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

(57) The present invention relates to a steel sheet and a manufacturing method thereof and, more specifically, to a steel sheet having excellent abrasion resistance and a manufacturing method thereof.

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Description

Technical Field

5 **[0001]** The present disclosure relates to a steel sheet and a manufacturing method thereof, and more particularly, to a steel sheet having excellent abrasion resistance and a manufacturing method thereof.

Background Art

10 **[0002]** Construction machinery and industrial machinery used in many industrial fields such as construction, civil engineering, mining, and cement industry have severe abrasion occurrence by friction during working, and application of materials exhibiting abrasion resistance properties is needed.

[0003] In general, since abrasion resistance and hardness are related to each other in a thick steel sheet, there is a need to increase hardness in the thick steel sheet where abrasion is concerned. In order to secure more stable abrasion resistance, it is necessary to have uniform hardness from the surface of the thick steel sheet to the inside of a sheet thickness (near $t/2$, t : sheet thickness). That is to say, there is a need to have the same hardness on the surface and in the inside of the thick steel sheet.

[0004] Therefore, in order to secure lifespan of a material by securing center hardness as well as excellent abrasion resistance by securing surface hardness, there is a need for a method of securing hardness at or above a certain level both on the surface and in the center.

[0005] (Patent Document 1) Korean Patent Laid-Open Publication No. 2018-0073368

Summary of Invention

25 Technical Problem

[0006] An aspect of the present disclosure is to provide a steel sheet and a manufacturing method thereof.

[0007] Another aspect of the present disclosure is to provide steel sheet having excellent abrasion resistance and a manufacturing method thereof.

30 **[0008]** An object of the present disclosure is not limited to the above description. A person skilled in the art will have no difficulty in understanding further objects of the present disclosure from the overall descriptions of the present specification.

Solution to Problem

35 **[0009]** According to an aspect of the present disclosure, a steel sheet includes, by weight: 0.100 to 0.190% of carbon (C), 0.50% or less of silicon (Si), 0.50 to 3.00% of manganese (Mn), 0.050% or less of phosphorus (P), 0.020% or less of sulfur (S), 0.05% or less of aluminum (Al), 1.50% or less of chromium (Cr), 1.00% or less of molybdenum (Mo), 0.020% or less of titanium (Ti), 50 ppm or less of boron (B), a remainder of iron (Fe), and other unavoidable impurities,

40 wherein a R1 value defined in the following Relation 1 is 2.00 or more, a R2 value defined in the following Relation 2 is 0.70 or more, and a microstructure includes 15% by area or more of martensite at a 1/2 point in a thickness center direction from a surface:

50 [Relation 1]

$$R1 = ([Ti]/[B]) \times [Cr] \times [Mo]$$

wherein [Ti], [B], [Cr], and [Mo] are wt% of each element,

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[Relation 2]

$$R2 = [C] + [Mn] / 6 + ([Ni] + [Cu]) / 15 + ([Cr] + [Mo]) / 5$$

wherein [C], [Mn], [Ni], [Cu], [Cr], and [Mo] are wt% of each element.

[0010] The steel sheet may further include one or more of 0.50% or less of nickel (Ni), 0.50% or less of copper (Cu), 0.05% or less of niobium (Nb), and 2 to 100 ppm of calcium (Ca).

[0011] The microstructure of the steel sheet may include 90% by area or more of the martensite at a 2 mm point in the thickness center direction from the surface.

[0012] The microstructure of the steel sheet may include bainite as a residual structure at a 1/2 point in the thickness center direction from the surface and may include bainite as a residual structure at a 2 mm point in the thickness center direction from the surface.

[0013] The steel sheet may have a surface hardness, which is a hardness at a 2 mm point in the thickness center direction from the surface, of 360 to 440 HBW, and a center hardness, which is a hardness at a 1/2 point in the thickness center direction from the surface, of 335 HBW or more.

[0014] The steel sheet may have a thickness of 80 mm or more.

[0015] According to another aspect of the present disclosure, a manufacturing method of a steel sheet includes: heating a steel slab including, by weight: 0.100 to 0.190% of carbon (C), 0.50% or less of silicon (Si), 0.50 to 3.00% of manganese (Mn), 0.050% or less of phosphorus (P), 0.020% or less of sulfur (S), 0.05% or less of aluminum (Al), 1.50% or less of chromium (Cr), 1.00% or less of molybdenum (Mo), 0.020% or less of titanium (Ti), 50 ppm or less of boron (B), a remainder of iron (Fe), and other unavoidable impurities, and has a R1 value defined in the following Relation 1 of 2.00 or more and a R2 value defined in the following Relation 2 of 0.70 or more;

rough rolling the heated steel slab;

finish hot rolling the rough rolled steel sheet;

air cooling the finish hot rolled steel sheet to room temperature;

reheating the air cooled steel sheet to a temperature range of 850 to 930°C; and

cooling the reheated steel sheet to 200°C or lower at a cooling rate of 0.50°C/s or more;

[Relation 1]

$$R1 = ([Ti] / [B]) \times [Cr] \times [Mo]$$

wherein [Ti], [B], [Cr], and [Mo] are wt% of each element,

[Relation 2]

$$R2 = [C] + [Mn] / 6 + ([Ni] + [Cu]) / 15 + ([Cr] + [Mo]) / 5$$

wherein [C], [Mn], [Ni], [Cu], [Cr], and [Mo] are wt% of each element.

