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(54) **HOT ROLLED STEEL SHEET FOR GROUND REINFORCEMENT AND STEEL PIPE FOR GROUND REINFORCEMENT, AND MANUFACTURING METHODS THEREOF**

(57) The present invention relates to: a hot rolled steel sheet for ground reinforcement and a steel pipe for ground reinforcement, which have excellent strength and formability; and manufacturing methods thereof.

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Description

Technical Field

5 **[0001]** The present disclosure relates to a hot-rolled steel sheet for ground reinforcement and a steel pipe for ground reinforcement, having excellent strength and formability, and manufacturing methods thereof.

Background Art

10 **[0002]** As the number of facilities such as underground tunnels, underground transfer centers and underground shopping centers for undergrounding of roads increases, the need for ground reinforcement materials serving as the basis for such facilities is increasing. Accordingly, a new steel pipe standard for ground reinforcement (KS D 3872) was established. A steel pipe for ground reinforcement used to reinforce ground structures in civil engineering, construction and the like should satisfy a YS of 800 MPa, TS of 860 MPa, and EL of 10% or more in a longitudinal direction. In order to satisfy the physical properties, a hot-rolled steel sheet is required to have high strength of a YS of 700 MPa or more and a TS of 750 MPa or more, and formability of EL of 15% or more. It is easy to obtain high strength by using a low-temperature structure such as bainite, martensite, and the like, but the structure has the disadvantage of causing softening in a weld zone due to a slow cooling rate after welding, thereby deteriorating the physical properties of the weld zone.

15 **[0003]** Meanwhile, in order to manufacture a small-diameter steel pipe, suitable for ground reinforcement, the formability thereof should be excellent, since the small diameter of the steel pipe is subject to a lot of work hardening during piping, and a microstructure thereof should be uniform to enable pipe production without shape defects.

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Summary of Invention

25 Technical Problem

[0004] An aspect of the present disclosure is to provide a hot-rolled steel sheet for ground reinforcement and a steel pipe for ground reinforcement, having excellent strength and formability, and manufacturing methods thereof.

30 Solution to Problem

[0005] According to an aspect of the present disclosure, provided is a hot-rolled steel sheet for ground reinforcement having excellent strength and formability, the hot-rolled steel sheet for ground reinforcement including by weight: 0.05 to 0.1% of C, 0.1% or less (excluding 0%) of Si, 1.5 to 1.9% of Mn, 0.05 to 0.15% of Ti, 0.03 to 0.1% of Nb, 0.03 to 0.1% of Mo, 0.02% or less (excluding 0%) of P, 0.02% or less (excluding 0%) of S, 0.01% or less (excluding 0%) of N, with a balance of Fe and inevitable impurities, wherein the following Relational expressions 1 and 2 are satisfied, wherein the hot-rolled steel sheet for ground reinforcement has a microstructure including by area, 90% or more of ferrite, wherein a grain of the ferrite has an average size of 15 μm or less, wherein the hot-rolled steel sheet includes by weight, 0.05% or more of a carbide containing Ti, Nb, and Mo, alone or in combination thereof, wherein the carbide has an average size of 20 nm or less.

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$$0.002 \leq (\text{Ti}/48 + \text{Mo}/96 + \text{Nb}/93) \leq 0.004 \quad [\text{Relational expression 1}]$$

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$$0.002 \leq (\text{C}/12) - (\text{Ti}/48 + \text{Mo}/93) \leq 0.006 \quad [\text{Relational expression 2}]$$

[0006] In the above Relational expressions 1 and 2, where a content of each alloy element refers to weight%.

50 **[0007]** Another aspect of the present disclosure is to provide a steel pipe for ground reinforcement having excellent strength and formability manufactured using the hot-rolled steel sheet.

[0008] According to an aspect of the present disclosure, provided is a method of manufacturing a hot-rolled steel sheet for ground reinforcement having excellent strength and formability, the method including: reheating a steel slab including, by weight: 0.05 to 0.1% of C, 0.1% or less (excluding 0%) of Si, 1.5 to 1.9% of Mn, 0.05 to 0.15% of Ti, 0.03 to 0.1% of Nb, 0.03 to 0.1% of Mo, 0.02% or less (excluding 0%) of P, 0.02% or less (excluding 0%) of S, 0.01% or less (excluding 0%) of N, with a balance of Fe and inevitable impurities, wherein the following Relational expressions 1 and 2 are satisfied, at a temperature within a range of 1150°C to 1300°C; finish hot rolling the reheated steel slab at a temperature within a range of 800 to 950°C to obtain a hot-rolled steel sheet; and coiling the hot-rolled steel sheet at a temperature

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within a range of 550°C to 700°C.

$$0.002 \leq (\text{Ti}/48 + \text{Mo}/96 + \text{Nb}/93) \leq 0.004$$

[Relational expression 1]

$$0.002 \leq (\text{C}/12) - (\text{Ti}/48 + \text{Mo}/96 + \text{Nb}/93) \leq 0.006$$

[Relational expression 2]

[0009] In the above Relational expressions 1 and 2, where a content of each alloy element refers to weight%.

[0010] Another aspect of the present disclosure is to provide a method of manufacturing a steel pipe for ground reinforcement having excellent strength and formability, including the operation of obtaining a steel pipe by piping the hot-rolled steel sheet manufactured by the above manufacturing method.

