	10
Inventive Example 9	K	20	220	15	400	300	10
Inventive Example 10	L	20	220	15	450	300	10

[0090] For each steel sheet, the fraction of microstructure, the product of tensile strength and elongation rate (TS×EI), the TTS value, the W value, and the HER value were measured, and the results are shown in the following Table 4. Ferrite (F), bainite (B), tempered martensite (TM), and pearlite (P) in the microstructure were observed through SEM after nital etching of the polished cross section of a specimen. Among them, the fractions of bainite and tempered martensite which were difficult to be distinguished were calculated using an expansion curve after dilatation evaluation. Meanwhile, since it is also difficult to distinguish fresh martensite (FM) and retained austenite (retained γ), the value obtained by subtracting the fraction of retained austenite calculated by X-ray diffraction from the fraction of martensite and retained austenite observed by SEM was determined as a fresh martensite fraction.

[0091] The product of tensile strength and elongation rate (TS×EI) was measured by a tensile test. The tensile test was performed by evaluation of a specimen collected in accordance with the standard of JIS No. 5 based on a 90° direction to a rolling direction of a rolled steel material.

[0092] The TTS value was calculated based on the following Relation 2, after measuring a thickness before rupture (t_0) and a thickness after rupture (t_1) of a specimen performed by the JIS 5 standard test method:

[Relation 2]

$$TTS = \ln(t_0/t_1)$$

[0093] The W value was calculated by the following Relation 1, based on the calculated TTS value (TTS) and the content of B (B) added in the manufacture of the steel sheet:

[Relation 1]

$$W = TTS \times 100 \times B$$

[0094] The HER value was calculated by the formula of [(maximum diameter - initial diameter)/initial diameter × 100], after punching a hole having an initial diameter of 10 mm in the center of rolled steel material of 120 mm× 120 mm, pushing it up in a conical shape, and measuring a maximum diameter having no crack observed by the naked eye.

[Table 4]

Classification	Microstructure (% by area)						TS×EL (MPa%)	TTS value	W value	HER (%)
	F	B	TM	FM	Retained γ	P				
Inventive Example 1	0	21	56	1	22	0	30861	0.386	0.10	36
Comparative Example 1	Poor pickling									
Comparative Example 2	Rupture occurrence during cold rolling									
Comparative Example 3	Poor pickling									

(continued)

	Classification	Microstructure (% by area)						TS×EL (MPa%)	TTS value	W value	HER (%)
		F	B	TM	FM	Retained γ	P				
5	Comparative Example 4	Rupture occurrence during cold rolling									
	Comparative Example 5	33	4	1	0	1	61	13809	0.348	0.09	34
	Comparative Example 6	21	8	57	9	5	0	28666	0.389	0.10	12
10	Comparative Example 7	14	11	58	1	3	13	21891	0.424	0.11	24
	Inventive Example 2	0	21	61	0	18	0	30406	0.415	0.16	32
	Inventive Example 3	0	16	63	0	21	0	33204	0.316	0.12	31
15	Inventive Example 4	0	25	55	1	19	0	27670	0.349	0.13	32
	Inventive Example 5	0	29	51	2	18	0	32172	0.341	0.10	28
	Comparative Example 8	0	2	93	0	5	0	18302	0.393	0.12	9
20	Comparative Example 9	0	76	4	1	19	0	20117	0.371	0.11	22
	Comparative Example 10	0	15	78	2	5	0	11903	0.405	0.12	7
	Comparative Example 11	0	24	67	1	8	0	19443	0.385	0.12	24
25	Comparative Example 12	0	14	77	2	7	0	18625	0.391	0.12	7
	Comparative Example 13	0	29	62	4	5	0	20144	0.405	0.12	21
	Inventive Example 6	0	22	54	0	24	0	25251	0.592	0.12	25
30	Inventive Example 7	0	14	68	0	18	0	32959	0.449	0.08	33
	Inventive Example 8	0	25	53	1	21	0	31549	0.562	0.23	34
	Comparative Example 14	0	41	35	2	22	0	28314	0.422	0.03	18
35	Comparative Example 15	0	23	51	1	25	0	25345	0.472	0.01	9
	Comparative Example 16	0	19	56	1	24	0	29374	0.511	0.02	13
	Comparative Example 17	0	21	58	0	21	0	26207	0.482	0.00	11
	Inventive Example 9	0	24	59	0	17	0	36255	0.615	0.19	31
	Inventive Example 10	0	15	66	1	18	0	34703	0.572	0.15	35

[0095] As shown in Tables 1 to 4, in Inventive Examples 1 to 10 satisfying the alloy composition and manufacturing conditions suggested in the present disclosure, TS×EI was measured to be 22,000 MPa% or more, the HER value was measured to be 20% or more, and the W value was measured to be 0.08 or more. That is, it was found that Inventive Examples 1 to 10 had excellent strength and excellent ductility, hole expandability, and workability. Meanwhile, in Comparative Examples 1 to 4 in which the temperature conditions and treatment time conditions in the hot rolling annealing heat treatment process were adjusted to be out of the range of the examples of the present disclosure, defects occurred in the pickling process or rupture occurred in the cold rolling process.