[0016] The steel slab may further include one or more of 0.50% or less of nickel (Ni), 0.50% or less of copper (Cu), 0.05% or less of niobium (Nb), and 2 to 100 ppm of calcium (Ca).

[0017] The heating may be performed in a temperature range of 1050 to 1250°C,

the rough rolling may be performed in a temperature range of 950 to 1050°C,

the finish hot rolling may be performed in a temperature range of 750 to 950°C, and

the reheating may be performed for a residence time of 1.3t+10 min to 1.3t+60 min (t: sheet thickness, mm).

[0018] The cooled steel sheet may have a thickness of 80 mm or more.

Advantageous Effects of Invention

[0019] According to an example embodiment of the present disclosure, a steel sheet and a manufacturing method thereof may be provided.

[0020] According to an example embodiment of the present disclosure, a steel sheet having excellent abrasion resistance and a manufacturing method thereof may be provided.

[0021] According to an example embodiment of the present disclosure, a steel sheet which has excellent surface and center hardnesses and may be used in construction machinery, industrial machinery, and the like used in many industrial fields such as construction, civil engineering, mining, and cement industries, and a manufacturing method thereof may be provided.

[0022] 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

[0023] Preferred example embodiments of the present disclosure will be described in the following. The example embodiments of the present disclosure may be modified in various forms, and the scope of the disclosure should not be interpreted to be limited to the example embodiments set forth below. These example embodiments are provided in order to describe the present disclosure in more detail to those with ordinary skill in the art to which the present disclosure pertains.

[0024] Hereinafter, the present disclosure will be described in detail.

[0025] The steel composition of the present disclosure will be described in detail in the following.

[0026] Unless otherwise particularly mentioned in the present disclosure, % indicating the content of each element is based on the weight.

[0027] A steel sheet according to an example embodiment of the present disclosure may include, by weight: 0.100 to 0.190% of carbon (C), 0.50% or less of silicon (Si), 0.50 to 3.00% of manganese (Mn), 0.050% or less of phosphorus (P), 0.020% or less of sulfur (S), 0.05% or less of aluminum (Al), 1.50% or less of chromium (Cr), 1.00% or less of molybdenum (Mo), 0.020% or less of titanium (Ti), and 50 ppm or less of boron (B).

Carbon (C): 0.100 to 0.190%

[0028] Carbon (C) is an element which is efficient for increasing strength and hardness in a steel having a martensite structure and effective for improving hardenability. In order to sufficiently secure the effects described above, carbon (C) may be added at 0.100% or more. According to an example embodiment of the present disclosure, it may be 0.110% or more. However, when a carbon (C) content is more than 0.190%, it exceeds the upper limit of targeted surface hardness, and also may deteriorate weldability and toughness later. According to an example embodiment of the present disclosure, the carbon (C) content may be 0.190% or less. According to an example embodiment of the present disclosure, it may be 0.180% or less.

Silicon (Si): 0.50% or less

[0029] Silicon (Si) is an element which is effective for improving strength due to deoxidization and solid solution strengthening. In order to obtain the effect described above, silicon (Si) may be added at 0.50% or less. When the content is more than 0.50%, scales are excessively produced and grow on the surface during hot rolling and may remain as a surface defect in a final sheet material state. In addition, weldability may be deteriorated. Therefore, in the present disclosure, the content of silicon (Si) may be controlled to 0.50% or less. According to an example embodiment of the present disclosure, it may be 0.45% or less. However, 0% is excluded considering an increase in loads, manufacturing costs, and the like during a steelmaking process.

Manganese (Mn): 0.50 to 3.00%

[0030] Manganese (Mn) is an element which suppresses ferrite production and lowers an Ar₃ temperature to effectively increase quenchability, thereby improving strength and toughness of a steel. According to an example embodiment of the present disclosure, the manganese (Mn) may be contained at 0.50% or more in order to secure hardness of an extra-thick steel plate. According to an example embodiment of the present disclosure, it may be 0.60% or more. Meanwhile, when the content is more than 3.00%, MnS segregation is caused in the center of a rolled sheet material, and in the worst case, there is a risk of leading to sheet rupture after a heat treatment. According to an

example embodiment of the present disclosure, it may be 2.80% or less.