Advantageous Effects of Invention

[0011] As set forth above, according to an aspect of the present disclosure, a hot-rolled steel sheet for ground reinforcement having excellent strength and formability and manufacturing methods thereof may be provided.

Best Mode for Invention

[0012] Hereinafter, a hot-rolled steel sheet according to an embodiment of the present disclosure will be described. First, an alloy composition of the present invention will be described. A content of the alloy composition described below is in weight percent.

Carbon (C): 0.05 to 0.1%

[0013] Carbon (C) is an element added not only for solid solution strengthening but also for forming a carbide with Ti, Nb, and Mo, and to secure a tensile strength. In order to obtain the above-described effects, C is preferably added in an amount of 0.05% or more. However, when a content of carbon (C) exceeds 0.1%, carbide coarsening occurs and a precipitation strengthening effect cannot be sufficiently secured, and a pearlite fraction may increase in the microstructure, making it impossible to secure 90% or more of ferrite desired in the present disclosure. Therefore, the content of carbon (C) is preferably in a range of 0.05 to 0.1%. A lower limit of the content of carbon (C) is more preferably 0.06%, more preferably 0.065%, and most preferably 0.07%. An upper limit of the C content is more preferably 0.09%, more preferably 0.085%, and most preferably 0.08%.

Silicon (Si): 0.1% or less (excluding 0%)

[0014] Silicon (Si) is not only useful for deoxidizing steel, but is also effective in securing strength through solid solution strengthening. However, when the Si content exceeds 0.1%, there is a disadvantage in that a silicon oxide is formed, making plating difficult. Therefore, it is preferable that the Si content is 0.1% or less. The Si content is more preferably 0.08% or less, even more preferably 0.065% or less, and most preferably 0.05% or less.

Manganese (Mn): 1.5 to 1.9%

[0015] Manganese (Mn) is added to achieve a solid solution strengthening effect and to secure hardenability of a weld zone when cooled after welding. In order to obtain the above-described effects, it is preferable that 1.5% or more of Mn is added. However, when a content of Mn exceeds 1.9%, Mn segregation increases, which may cause defects and material deviations during continuous casting. Therefore, the Mn content is preferably in the range of 1.5 to 1.9%. A lower limit of the Mn content is more preferably 1.55%, even more preferably 1.6%, and most preferably 1.65%. An upper limit of the Mn content is more preferably 1.85%, even more preferably 1.8%, and most preferably 1.75%.

Titanium (Ti): 0.05 to 0.15%

[0016] Titanium (Ti) is added for precipitation strengthening effect and suppression of grain coarsening. When the Ti content is less than 0.05%, it is difficult to obtain the high strength targeted by the present disclosure, and when the Ti content exceeds 0.15%, coarse carbides are formed, making precipitation strengthening ineffective. Therefore, the Ti content is preferably in the range of 0.05 to 0.15%. A lower limit of the Ti content is more preferably 0.07%, even more

preferably 0.08%, and most preferably 0.09%. An upper limit of the Ti content is more preferably 0.14%, even more preferably 0.13%, and most preferably 0.12%.

Niobium (Nb): 0.03 to 0.1%

[0017] Niobium (Nb) is added to suppress recrystallization during hot rolling to obtain a finer grain size, in addition to the precipitation strengthening effect. When the Nb content is less than 0.03%, it may be difficult to obtain a sufficient precipitation strengthening effect, and when the Nb content exceeds 0.1%, the strength may decrease due to the formation of coarse precipitates. Therefore, it is preferable that the Nb content is in the range of 0.03 to 0.1%. A lower limit of the Nb content is more preferably 0.035%, even more preferably 0.038%, and most preferably 0.04%. An upper limit of the Nb content is more preferably 0.08%, even more preferably 0.07%, and most preferably 0.06%.

Molybdenum (Mo): 0.03 to 0.1%

[0018] Molybdenum (Mo) is added to suppress precipitate growth. In addition, Mo delays the formation of ferrite and allows ferrite to be formed at a low temperature, thereby contributing to grain refinement. When the Mo content is less than 0.03%, it may be difficult to sufficiently obtain the above-described effects. On the other hand, when the Mo content exceeds 0.1%, economic feasibility may decrease. Therefore, the Mo content is preferably in the range of 0.03 to 0.1%. A lower limit of the Mo content is more preferably 0.035%, even more preferably 0.04%, and most preferably 0.045%. An upper limit of the Mo content is more preferably 0.09%, even more preferably 0.08%, and most preferably 0.07%.

Phosphorous (P): 0.02% or less (excluding 0%)

[0019] Phosphorous (P) is an impurity element which segregates at grain boundaries and reduces toughness, so it is preferable that P is not included as much as possible, and in the present disclosure, an upper limit of the P content is limited to 0.02%. The P content is more preferably 0.018% or less, even more preferably 0.017% or less, and most preferably 0.015% or less.

Sulfur (S): 0.02% or less (excluding 0%)

[0020] Sulfur (S) is an impurity element and is the main element forming MnS. Since S reduces toughness due to the formation of coarse MnS, in the present disclosure, the S content is limited to 0.02% or less. The S content is more preferably 0.015% or less, even more preferably 0.01% or less, and most preferably 0.005% or less.