[0096] In Comparative Example 5 having a low first heating temperature (or first maintaining temperature), ferrite was excessively formed, and the area fractions of bainite and tempered martensite were insufficient. Accordingly, in Comparative Example 5, TS×EI was measured to be less than 22,000 MPa%, and the strength was lowered.

[0097] In Comparative Example 6 having a short first maintenance time, the microstructure was non-uniformly formed, ferrite was excessively formed, and the area fractions of bainite and retained austenite were insufficient. Accordingly, in Comparative Example 6, the HER value was measured to be less than 20%, and the hole expandability was not good.

[0098] In Comparative Example 7 having a low average cooling rate in the first cooling, ferrite was excessively formed, and the area fraction of retained austenite was insufficient. Accordingly, in Comparative Example 7, TS×EI was measured to be less than 22,000 MPa%, and the strength was not good.

[0099] In Comparative Example 8 having a low first cooling temperature, tempered martensite was excessively formed, and the fractions of bainite and retained austenite were insufficient. Accordingly, in Comparative Example 8, the HER value was measured to be less than 20%, and the hole expandability was lowered.

[0100] In Comparative Example 9 having a high first cooling temperature, bainite was excessively formed, and tempered martensite was insufficiently formed. Accordingly, in Comparative Example 9, TS×EI was measured to be less than 22,000 MPa%, and the strength was not good.

[0101] In Comparative Examples 10 and 11 having a lower or higher second heating temperature (or second maintaining temperature), the area fraction of retained austenite was insufficient. Accordingly, in Comparative Examples 10 and 11, TS×EI was measured to be less than 22,000 MPa%, and the strength was lowered. In addition, in Comparative Example 10, tempered martensite was excessively formed, and the HER value was measured to be less than 20%.

[0102] In Comparative Example 12 having a short second maintenance time, formation of retained austenite was insufficient. Accordingly, in Comparative Example 12, TS×EI was measured to be less than 22,000 MPa%, and the HER value was measured to be less than 20%.

[0103] In Comparative Example 13 having a long second maintenance time, since the formation of retained austenite was insufficient, TS×EI was measured to be less than 22,000 MPa%, and the strength was not good.

[0104] In Comparative Examples 14 to 17 having a low content of B, the W value defined by Relation 1 was measured to be less than 0.08. Accordingly, the HER value was measured to be less than 20%, and the workability and hole expandability of the steel sheet were not good.

[0105] The above embodiment is one example, and the present disclosure is not limited thereto. Any of those having substantially the same configuration and the same working effect as the technical idea described in the claims of the present disclosure is included in the technical scope of the present disclosure.

Claims

1. A steel sheet comprising, by weight: 0.25 to 0.55% of C, 3.0% or less (excluding 0%) of Si, 0.9 to 3.4% of Mn, 3.0% or less (excluding 0%) of Al, 0.15% or less (excluding 0%) of P, 0.03% or less (excluding 0%) of S, 0.03% or less (excluding 0%) of N, 0.0015 to 0.005% of B, a balance of Fe, and inevitable impurities,

wherein the microstructure includes tempered martensite, bainite, and retained austenite, and a W value defined by the following Relation 1 is 0.08 or more:

$$[\text{Relation 1}]$$

$$W = TTS \times 100 \times B$$

wherein TTS is a value calculated based on the following Relation 2 after measuring a thickness before rupture and a thickness after rupture of a specimen performed by a test method of the tensile test JIS 5 standard, and B is a content (wt%) of boron included in the steel sheet,

$$[\text{Relation 2}]$$

$$TTS = \ln(t_0/t_1)$$

wherein t₀ is a thickness before rupture of a specimen performed by a test method of the tensile test JIS 5 standard, and t₁ is a thickness after rupture of a specimen.

2. The steel sheet of claim 1, wherein the sum of contents of Si and Al is 1.0 to 6.0%.

3. The steel sheet of claim 1, further comprising: one or more selected from the following (1) to (3):

- (1) one or more of 0 to 0.5% of Ti, 0 to 0.5% of Nb, and 0 to 0.5% V,
- (2) one or more of 0 to 3.0% of Cr and 0 to 3.0% of Mo,
- (3) one or more of 0 to 4.5% of Cu and 0 to 4.5% of Ni.

4. The steel sheet of claim 1, wherein an area fraction of the tempered martensite is 30 to 85%, an area fraction of the bainite is 10 to 50%, and an area fraction of the retained austenite is 10 to 40%, of the total area fraction of the microstructure.

5. The steel sheet of claim 1,

wherein the microstructure further includes ferrite, and
an area fraction of the ferrite is 5% or less of the total area fraction of the microstructure.