Phosphorus (P): 0.050% or less

- 5 **[0031]** Phosphorus (P) is an element which is included unavoidably in steel and deteriorates toughness of the steel. Therefore, the content of phosphorus (P) may be lowered as much as possible to control to 0.050% or less. However, 0% is excluded considering the level of the content to be unavoidably contained in steel.

Sulfur (S): 0.020% or less

- 10 **[0032]** Sulfur (S) is an element which forms a MnS inclusion in steel to deteriorate steel toughness. Therefore, the content of sulfur (S) may be lowered as much as possible to control to 0.020% or less. However, 0% is excluded considering the level of the content to be unavoidably contained in steel.

- 15 Aluminum (Al): 0.05% or less

- [0033]** Aluminum (Al) is an element effective for lowering an oxygen content in molten steel as a deoxidizing agent of steel. When the content of aluminum (Al) is more than 0.05%, cleanliness of steel may be deteriorated. According to an example embodiment of the present disclosure, it may be 0.04% or less. However, 0% is excluded considering an increase in loads, manufacturing costs, and the like during a steelmaking process.

Chromium (Cr): 1.50% or less

- 25 **[0034]** Chromium (Cr) increases quenchability to increase steel strength and is favorable for securing hardness. For the effects described above, chromium (Cr) may be added at 1.50% or less. Meanwhile, when the content is more than 1.50%, in a process of charging the slab cooled to room temperature after steelmaking into a heating furnace for hot rolling and reheating, rupture due to thermal shock may occur. Besides, a carbon equivalent is excessively increased, resulting in poor weldability. According to an example embodiment of the present disclosure, the chromium (Cr) content may be 1.45% or less. However, 0% is excluded considering an increase in loads, manufacturing costs, and the like during a steelmaking process.

Molybdenum (Mo): 1.00% or less

- 35 **[0035]** Molybdenum (Mo) increases quenchability of steel, and, in particular, is effective for improving hardness of a thick material. In order to sufficiently obtain the effects described above, molybdenum (Mo) may be added. However, molybdenum (Mo) is an expensive element, and when its content is more than 1.00%, the manufacturing costs may be increased, and also weldability may be deteriorated. Therefore, in the present disclosure, the content of molybdenum (Mo) may be controlled to 1.00% or less. According to an example embodiment of the present disclosure, it may be 0.95% or less. Meanwhile, according to an example embodiment of the present disclosure, the lower limit of the content of molybdenum (Mo) may be 0.20%. According to an example embodiment of the present disclosure, the lower limit may be 0.25%. According to an example embodiment of the present disclosure, the lower limit may be 0.30%.

Titanium (Ti): 0.020% or less

- 45 **[0036]** Titanium (Ti) is an element which significantly increases the effect of B which is effective for improving steel quenchability. Specifically, the titanium (Ti) is bonded to nitrogen to form a TiN precipitate and suppress BN formation, thereby increasing B in a solid solution state to significantly increase quenchability improvement. However, when the content of titanium (Ti) is more than 0.020%, a coarse TiN precipitate is formed to deteriorate steel toughness. Therefore, according to an example embodiment of the present disclosure, when the titanium (Ti) is added, the content may be limited to 0.020% or less. According to an example embodiment of the present disclosure, it may be 0.018% or less.

Boron (B): 50 ppm or less

- 55 **[0037]** Boron (B) is a very effective element for improving strength by increasing quenchability of steel only with addition of a small amount. However, when the content is excessive, toughness and weldability of steel are rather deteriorated, and thus, the content may be controlled to 50 ppm or less.

[0038] The steel material of the present disclosure may include a remainder of iron (Fe) and unavoidable impurities, in addition to the composition described above. Since the unavoidable impurities may be incorporated unintentionally in a common manufacturing process, they may not be excluded. Since these impurities are known to any person skilled in the common steel manufacturing field, the entire contents are not particularly mentioned in the present specification.

[0039] The steel sheet according to an example embodiment of the present disclosure may further include one or more of 0.50% or less of nickel (Ni), 0.50% or less of copper (Cu), 0.05% or less of niobium (Nb), and 2 to 100 ppm of calcium (Ca).

[0040] According to an example embodiment of the present disclosure, elements favorable for securing the targeted physical properties may be further included, in addition to the alloy composition described above.

Nickel (Ni): 0.50% or less

[0041] Nickel (Ni) is generally an element effective for improving toughness along with strength of steel. However, when the content is more than 0.50%, the manufacturing costs may be increased. Therefore, according to an example embodiment of the present disclosure, when the nickel (Ni) is added, it may be added at 0.50% or less.

Copper (Cu): 0.50% or less

[0042] Copper (Cu) is an element which improves quenchability of steel and improves strength and toughness of steel by solid solution strengthening. However, when the content of copper (Cu) is more than 0.50%, surface defects occur, hot processability is deteriorated, and thus, according to an example embodiment of the present disclosure, the content may be limited to 0.50% or less.