Nitrogen (N): 0.01% or less (excluding 0%)

[0021] Nitrogen (N) is an impurity element, and when the N content exceeds 0.01%, N reacts with Ti and Nb at high temperatures to form nitrides, so N has a disadvantage of lowering the strength of the steel material by reducing the content of Ti and Nb, substantially contributing to precipitation strengthening. Therefore, it is preferable that the N content is 0.01% or less. The N content is more preferably 0.008% or less, even more preferably 0.007% or less, and most preferably 0.006% or less.

[0022] In addition, it is preferable that the hot-rolled steel sheet of the present disclosure satisfies the following Relational expressions 1 and 2.

$$0.002 \leq (Ti/48 + Mo/96 + Nb/93) \leq 0.004 \quad [\text{Relational expression 1}]$$

[0023] The above Relational expression 1 is a parameter for improving strength by controlling the contents of Ti, Mo, and Nb, which are precipitation strengthening elements. When the value of $(Ti/48 + Mo/96 + Nb/93)$ is less than 0.002, an amount of precipitates may be too small to be effective in improving strength. On the other hand, when the value of $(Ti/48 + Mo/96 + Nb/93)$ exceeds 0.004, effective precipitation strengthening effect may not be obtained due to coarsening of the precipitates.

$$0.002 \leq (C/12) - (Ti/48 + Mo/96 + Nb/93) \leq 0.006 \quad [\text{Relational expression 2}]$$

[0024] The above Relational expression 2 is a parameter representing the content of C used in the solid solution strengthening effect excluding the content of C used in the precipitation strengthening effect. When the value of $(C/12) - (Ti/48 + Mo/96 + Nb/93)$ is less than 0.002, the high strength targeted in the present disclosure cannot be obtained.

since a ferrite phase does not obtain sufficient strength. On the other hand, when the value of $(C/12) - (Ti/48 + Mo/96 + Nb/93)$ exceeds 0.006, as the content of remaining C increases excessively, the precipitates may easily become coarse, so that the target strength cannot be obtained, and as a pearlite fraction increases, it may be difficult to obtain 90% or more of ferrite, targeted in the present disclosure. In addition, as the formation of pearlite is promoted in a central portion of the steel sheet in which a cooling rate is relatively slow, a large difference in hardness between the surface and the interior thereof occurs. As a result, a difference in hardness occurs in the thickness direction even in a steel pipe. In addition, during rolling processing, certain parts may undergo a large amount of processing, which may cause problems such as shape defects, occurrence of cracks and the like. Rolling processing refers to a process of forming protrusions on a surface of the steel pipe.

[0025] The remaining component of the present disclosure is iron (Fe). However, since in the common manufacturing process, unintended impurities may be inevitably incorporated from raw materials or the surrounding environment, the component may not be excluded. Since these impurities are known to any person skilled in the common manufacturing process, the entire contents thereof are not particularly mentioned in the present specification.

[0026] It is preferable that the hot-rolled steel sheet of the present disclosure has a microstructure including by area, 90% or more of ferrite. In the present disclosure, it is important to secure 90% or more of ferrite to secure excellent formability. In theory, the microstructure of the present disclosure is preferably a single phase of ferrite, but one or more of pearlite, retained austenite, bainite, and martensite may inevitably be formed in the microstructure during the manufacturing process. However, if a low-temperature transformation phase such as bainite or martensite increases, the formability deteriorates. In addition, if pearlite is present on the surface of the steel pipe, cracks are likely to occur during rolling processing due to cementite, a hard phase. Therefore, it is preferable that the remaining structure is as small as possible. A fraction of the ferrite is more preferably 93% or more, and even more preferably 95% or more. Meanwhile, the ferrite may be one or more of polygonal ferrite, bainitic ferrite, and asymmetric ferrite.

[0027] In this case, a grain of the ferrite preferably have an average size of 15 μm or less. When the size of the grain of the ferrite exceed 15 μm , sufficient strength may not be obtained due to grain coarsening. The grain size of the ferrite is more preferably 12 μm or less, and even more preferably 10 μm or less.

[0028] The hot-rolled steel sheet of the present disclosure preferably includes by weight, 0.05% or more of a carbide containing Ti, Nb, and Mo alone or in combination thereof, wherein the carbide preferably has an average size of 20 nm or less. As described above, by forming by weight, a large amount of fine carbides in an amount of 0.05% or more with an average size of 20 nm or less, an excellent strength improvement effect may be obtained without destruction of the carbides. A fraction of the carbides is more preferably 0.07% or more, by weight, and even more preferably 0.08% or more, by weight. The average size of the carbides is more preferably 15 nm or less, and even more preferably 10 nm or less. Meanwhile, in the present disclosure, the more the carbides are formed, the more advantageous they are, so there an upper limit of the carbides is not particularly limited, but considering the contents of Ti, Nb, and Mo contained in steel, it is difficult to exceed 0.2% by weight.

[0029] The hot-rolled steel sheet of the present disclosure provided as described above may have a yield strength (YS) of 700MPa or more, a tensile strength (TS) of 750 MPa or more, and an elongation (EL) of 15% or more, thereby securing excellent strength and formability.

[0030] Meanwhile, the present disclosure may provide a steel pipe manufactured using the hot-rolled steel sheet.