6. The steel sheet of claim 1, wherein the steel sheet has a product of tensile strength and elongation rate (TS×EI) of 22,000 MPa% or more and a HER value of 20% or more.

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

reheating a steel slab comprising, by weight: 0.25 to 0.55% of C, 3.0% or less (excluding 0%) of Si, 0.9 to 3.4% of Mn, 3.0% or less (excluding 0%) of Al, 0.15% or less (excluding 0%) of P, 0.03% or less (excluding 0%) of S, 0.03% or less (excluding 0%) of N, 0.0015 to 0.005% of B, a balance of Fe, and inevitable impurities;

finish hot rolling the reheated steel slab;

winding the finish hot rolled steel sheet;

heat treating the wound steel sheet by hot rolling annealing in a temperature range of 500 to 850°C for 600 to 85000 seconds;

cold rolling the steel sheet which is heat treated by hot rolling annealing;

first heating the cold rolled steel sheet at a first heating temperature of Ac1 or higher, and first maintaining the steel sheet for 120 seconds or more;

first cooling the first heated steel sheet to a first cooling temperature of 100 to 300°C at an average cooling rate of 20°C/s or more;

second heating the first cooled steel sheet to a second heating temperature of 300 to 500°C, and second maintaining the steel sheet for 300 to 90000 seconds; and

second cooling the second heated steel sheet to room temperature.

8. The method for manufacturing a steel sheet of claim 7, wherein in the reheating, the sum of the contents of Si and Al of the steel slab is 1.0 to 6.0%.

9. The method for manufacturing a steel sheet of claim 7, wherein in the reheating, the steel slab further comprises one or more selected from the following (1) to (3):

(1) one or more of 0 to 0.5% of Ti, 0 to 0.5% of Nb, and 0 to 0.5% of V,

(2) one or more of 0 to 3.0% of Cr and 0 to 3.0% of Mo,

(3) one or more of 0 to 4.5% Cu and 0 to 4.5% of Ni.

10. The method for manufacturing a steel sheet of claim 7, wherein the reheating is performed at 1000 to 1350°C, and the finish hot rolling is performed at 800 to 1000°C.

11. The method for manufacturing a steel sheet of claim 7, wherein in the winding, the finish hot rolled steel sheet is cooled to 300 to 700°C at an average cooling rate of 10°C/s or more and then wound.

12. The method for manufacturing a steel sheet of claim 7, wherein the cold rolling is performed at a reduction rate of 20 to 90%.

13. The method for manufacturing a steel sheet of claim 7, wherein in the first maintaining, the cold rolled steel sheet is heated to the first heating temperature at the average heating rate of 10°C/s or more.

14. The method for manufacturing a steel sheet of claim 7, wherein in the second maintaining, the first cooled steel sheet is heated to the second heating temperature at an average heating rate of 15°C/s or more.

15. The method for manufacturing a steel sheet of claim 7, wherein in the second cooling, the second heated steel sheet is cooled to room temperature at the average cooling rate of 1°C/s or more.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/019641

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/04(2006.01)i; C22C 38/02(2006.01)i; C22C 38/00(2006.01)i; C22C 38/06(2006.01)i; C22C 38/14(2006.01)i;
C22C 38/12(2006.01)i; C22C 38/34(2006.01)i; C22C 38/38(2006.01)i; C22C 38/08(2006.01)i; C22C 38/16(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 38/04(2006.01); C21D 6/00(2006.01); C21D 9/46(2006.01); C22C 38/00(2006.01); C22C 38/02(2006.01);
C22C 38/06(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: 강판(steel sheet), 템퍼드 마르텐사이트(tempered martensite), 베이나이트
(bainite), 오스테나이트(austenite), 보론(boron), 소둔(annealing), 냉각(cooling), 가열(heating), 냉간압연(cold
rolled), 열간압연(hot rolled)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2010-275608 A (KOBELTD. et al.) 09 December 2010 (2010-12-09) See paragraphs [0029]-[0033], [0059] and [0077], claims 1-6 and 8 and tables 3-6.	1-15
A	WO 2023-153097 A1 (NIPPON STEEL CORPORATION) 17 August 2023 (2023-08-17) See claims 1, 3 and 7.	1-15
A	JP 2010-126770 A (JFE STEEL CORP.) 10 June 2010 (2010-06-10) See paragraph [0039] and claims 1-5.	1-15
A	KR 10-2016-0095037 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORPORATION) 10 August 2016 (2016-08-10) See paragraphs [0076]-[0079] and claims 1-2 and 4.	1-15
A	KR 10-2015-0000892 A (VOESTALPINE STAHL GMBH et al.) 05 January 2015 (2015-01-05) See paragraphs [0074]-[0078] and claim 1.	1-15

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

* Special categories of cited documents:

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

“D” document cited by the applicant in the international application

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

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

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

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

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

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

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

“&” document member of the same patent family

Date of the actual completion of the international search

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Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

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