Niobium (Nb): 0.05% or less

[0043] Niobium (Nb) may be brought into a solid solution state and increase hardenability of austenite. In addition, it is an element which forms a carbonitride such as Nb(C,N) to increase steel strength and is effective for suppressing austenite crystal grain growth. However, when the content of niobium (Nb) is more than 0.05%, ultra-high temperature working at 1200°C or higher is needed, and also coarse crystal grains and precipitates are formed, resulting in deterioration of toughness of a steel material. Therefore, according to an example embodiment of the present disclosure, when the niobium (Nb) is added, the content may be limited to 0.05% or less.

Calcium (Ca): 2 to 100 ppm

[0044] Calcium (Ca) has excellent bonding strength to S and produces CaS, thereby suppressing production of MnS which segregates in a thickness center part of a steel material. In addition, CaS produced by adding the calcium (Ca) has an effect of increasing corrosion resistance under a humid external environment. According to an example embodiment of the present disclosure, 2 ppm or more of calcium (Ca) may be added for the effects described above. Meanwhile, when the content is more than 100 ppm, there may be a problem of causing nozzle blockage and the like during steelmaking operation.

[0045] The steel sheet according to an example embodiment of the present disclosure may have a R1 value defined in the following Relation 1 of 2.00 or more:

[Relation 1]

$$R1 = ([Ti]/[B]) \times [Cr] \times [Mo]$$

wherein [Ti], [B], [Cr], and [Mo] are wt% of each element.

[0046] According to an example embodiment of the present disclosure, the condition in which the R1 value defined in Relation 1 is 2.00 or more is satisfied, thereby securing targeted center hardness. According to an example embodiment of the present disclosure, quenchability of steel is increased by controlling a content relationship of Ti, B, Cr, and Mo through Relation 1, and thus, the hardness suggested in the present disclosure may be secured.

[0047] According to an example embodiment of the present disclosure, the center hardness may refer to a hardness at a 1/2 point in the thickness center direction from the steel sheet surface.

[0048] According to an example embodiment of the present disclosure, the R1 value defined in Relation 1 may be

2.10 or more. Meanwhile, though the upper limit of R1 of Relation 1 is not particularly limited, it may be 7.00 or less. According to an example embodiment of the present disclosure, it may be 6.00 or less.

[0049] According to an example embodiment of the present disclosure, the R2 value defined in Relation 2 may be 0.70 or more:

[Relation 2]

$$R2 = [C] + [Mn] / 6 + ([Ni] + [Cu]) / 15 + ([Cr] + [Mo]) / 5$$

wherein [C], [Mn], [Ni], [Cu], [Cr], and [Mo] are wt% of each element.

[0050] According to an example embodiment of the present disclosure, the condition in which the R2 value defined in Relation 2 is 0.70 or more is satisfied, thereby securing both the center hardness and the surface hardness simultaneously. According to an example embodiment of the present disclosure, the content relationship of C, Mn, Ni, Cu, Cr, and Mo is controlled by Relation 2 to increase the strength and hardness of steel, thereby securing the hardness suggested in the present disclosure.

[0051] According to an example embodiment of the present disclosure, the center hardness may refer to a hardness at a 1/2 point in the thickness center direction from the steel sheet surface, and the surface hardness may refer to a hardness at a 2 mm point from the steel sheet surface.

[0052] According to an example embodiment of the present disclosure, the R2 value defined in Relation 2 may be 0.71 or more. Meanwhile, though the upper limit of R1 of Relation 1 is not particularly limited, it may be 0.90 or less. According to an example embodiment of the present disclosure, it may be 0.85 or less.

[0053] Hereinafter, the steel microstructure of the present disclosure will be described in detail.

[0054] Unless otherwise particularly mentioned in the present disclosure, % indicating the fraction of the microstructure is based on the area.

[0055] The microstructure of the steel sheet according to an example embodiment of the present disclosure includes 15% by area or more of martensite and residual bainite at a 1/2 point in the thickness center direction from the surface, and 90% by area or more of martensite and residual bainite at a 2 mm point in the thickness center direction from the surface.

[0056] In the present disclosure, the martensite is distinguished from tempered martensite which is developed by subsequently performing a tempering heat treatment after quenching.

[0057] According to an example embodiment of the present disclosure, when martensite is less than 90% at a 2 mm point in the thickness center direction from the steel sheet surface, it may be difficult to secure targeted hardness. According to an example embodiment of the present disclosure, martensite may be 100%.

[0058] Meanwhile, at a 1/2 point in the thickness center direction from the steel sheet surface, a cooling rate is physically low as compared with the steel sheet surface, and it may be difficult to include 90% or more of martensite. In order to secure a level of hardness targeted in the present disclosure, martensite may be 15% or more. When martensite is less than 15%, it may be difficult to secure a targeted level of hardness. According to an example embodiment of the present disclosure, martensite may be 17% or more. According to an example embodiment of the present disclosure, though the upper limit of a martensite fraction is not particularly limited at a 1/2 point in the thickness center direction from the surface, it may be 90% or less.