[0031] The steel pipe of the present disclosure may have a yield strength (YS) of 800MPa or more, a tensile strength (TS) of 800MPa or more, and an elongation (EL) of 10% or more, thereby securing excellent strength and formability.

[0032] On the other hand, during rolling processing, the steel pipe should be uniformly deformed in a thickness direction to ensure stable rolling processing without defects occurring due to stress concentration during processing. The steel pipe of the present disclosure has a deviation in hardness of 15% or less, which has an advantage of securing uniform hardness, which is advantageous for rolling processing. The deviation in hardness may be defined as $[(\text{maximum hardness value} - \text{minimum hardness value})/\text{maximum hardness value} \times 100]$ from each hardness value measured at points of 0.5mm, $t/4$, and $t/2$ points, where t is a thickness of a steel pipe, in the thickness direction from a surface of the steel pipe.

[0033] Hereinafter, a manufacturing method of a hot-rolled steel sheet according to an embodiment of the present disclosure will be described.

[0034] First, a steel slab satisfying the above-described alloy composition and Relational expressions 1 and 2 is reheated at a temperature within a range of 1150 to 1300°C. Reheating the steel slab at a temperature within a range of 1150 to 1300°C is to make the alloy composition and microstructure uniform. When the reheating temperature is lower than 1150°C, precipitates formed on the slab are not dissolved and an optimal precipitation strengthening effect cannot be obtained in a subsequent process. In addition, when the reheating temperature is higher than 1300°C, excessive grain growth occurs, making it difficult to secure the target material and quality. Therefore, it is preferable that the reheating temperature of the steel slab is in the range of 1150 to 1300°C. A lower limit of the reheating temperature is more preferably 1170°C, even more preferably 1180°C, and most preferably 1200°C. An upper limit of the reheating temperature is more preferably 1290°C, even more preferably 1270°C, and most preferably 1250°C.

[0035] Thereafter, the reheated steel slab is subjected to finish hot rolling at a temperature within a range of 800 to 950°C to obtain a hot-rolled steel sheet. When the finish hot rolling temperature is lower than 800°C, a portion of austenite may be transformed into ferrite, causing a final grain size thereof to become non-uniform, and when the finish hot rolling temperature is higher than 950°C, scale defects, or the like may occur. Therefore, it is preferable that the finish hot rolling temperature is in the range of 800 to 950°C. A lower limit of the finish hot rolling temperature is more preferably 820°C, even more preferably 825°C, and most preferably 850°C. An upper limit of the finish hot rolling temperature is more preferably 940°C, even more preferably 920°C, and most preferably 900°C.

[0036] Thereafter, the hot rolled steel sheet is coiled at a temperature within a range of 550 to 700°C. When the coiling temperature is lower than 550°C, not only can the microstructure desired by the present disclosure not be obtained, but also a sufficient precipitation strengthening effect cannot be obtained due to insufficient carbide formation. When the coiling temperature is higher than 700°C, coarsening of the carbide occurs and the target strength cannot be obtained. Therefore, the coiling temperature is preferably in the range of 550 to 700°C. A lower limit of the coiling temperature is more preferably 600°C, even more preferably 620°C, and most preferably 640°C. An upper limit of the coiling temperature is more preferably 680°C, even more preferably 665°C, and most preferably 650°C. Meanwhile, cooling after the finish hot rolling to coiling may be performed on a run-out table.

[0037] Meanwhile, in the present disclosure, a steel pipe may be obtained by obtaining a hot-rolled steel sheet through the above-described process and then piping the hot-rolled steel sheet. In this case, electric resistance welding (ERW), or the like may be used as a welding method during the piping. In addition, the present disclosure may further include an operation of rolling processing the steel pipe after obtaining the steel pipe.

[0038] Mode for Invention

[0039] 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 by illustration, and 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.

(Example)

[0040] After preparing a steel slab having the alloy composition shown in Table 1 below, the steel slab was reheated, finish hot rolled, and coiled under the conditions shown in Table 2 below to manufacture a hot-rolled steel sheet having a thickness of 2.8 to 6 mm. Thereafter, the manufactured hot-rolled steel sheet was piped to manufacture a steel pipe. In this case, roll forming and electric resistance welding, which are a common manufacturing method for electrically welded steel pipes, were used when manufacturing the pipe, pipe manufacturing conditions (t/D) according to a thickness of the material (t) and a diameter (D) of the steel pipe was applied at 14% or more. A microstructure, precipitates, and mechanical properties of the hot-rolled steel sheets and steel pipes manufactured in this way manner measured, and the hardness of the steel pipes in each location in the thickness direction was additionally measured, and the results thereof were shown in Tables 3 and 4 below.

[0041] A type and fraction of the microstructure were measured using an optical microscope (OM). In addition, a size of ferrite grains was photographed using a scanning electron microscope (SEM) and then measured using the circular intercept method of ASTM E 112.

[0042] A size of precipitates was measured by collecting precipitates from a specimen using the carbon replica method and using a transmission electron microscope (TEM). A fraction of the precipitates was obtained by measuring the contents of Ti, Nb, and Mo using a residue extraction method.

[0043] A yield strength (YS), tensile strength (TS), and elongation (EL) were measured by performing a tensile test using a tensile test method of the KS B 0802 standard. In the case of a hot-rolled steel sheet, test specimens were processed using a No. 5 test specimen of the KS B 0801 standard with a longitudinal direction aligned with a hot rolling direction. In addition, in the case of a steel pipe, a tensile test was performed using a No. 11 test specimen of the KS B 0801 standard.