[0059] The steel sheet surface and the center microstructure may include bainite as a residual structure other than martensite. Both hardnesses on the surface and in the center may be met to a certain level or higher, by including bainite as a residual structure.

[0060] The steel sheet according to an example embodiment of the present disclosure may have a surface hardness, which is a hardness at a 2 mm point in the thickness center direction from the surface, of 360 to 440 HBW, and a center hardness, which is a hardness at a 1/2 point in the thickness center direction from the surface, of 335 HBW or more, and a thickness of 80 mm or more.

[0061] The steel sheet according to an example embodiment of the present disclosure may have the thickness of 90 mm or more. The steel sheet according to an example embodiment of the present disclosure may have the thickness of 100mm or more. According to an example embodiment of the present disclosure, the upper limit of the thickness of the steel sheet is not particularly limited, but may be 140 mm or less. The steel sheet according to an example embodiment of the present disclosure may have the thickness of 130 mm or less. According to an example embodiment of the present disclosure, the center hardness may be 440 HBW or less.

[0062] Hereinafter, the manufacturing method of the steel of the present disclosure will be described in detail.

[0063] The above-described alloy composition of the steel sheet according to an example embodiment of the present disclosure may be manufactured by heating, rough rolling, finish hot rolling, air cooling, reheating, and cooling.

[Heating]

[0064] A steel slab satisfying the alloy composition according to an example embodiment of the present disclosure may be heated in a temperature range of 1050 to 1250°C.

[0065] When a slab heating temperature is lower than 1050°C, a microalloy such as Nb is not sufficiently brought into a solid solution state, and also the slab surface temperature is relatively lowered, so that the load applied to a roller may be increased during hot rolling. However, when the temperature is higher than 1250°C, austenite crystal grains are coarsened to cause a risk of forming a non-uniform structure, and scales are excessively produced and grow to finally remain as a surface defect without peeling off well during rolling.

[Rough rolling]

[0066] The heated steel slab may be rough rolled in a temperature range of 950 to 1050°C.

[0067] The heated steel slab may be rough rolled to obtain a rough rolled bar.

[0068] During the rough rolling, when the temperature is lower than 950°C, a rolling load is increased to perform rolling relatively weakly, so that deformation is not sufficiently transferred to the center in the slab thickness direction, and defects such as pores may not be removed. However, during rough rolling, when the temperature is higher than 1050°C, rolling and recrystallization occur simultaneously, and then particles grow, so that initial austenite particles may be excessively coarsened.

[Finish hot rolling]

[0069] The rough rolled steel sheet may be finish hot rolled to a temperature range of 750 to 950°C.

[0070] The rough rolled steel sheet may be finish hot rolled to obtain a hot rolled steel sheet.

[0071] During the finish hot rolling, when the temperature is lower than 750°C, dual phase rolling is performed, so that ferrite may be produced in the microstructure. However, when the temperature is higher than 950°C, the particle size of a final structure may be coarsened to deteriorate toughness.

[Air cooling]

[0072] The finish hot rolled steel sheet may be air cooled to room temperature.

[0073] Though the air cooling conditions after the finish hot rolling are not particularly defined in the present disclosure, they may be common conditions applied in the same technical field.

[Reheating]

[0074] The air cooled steel sheet may be reheated in a temperature range of 850 to 930°C for a residence time of $1.3t + 10$ minutes to $1.3t + 60$ minutes (t : sheet thickness, mm).

[0075] According to an example embodiment of the present disclosure, the reheating may perform a reverse transformation from the hot rolled steel sheet formed of ferrite and pearlite into an austenite single phase.

[0076] When the reheating temperature is lower than 850°C, austenitization is not sufficiently performed, so that coarse soft ferrite may be mixed to deteriorate the hardness of a final product. However, when the reheating temperature is higher than 930°C, austenite crystal grains are coarsened to increase quenchability, but the low-temperature toughness of the steel sheet may be deteriorated.

[0077] During the reheating, when the residence time is less than $1.3t + 10$ minutes (t : sheet thickness, mm), austenitization does not sufficiently occur, so that it may be difficult to sufficiently obtain phase transformation by subsequent cooling, that is, a martensite structure. Meanwhile, during the reheating, when the residence time is more than $1.3t + 60$ minutes (t : sheet thickness, mm), austenite crystal grains are coarsened to increase quenchability, but which may result in deterioration of toughness.

[Cooling]

[0078] The reheated steel sheet may be cooled to 200°C or lower at a cooling rate of 0.50°C/s or more.

[0079] According to an example embodiment of the present disclosure, a cooling end temperature may be based on a temperature at a 1/2 point in the thickness center direction from the steel sheet surface.

[0080] During the cooling, when the cooling rate is less than 0.50°C/s or the cooling end temperature is higher than 200°C, a bainite phase may be excessively formed after final cooling. Though the upper limit of the cooling rate is not particularly limited in the present disclosure, a person skilled in the art may appropriately set it considering facility

limitations. Meanwhile, according to an example embodiment of the present disclosure, the cooling rate may be 0.70°C/s or more during the cooling. According to an example embodiment of the present disclosure, it may be 1.00°C/s or more. According to an example embodiment of the present disclosure, the cooling may be water cooling.

5 Mode for Invention

[0081] 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 not intended to limit the right scope of the present disclosure.

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(Examples)

[0082] After preparing a steel slab having the alloy composition of the following Table 1, steel slab heating - rough rolling - finish hot rolling - air cooling - reheating - cooling was performed on the steel slab under the conditions of Table 2 to manufacture a hot rolled steel sheet.

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[Table 1]

Steel type	Alloy composition (wt%)														Relation 1	Relation 2
	C	Si	Mn	P	S	Al	Cr	Mo	Ti	B	Ni	Cu	Nb	Ca	R1	R2
A	0.152	0.27	1.51	0.009	0.002	0.03	1.02	0.65	0.016	0.0021	0.29	0.01	0.02	0.0012	5.05	0.76
B	0.156	0.31	1.85	0.005	0.002	0.03	0.83	0.62	0.017	0.0018	0.33	0.03	0.01	0.0015	4.86	0.78
C	0.154	0.24	2.10	0.007	0.001	0.03	0.81	0.53	0.015	0.0020	0.15	0.02	0.01	0.0009	3.22	0.78
D	0.058	0.24	1.12	0.005	0.001	0.05	0.78	0.47	-	0.0015	1.53	0.02	-	0.0010	0.00	0.60
E	0.281	0.25	1.43	0.006	0.002	0.02	1.50	0.41	0.0060	0.0019	-	0.01	-	0.0005	1.94	0.90
F	0.150	0.26	1.21	0.008	0.003	0.03	0.44	0.30	-	0.0021	-	0.14	0.01	-	0.00	0.51
G	0.148	0.30	1.42	0.007	0.002	0.04	0.82	0.21	0.02C	0.0010	0.21	0.03	0.02	0.0007	3.44	0.61

[Relation 1]

$$R1 = ([Ti] / [B]) \times [Cr] \times [Mo]$$

wherein [Ti], [B], [Cr], and [Mo] are wt% of each element,

[Relation 2]

$$R2 = [C] + [Mn] / 6 + ([Ni] + [Cu]) / 15 + ([Cr] + [Mo]) / 5$$

wherein [C], [Mn], [Ni], [Cu], [Cr], and [Mo] are wt% of each element.

[Table 2]

Specimen No.	Steel type	Heating	Rough rolling	Finish hot rolling	Reheating		Cooling	
		Temperature (°C)	Temperature (°C)	Temperature (°C)	Temperature (°C)	Residence time (min)	Speed (°C/s)	Temperature (°C)
1	A	1162	995	880	915	157	1.92	19
2	A	1126	994	931	868	160	1.53	21
3	A	1143	982	924	925	194	0.77	35
4	B	1123	1040	935	916	153	1.72	26
5	B	1162	997	926	888	186	0.86	23
6	B	1137	978	942	900	209	0.77	219
7	C	1152	1012	945	890	196	0.64	18
8	C	1142	976	931	912	180	0.47	20
9	C	1144	997	917	911	157	1.66	29
10	D	1135	1021	904	900	170	2.01	25
11	D	1153	1007	925	909	176	1.24	22
12	D	1146	990	941	887	197	0.79	19
13	E	1160	1043	921	923	200	0.88	151
14	E	1133	1020	953	911	187	0.75	33
15	E	1146	997	940	915	163	1.81	22
16	F	1129	1017	886	914	178	1.12	26
17	F	1143	1006	932	926	192	0.76	218
18	F	1152	988	928	904	200	0.68	20
19	G	1139	1017	878	921	148	2.85	19
20	G	1141	979	946	918	166	1.64	231
21	G	1150	986	918	920	190	0.43	20

[0083] The microstructure and the physical properties of the manufactured steel sheets were measured and then are shown in the following Table 3.

[0084] At this time, a specimen was cut into a random size to manufacture a mirror surface, corrosion was performed using a Nital etchant, and then a surface point which was a 2 mm point from the surface and a center point which was a 1/2 point of the thickness center were observed using an optical microscope and an electron scanning microscope.

[0085] Further, the surface and center hardnesses were measured using a Brinell hardness tester (load: 3000 kgf, 10 mm tungsten indenter ball). At this time, the surface hardness was an average value of three measurements after 2 mm milling working of the steel sheet surface, and the center hardness was an average value of three measurements obtained in the same manner as in the surface after machine cutting exactly at a 1/2 point in the steel sheet thickness direction and manufacturing a mirror surface.