[0044] The hardness in each location in the thickness direction was measured with a 1kg load using a Vickers hardness meter at points 0.5mm, t/4, and t/2, where t is a thickness of a steel pipe, in the thickness direction from an outer surface of the steel pipe. In this case, 5 points were measured at each location and an average value thereof was obtained. In addition, the deviation in hardness shown in Table 3 below was calculated as [(maximum hardness value - minimum hardness value) / maximum hardness value × 100] from each hardness value measured in each location.

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[Table 1]

Steel type No.	Alloy composition (weight%)										
	C	Si	Mn	P	S	Ti	Nb	Mo	N	Expression 1	Expression 2
Inventive Steel 1	0.0699	0.012	1.668	0.0138	0.0038	0.0929	0.041	0.049	0.003	0.00289	0.00294
Inventive Steel 2	0.0989	0.015	1.692	0.0134	0.0032	0.0895	0.038	0.051	0.003	0.00280	0.00544
Inventive Steel 3	0.058	0.013	1.702	0.0138	0.0028	0.086	0.041	0.054	0.003	0.00280	0.00204
Inventive Steel 4	0.071	0.015	1.892	0.0132	0.0042	0.103	0.04	0.052	0.003	0.00312	0.00280
Inventive Steel 5	0.074	0.013	1.525	0.0133	0.0042	0.0989	0.038	0.054	0.003	0.00303	0.00314
Inventive Steel 6	0.0846	0.012	1.725	0.0133	0.003	0.141	0.05	0.044	0.003	0.00393	0.00312
Inventive Steel 7	0.0862	0.012	1.742	0.0135	0.0038	0.052	0.052	0.041	0.003	0.00207	0.00511
Inventive Steel 8	0.0634	0.013	1.696	0.0138	0.0041	0.069	0.0951	0.064	0.004	0.00313	0.00216
Inventive Steel 9	0.0653	0.014	1.667	0.0145	0.0042	0.082	0.032	0.065	0.004	0.00273	0.00271
Inventive Steel 10	0.068	0.022	1.712	0.0175	0.0035	0.1011	0.043	0.092	0.003	0.00353	0.00214
Inventive Steel 11	0.068	0.022	1.712	0.0175	0.0035	0.1011	0.043	0.033	0.003	0.00291	0.00275
Comparative Steel 1	0.068	0.012	1.702	0.0151	0.0048	0.048	0.018	0.042	0.004	0.00163	0.00404
Comparative Steel 2	0.072	0.013	1.682	0.0131	0.0035	0.16	0.041	0.049	0.003	0.00428	0.00172
Comparative Steel 3	0.0702	0.015	1.435	0.0111	0.0042	0.1011	0.04	0.058	0.003	0.00314	0.00281
Comparative Steel 4	0.073	0.014	1.698	0.011	0.0042	0.0956	0.12	0.051	0.003	0.00381	0.00274

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(continued)

Steel type No.	Alloy composition (weight%)										
	C	Si	Mn	P	S	Ti	Nb	Mo	N	Expression 1	Expression 2
Comparative Steel 5	0.043	0.013	1.703	0.0113	0.0034	0.102	0.041	0.053	0.003	0.00312	0.00047
Comparative Steel 6	0.115	0.018	1.688	0.0142	0.0044	0.1011	0.04	0.048	0.003	0.00304	0.00655
Comparative Steel 7	0.0989	0.013	1.172	0.0113	0.0033	0.062	0.035	0.032	0.004	0.00200	0.00624
Comparative Steel 8	0.082	0.014	1.55	0.0135	0.0042	0.123	0.072	0.082	0.003	0.00419	0.00264
[Expression 1] $(Ti/48 + Mo/96 + Nb/93)$ [Expression 2] $(C/12) - (Ti/48 + Mo/96 + Nb/93)$											

[Table 2]

Division	Steel type No.	Reheating temperature (°C)	Finish hot rolling temperature (°C)	Coiling temperature(°C)
Inventive Example 1	Inventive Steel 1	1214	892	612
Inventive Example 2	Inventive Steel 1	1156	888	614
Inventive Example 3	Inventive Steel 1	1208	806	624
Inventive Example 4	Inventive Steel 1	1231	945	631
Inventive Example 5	Inventive Steel 1	1210	878	552
Inventive Example 6	Inventive Steel 1	1212	869	692
Comparative Example 1	Inventive Steel 1	1121	891	614
Comparative Example 2	Inventive Steel 1	1213	789	621
Comparative Example 3	Inventive Steel 1	1215	972	622
Comparative Example 4	Inventive Steel 1	1208	885	518
Comparative Example 5	Inventive Steel 1	1209	886	711
Inventive Example 7	Inventive Steel 2	1210	895	615
Inventive Example 8	Inventive Steel 3	1205	900	612
Inventive Example 9	Inventive Steel 4	1214	895	613
Inventive Example 10	Inventive Steel 5	1222	873	624
Inventive Example 11	Inventive Steel 6	1205	865	618
Inventive Example 12	Inventive Steel 7	1198	857	614
Inventive Example 13	Inventive Steel 8	1202	858	611
Inventive Example 14	Inventive Steel 9	1195	868	608
Inventive Example 15	Inventive Steel 10	1194	884	603
Inventive Example 16	Inventive Steel 11	1213	868	603

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(continued)

Division	Steel type No.	Reheating temperature (°C)	Finish hot rolling temperature (°C)	Coiling temperature(°C)
Comparativ e Example 6	Comparative Steel 1	1211	890	620
Comparativ e Example 7	Comparative Steel 2	1201	912	608
Comparativ e Example 8	Comparative Steel 3	1205	968	612
Comparativ e Example 9	Comparative Steel 4	1211	867	608
Comparativ e Example 10	Comparative Steel 5	1205	901	621
Comparativ e Example 11	Comparative Steel 6	1209	895	612
Comparativ e Example 12	Comparative Steel 7	1210	876	618
Comparativ e Example 13	Comparative Steel 8	1205	865	582

[Table 3]

Divisio n	Microstructure			Carbide containing alone or combination of Ti, Nb, and Mo	
	Ferrite (area %)	Remainder (area %)	Ferrite grain size (μm)	fraction(weig ht%)	Average size (nm)
Inventi ve Example 1	98.9	P: 1.1	8.8	0.107	5.6
Inventi ve Example 2	99.0	P:1.0	8.5	0.095	5.5
Inventi ve Example 3	97.2	P:2.8	6.7	0.123	10.8
Inventi ve Example 4	95.9	P:4.1	13.5	0.122	6.2
Inventi ve Example 5	92.8	B:6.1, M:1.1	7.8	0.076	4.8
Inventi ve Example 6	90.3	P : 9.7	7.9	0.128	7.5
Compara tive Example 1	98.8	P:1.2	8.3	0.046	6.2
Compara tive Example 2	97.5	P:2.5	6.5	0.102	28.4
Compara tive Example 3	98.2	P:1.8	15.3	0.093	6.8
Compara tive Example 4	86.3	B:12.5, M:1.2	8.0	0.044	5.5
Compara tive Example 5	86.8	P:13.2	10.3	0.106	23.1
Inventi ve Example 7	91.2	P:8.8	8.8	0.111	14.2
Inventi ve Example 8	99.2	P:0.8	9.2	0.092	4.8
Inventi ve Example 9	99.0	P:1.0	9.8	0.087	7.0
Inventi ve Example 10	98.5	P:1.5	9.7	0.114	4.5
Inventi ve Example 11	98.0	P:2.0	7.5	0.141	18.2
Inventi ve Example 12	98.2	P:1.8	8.3	0.072	5.9
Inventi ve Example 13	98.1	P:1.9	5.2	0.115	6.8
Inventi ve Example 14	99.5	P:0.5	9.2	0.106	7.2
Inventi ve Example 15	96.8	B:2.1, RA:1.1	8.5	0.110	3.8
Inventi ve Example 16	98.2	P:1.8	9.8	0.101	6.7
Compara tive Example 6	97.8	P:2.2	10.2	0.046	6.5
Compara tive Example 7	97.5	P:2.5	8.1	0.156	52.5

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(continued)

Divisio n	Microstructure			Carbide containing alone or combination of Ti, Nb, and Mo	
	Ferrite (area %)	Remainder (area %)	Ferrite grain size (μm)	fraction(weig ht%)	Average size (nm)
Compara tive Example 8	99.5	P:0.5	14.6	0.049	9.8
Compara tive Example 9	98.2	P:1.8	4.8	0.131	51.3
Compara tive Example 10	99.2	P:0.8	9.2	0.059	6.6
Compara tive Example 11	87.7	P:12.3	9.5	0.113	22.1
Compara tive Example 12	90.5	P:9.5	7.5	0.047	6.7
Compara tive Example 13	94.8	P:5.2	6.9	0.175	48.2
P: Pearlite, RA: Retained Austenite, B: Bainite, M: Martensite					

[Table 4]

Divisi on	Hot-rolled steel sheet			Steel pipe						
	YS (MPa)	TS (MPa)	EL (%)	YS (MPa)	TS (MPa)	EL (%)	Hardness in each location in a thickness direction (Hv)			Devia tions in hardn ess (%)
							0.5mm from surface	t/4	t/2	
Invent ive Examl e 1	733	793	22.4	867	922	14	267	288	296	10
Invent ive Examl e 2	712	769	23.1	825	882	14	273	275	297	8
Invent ive Examl e 3	717	760	20.3	835	878	13	268	274	282	5
Invent ive Examl e 4	734	797	21.5	872	922	14	272	290	288	6
Invent ive Examl e 5	715	762	22.4	847	890	14	268	275	276	3
Invent ive Examl e 6	712	775	21.8	821	894	14	268	279	288	7
Compar ative Examl e 1	679	735	23.3	789	852	15	257	267	264	4
Compar ative Examl e 2	651	743	24.1	774	848	15	260	265	267	3
Compar ative Examl e 3	671	735	22.3	788	842	14	251	263	265	5
Compar ative Examl e 4	672	752	21.1	781	862	14	255	272	277	8