[Table 3]

Specimen No.	Steel type	Thickness (mm)	Microstructure (% by area)				Physical properties		Classification
			Surface		Center		Hardness (HBW)		
			M	B	M	B	Surface	Center	
1	A	90	100	0	49	51	417	357	Inventive Example 1
2	A	100	99	1	40	60	421	344	Inventive Example 2
3	A	120	98	2	15	85	409	338	Inventive Example 3
4	B	95	99	1	45	55	411	352	Inventive Example 4
5	B	110	100	0	24	76	416	343	Inventive Example 5
6	B	120	88	12	12	88	347	309	Comparative Ex-ample 1
7	C	130	100	0	19	81	419	352	Inventive Example 6
8	C	120	100	0	14	85	408	308	Comparative Ex-ample 2
9	C	100	99	1	43	57	400	348	Inventive Example 7
10	D	90	100	0	51	49	349	244	Comparative Ex-ample 3
11	D	100	99	1	33	67	355	231	Comparative Ex-ample 4
12	D	120	100	0	23	77	341	219	Comparative Ex-ample 5
13	E	120	100	0	45	55	537	400	Comparative Ex-ample 6
14	E	120	100	0	42	58	512	397	Comparative Ex-ample 7
15	E	100	100	0	47	53	525	379	Comparative Ex-ample 8
16	F	110	100	0	10	90	406	228	Comparative Ex-ample 9
17	F	120	89	11	12	88	349	220	Comparative Ex-ample 10

(continued)

Specimen No.	Steel type	Thickness (mm)	Microstructure (% by area)				Physical properties		Classification
			Surface		Center		Hardness (HBW)		
			M	B	M	B	Surface	Center	
18	F	130	98	2	14	86	412	211	Comparative Ex-ample 11
19	G	85	99	1	12	88	424	250	Comparative Ex-ample 12
20	G	100	86	14	13	87	341	245	Comparative Ex-ample 13
21	G	120	100	0	14	86	418	226	Comparative Ex-ample 14
* M: Martensite, B: Bainite									

[0086] As shown in Table 3, in the inventive examples satisfying the alloy composition and manufacturing conditions of the present disclosure, the microstructure characteristics suggested in the present disclosure were satisfied, and the targeted physical properties in the present disclosure were also secured.

[0087] However, Comparative Example 1 is the example in which the end temperature was out of the conditions of the present disclosure during cooling. The cooling end temperature was excessively high, martensite was insufficiently formed on the steel sheet surface, and as a result, the targeted hardness was not secured.

[0088] Comparative Example 2 is the example in which the cooling rate was excessively low. Thus, the martensite fraction in the steel sheet center was insufficient. As a result, the targeted center hardness was insufficient.

[0089] Comparative Examples 3 to 8 are the examples which did not satisfy the alloy composition conditions of the present disclosure. Comparative Examples 3 to 5 are the examples in which a carbon content was insufficient, and Relation 1 or 2 was not satisfied. As a result, surface hardness and center hardness were poor. Comparative Examples 6 to 8 are the examples in which the carbon content exceeded the range of the present disclosure and Relation 1 was not satisfied. As a result, the center hardness was sufficient, but the surface hardness was not appropriately secured.

[0090] Comparative Examples 9 to 14 are the examples in which the alloy composition range suggested in the present disclosure was satisfied, but Relation 1 or 2 was not satisfied. As a result, the targeted surface and center hardnesses in the present disclosure were not secured.

[0091] Hereinabove, the present disclosure has been described in detail by the example embodiments, but other example embodiments having different forms are possible. Therefore, the technical spirit and scope of the claims set forth below are not limited by the example embodiments.

Claims

1. A steel sheet comprising, by weight: 0.100 to 0.190% of carbon (C), 0.50% or less of silicon (Si), 0.50 to 3.00% of manganese (Mn), 0.050% or less of phosphorus (P), 0.020% or less of sulfur (S), 0.05% or less of aluminum (Al), 1.50% or less of chromium (Cr), 1.00% or less of molybdenum (Mo), 0.020% or less of titanium (Ti), 50 ppm or less of boron (B), a remainder of iron (Fe), and other unavoidable impurities,

wherein a R1 value defined in the following Relation 1 is 2.00 or more,

a R2 value defined in the following Relation 2 is 0.70 or more, and

a microstructure includes 15% by area or more of martensite at a 1/2 point in a thickness center direction from a surface:

[Relation 1]

$$R1 = ([Ti]/[B]) \times [Cr] \times [Mo]$$

wherein [Ti], [B], [Cr], and [Mo] are wt% of each element,

[Relation 2]

$$R2 = [C] + [Mn] / 6 + ([Ni] + [Cu]) / 15 + ([Cr] + [Mo]) / 5$$

wherein [C], [Mn], [Ni], [Cu], [Cr], and [Mo] are wt% of each element.

2. The steel sheet of claim 1, further comprising: one or more of 0.50% or less of nickel (Ni), 0.50% or less of copper (Cu), 0.05% or less of niobium (Nb), and 2 to 100 ppm of calcium (Ca).
3. The steel sheet of claim 1, wherein the microstructure of the steel sheet includes 90% by area or more of the martensite at a 2 mm point in the thickness center direction from the surface.
4. The steel sheet of claim 3, wherein the microstructure of the steel sheet includes bainite as a residual structure at a 1/2 point in the thickness center direction from the surface and includes bainite as a residual structure at the 2 mm point in the thickness center direction from the surface.
5. The steel sheet of claim 1, wherein the steel sheet has a surface hardness, which is a hardness at a 2 mm point in the thickness center direction from the surface, of 360 to 440 HBW, and a center hardness, which is a hardness at a 1/2 point in the thickness center direction from the surface, of 335 HBW or more.
6. The steel sheet of claim 1, wherein the steel sheet has a thickness of 80 mm or more.
7. A manufacturing method of a steel sheet, the method comprising:

heating a steel slab including, by weight: 0.100 to 0.190% of carbon (C), 0.50% or less of silicon (Si), 0.50 to 3.00% of manganese (Mn), 0.050% or less of phosphorus (P), 0.020% or less of sulfur (S), 0.05% or less of aluminum (Al), 1.50% or less of chromium (Cr), 1.00% or less of molybdenum (Mo), 0.020% or less of titanium (Ti), 50 ppm or less of boron (B), a remainder of iron (Fe), and other unavoidable impurities, and has a R1 value defined in the following Relation 1 of 2.00 or more and a R2 value defined in the following Relation 2 of 0.70 or more;

rough rolling the heated steel slab;

finish hot rolling the rough rolled steel sheet;

air cooling the finish hot rolled steel sheet to room temperature;

reheating the air cooled steel sheet to a temperature range of 850 to 930°C; and

cooling the reheated steel sheet to 200°C or lower at a cooling rate of 0.50°C/s or more:

[Relation 1]

$$R1 = ([Ti] / [B]) \times [Cr] \times [Mo]$$

wherein [Ti], [B], [Cr], and [Mo] are wt% of each element,

[Relation 2]

$$R2 = [C] + [Mn] / 6 + ([Ni] + [Cu]) / 15 + ([Cr] + [Mo]) / 5$$

wherein [C], [Mn], [Ni], [Cu], [Cr], and [Mo] are wt% of each element.

8. The manufacturing method of a steel sheet of claim 7, wherein the steel slab further includes one or more of 0.50% or less of nickel (Ni), 0.50% or less of copper (Cu), 0.05% or less of niobium (Nb), and 2 to 100 ppm of calcium (Ca).
 9. The manufacturing method of a steel sheet of claim 7,
- wherein the heating is performed in a temperature range of 1050 to 1250°C,
- the rough rolling is performed in a temperature range of 950 to 1050°C,
- the finish hot rolling is performed in a temperature range of 750 to 950°C, and

the reheating is performed for a residence time of $1.3t+10$ min to $1.3t+60$ min (t : sheet thickness, mm).

- 10.** The manufacturing method of a steel sheet of claim 7, wherein the cooled steel sheet has a thickness of 80 mm or more.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/015914

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/38(2006.01)i; **C22C 38/22**(2006.01)i; **C22C 38/28**(2006.01)i; **C22C 38/32**(2006.01)i; **C22C 38/58**(2006.01)i;
C21D 8/02(2006.01)i; **C21D 9/46**(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/38(2006.01); B21B 37/74(2006.01); C21D 8/02(2006.01); C22C 38/02(2006.01); C22C 38/06(2006.01);
 C22C 38/12(2006.01); C22C 38/44(2006.01); C22C 38/58(2006.01)

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

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

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

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

eKOMPASS (KIPO internal) & keywords: 경 도(hardness), 마르테나이트(martensite), 내마모성(wear resistance)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	KR 10-2015-0036798 A (JFE STEEL CORPORATION) 07 April 2015 (2015-04-07) See paragraphs [0084]-[0095] and claims 1-5.	1-2,7-8
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A	KR 10-2022-0062609 A (JFE STEEL CORPORATION) 17 May 2022 (2022-05-17) See claims 1-3.	1-10

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

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“&” document member of the same patent family

Date of the actual completion of the international search 17 January 2025	Date of mailing of the international search report 17 January 2025
Name and mailing address of the ISA/KR Korean Intellectual Property Office Government Complex-Daejeon Building 4, 189 Cheongsaro, Seo-gu, Daejeon 35208 Facsimile No. +82-42-481-8578	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 2022)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2024/015914

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Form PCT/ISA/210 (patent family annex) (July 2022)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/KR2024/015914

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