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5	Divisi on	Hot-rolled steel sheet			Steel pipe						
		YS (MPa)	TS (MPa)	EL (%)	YS (MPa)	TS (MPa)	EL (%)	Hardness in each location in a thickness direction (Hv)			Devia tions in hardn ess (%)
								0.5mm from surface	t/4	t/2	
10	Compar ative Exampl e 5	685	760	19.1	792	876	13	255	273	276	8
15	Invent ive Exampl e 7	711	798	20.1	838	932	14	273	291	294	7
	Invent ive Exampl e 8	705	760	24.4	824	877	15	268	275	272	3
20	Invent ive Exampl e 9	736	807	21.4	843	911	14	271	285	278	5
	Invent ive Exampl e 10	711	761	19.4	829	875	15	268	273	268	2
	Invent ive Exampl e 11	781	853	18.4	935	1012	13	298	315	311	5
25	Invent ive Exampl e 12	706	759	23.1	816	861	14	254	265	268	5
	Invent ive Exampl e 13	738	792	19.5	880	906	13	272	288	292	7
30	Invent ive Exampl e 14	711	761	21.5	836	878	14	260	272	276	6
	Invent ive Exampl e 15	754	812	22.3	868	911	15	271	284	284	5
	Invent ive Exampl e 16	714	772	22.3	851	885	14	264	275	272	4
35	Compar ative Exampl e 6	626	728	24.6	745	844	17	255	264	268	5
	Compar ative Exampl e 7	679	746	23.2	786	856	16	257	269	266	4
40	Compar ative Exampl e 8	692	767	23.1	782	815	15	252	268	275	8
	Compar ative Exampl e 9	675	772	24.0	781	878	16	265	274	285	7
	Compar ative Exampl e 10	682	745	28.2	782	848	20	255	268	274	7
55	Compar ative Exampl e 11	684	788	18.3	782	887	13	258	315	278	18

(continued)

Divisi on	Hot-rolled steel sheet			Steel pipe						
	YS (MPa)	TS (MPa)	EL (%)	YS (MPa)	TS (MPa)	EL (%)	Hardness in each location in a thickness direction (Hv)			Devia tions in hardn ess (%)
							0.5mm from surface	t/4	t/2	
Compar ative Examl e 12	648	736	24.8	756	848	17	251	304	272	17
Compar ative Examl e 13	681	742	20.2	787	851	14	259	272	268	5

[0045] As can be seen from Tables 1 to 4, in the case of Inventive Examples 1 to 16 satisfying the alloy composition, Relational expressions 1 and 2, and manufacturing conditions proposed by the present disclosure, it can be seen that excellent mechanical properties may be secured as the microstructure and precipitates targeted by the present disclosure are secured, and deviations in hardness of the steel pipe in each location in the thickness direction was also low.

[0046] In the case of Comparative Example 1, the alloy composition of the present disclosure was satisfied, but due to the low reheating temperature of the steel slab, redissolving of precipitation strengthening elements was insufficient, and sufficient precipitation strengthening effect was not obtained. Thus, the high strength targeted in the present disclosure was not secured.

[0047] In the case of Comparative Example 2, the alloy composition of the present disclosure was satisfied, but due to the low finish hot rolling temperature, coarse precipitates were formed during rolling so that a sufficient precipitation strengthening effect was not obtained. Thus, the high strength targeted in the present disclosure was not secured.

[0048] In the case of Comparative Example 3, the alloy composition of the present disclosure was satisfied, but due to the high finish hot rolling temperature, grains become coarse, so that the high strength targeted in the present disclosure was not secured.

[0049] In the case of Comparative Example 4, the alloy composition of the present disclosure was satisfied, but due to the low coiling temperature, not only was the microstructure desired in the present disclosure not obtained, but the sufficient precipitation strengthening effect was not obtained, so that the high strength targeted by the present disclosure was not secured.

[0050] In the case of Comparative Example 5, the alloy composition of the present disclosure was satisfied, but due to the high coiling temperature, coarse carbides were formed, and the high strength targeted by the present disclosure was not secured.

[0051] In the case of Comparative Example 6, due to the low contents of Ti and Nb, a sufficient precipitation strengthening effect was not obtained, and the high strength targeted by the present disclosure was not secured.

[0052] In the case of Comparative Example 7, due to the formation of coarse carbides due to the high Ti content, the high strength targeted by the present disclosure was not secured.

[0053] In the case of Comparative Example 8, due to the low content of Mn, the solid solution strengthening effect was low, and the sufficient precipitation strengthening effect was not obtained due to a change in phase transformation conditions during cooling, so the high strength targeted by the present disclosure was not secured.

[0054] In the case of Comparative Example 9, due to the formation of coarse carbides due to the high Nb content, the high strength targeted by the present disclosure was not secured.

[0055] In the case of Comparative Example 10, due to the low content of C, not only did it not satisfy Relational expression 2, but also the high strength targeted by the present disclosure was not secured.

[0056] In the case of Comparative Example 11, due to the high content of C, a solid solution C increased and a pearlite content increased, so the microstructure desired by the present disclosure was not obtained, and as Relational expression 2 was not satisfied, it can be seen that not only was the high strength targeted by the present disclosure not secured, but deviations in hardness of the steel pipe in each location in the thickness direction also increased.

[0057] In the case of Comparative Example 12, as Relational expression 2 was not satisfied, it can be seen that an appropriate balance between the precipitate and the solid solution C proposed in the present disclosure was not obtained, so not only was high strength not secured, and deviations in hardness of the steel pipe in each location in the thickness direction increased.

[0058] In the case of Comparative Example 13, as Relational expression 1 was not satisfied, a sufficient precipitation

strengthening effect was not obtained, so that the high strength targeted by the present disclosure was not secured.

Claims

1. A hot-rolled steel sheet for ground reinforcement, comprising by weight:

0.05 to 0.1% of C, 0.1% or less (excluding 0%) of Si, 1.5 to 1.9% of Mn, 0.05 to 0.15% of Ti, 0.03 to 0.1% of Nb, 0.03 to 0.1% of Mo, 0.02% or less (excluding 0%) of P, 0.02% or less (excluding 0%) of S, 0.01% or less (excluding 0%) of N, with a balance of Fe and inevitable impurities, wherein the following Relational expressions 1 and 2 are satisfied,

wherein the hot-rolled steel sheet for ground reinforcement has a microstructure including by area, 90% or more of ferrite,

wherein a grain of the ferrite has an average size of 15 μm or less,

wherein the hot-rolled steel sheet includes by weight, 0.05% or more of a carbide containing Ti, Nb, and Mo alone or in combination thereof,

wherein the carbide has an average size of 20 nm or less,

$$0.002 \leq (\text{Ti}/48 + \text{Mo}/96 + \text{Nb}/93) \leq 0.004 \quad [\text{Relational expression 1}]$$

$$0.002 \leq (\text{C}/12) - (\text{Ti}/48 + \text{Mo}/96 + \text{Nb}/93) \leq 0.006 \quad [\text{Relational expression 2}]$$

in the above Relational expressions 1 and 2, where a content of each alloy element refers to weight%.

2. The hot-rolled steel sheet for ground reinforcement of claim 1, wherein the microstructure comprises one or more of pearlite, retained austenite, bainite, and martensite, as a remaining structure thereof.

3. The hot-rolled steel sheet for ground reinforcement of claim 1, wherein the hot-rolled steel sheet has a yield strength (YS) of 700 MPa or more, a tensile strength (TS) of 750 MPa or more, and an elongation (EL) of 15% or more.

4. A steel pipe for ground reinforcement manufactured using the hot-rolled steel sheet described in any one of claims 1 to 3.

5. The steel pipe for ground reinforcement of claim 4, the steel pipe has a yield strength (YS) of 800 MPa or more, a tensile strength (TS) of 860 MPa or more, and an elongation (EL) of 10% or more.

6. The steel pipe for ground reinforcement of claim 4, the steel pipe has a deviation in hardness of 15% or less, where the deviation in hardness is defined as $[(\text{maximum hardness value} - \text{minimum hardness value}) / \text{maximum hardness value} \times 100]$ from each hardness value measured at points of 0.5 mm, $t/4$, and $t/2$, where t is a thickness of the steel pipe, in a thickness direction from a surface of the steel pipe.

7. A method for manufacturing a hot-rolled steel sheet for ground reinforcement, comprising: reheating a steel slab including, by weight:

0.05 to 0.1% of C, 0.1% or less (excluding 0%) of Si, 1.5 to 1.9% of Mn, 0.05 to 0.15% of Ti, 0.03 to 0.1% of Nb, 0.03 to 0.1% of Mo, 0.02% or less (excluding 0%) of P, 0.02% or less (excluding 0%) of S, 0.01% or less (excluding 0%) of N, with a balance of Fe and inevitable impurities, wherein the following Relational expressions 1 and 2 are satisfied, at a temperature within a range of 1150°C to 1300°C;

finish hot rolling the reheated steel slab at a temperature within a range of 800 to 950°C to obtain a hot-rolled steel sheet; and

coiling the hot-rolled steel sheet at a temperature within a range of 550°C to 700°C,

$$0.002 \leq (\text{Ti}/48 + \text{Mo}/96 + \text{Nb}/93) \leq 0.004 \quad [\text{Relational expression 1}]$$

$$0.002 \leq (C/12) - (Ti/48 + Mo/96 + Nb/93) \leq 0.006$$

[Relational expression 2]

- 5 in the above Relational expressions 1 and 2, where a content of each alloy element refers to weight%.
8. A method for manufacturing a steel pipe for ground reinforcement, comprising:
piping the hot-rolled steel sheet manufactured by the manufacturing method described in claim 7 to obtain a steel pipe.
- 10 9. The method for manufacturing a steel pipe for ground reinforcement of claim 8, further comprising, after obtaining the steel pipe:
rolling processing the steel pipe.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2022/019505

A. CLASSIFICATION OF SUBJECT MATTER C22C 38/04(2006.01)i; C22C 38/14(2006.01)i; C22C 38/12(2006.01)i; C22C 38/00(2006.01)i; C21D 8/02(2006.01)i; B21B 21/02(2006.01)i; B21C 47/02(2006.01)i According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) C22C 38/04(2006.01); B21B 3/00(2006.01); B21C 37/08(2006.01); C22C 38/00(2006.01); C22C 38/14(2006.01); C22C 38/38(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: 열연강판(hot rolled steel sheet), 강관(steel pipe), 페라이트(ferrite), 보강재(reinforcement), 결정립(grain)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
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☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents: "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 13 March 2023	Date of mailing of the international search report 14 March 2023	
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.	

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Information on patent family members

International application No.

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