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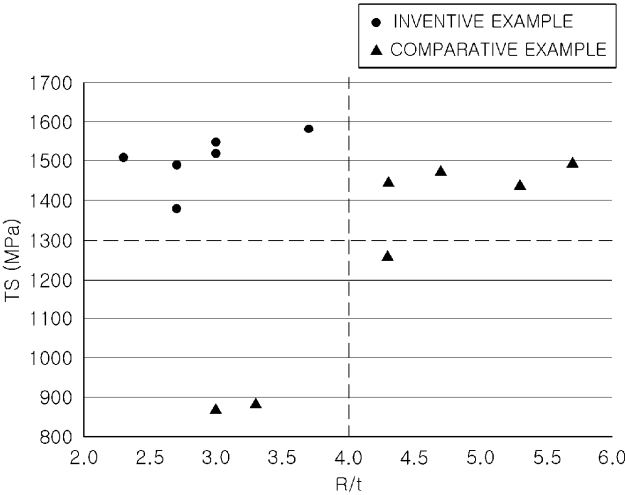
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(54) **HOT-ROLLED STEEL SHEET AND METHOD FOR MANUFACTURING SAME**

(57) The present invention relates to a hot-rolled steel sheet used in frames, structures, etc. and, to a hot-rolled steel sheet that ensures high hardness, strength, and excellent processing characteristics, and a method for manufacturing same.

[FIG. 1]



Description**Technical Field**

5 **[0001]** The present disclosure relates to a hot-rolled steel sheet used for frames, structures, and the like, and more particularly, to a hot-rolled steel sheet that secures high hardness, strength, and excellent processing characteristics, and a method for manufacturing the same.

Background Art

10 **[0002]** Conventionally, a wear-resistant hot-rolled steel sheet having high hardness has mainly utilized a martensitic microstructure to have high strength and hardness, and this high hardness leads to high wear resistance, so that it has been used for parts requiring wear resistance. However, due to poor bendability according to high strength, processing is limited, which has a disadvantage in that a roll forming method is utilized or only minimal processing is applied for use.

[0003] This acts as a similar limiting factor in high-strength hot-rolled steel sheets that utilize martensite as a primary phase, and various technologies have been proposed to overcome this.

[0004] Patent Document 1 suggests that excellent bendability can be secured in a 1 GPa-grade high-strength martensitic hot-rolled steel sheet when a hard phase of martensite and tempered martensite in a microstructure at positions of 200 μm and 100 μm from the surface is reduced compared to a central portion. In addition, Patent Document 2 suggests improving low-temperature impact toughness through microstructure refinement in a 1.2 GPa-grade martensitic steel, obtaining excellent flange formability by controlling precipitates, and obtaining high bendability by controlling surface roughness.

25 **[0005]** However, in Patent Document 1, it is difficult to secure sufficient strength, the change between the central portion and the surface layer of the steel sheet is not large, and there is no control over the microstructure and properties of the extreme surface layer of 100 μm or less, so the effect of improving bendability may be considered to be small. Meanwhile, Patent Document 2 has a limitation in improving bendability compared to strength with only surface roughness control, a certain level of surface roughness can be conventionally obtained only by passing through a pickling process, and there is a disadvantage in that manufacturing conditions must be strictly limited for precipitate control.

30 **[0006]** In addition, alloying elements such as Si, Mn, Mo, Cr, Cu, and Ni, which are mainly used to manufacture high-hardness steels as described above, are effective in improving hardness and formability, but when a large amount of alloying elements is added to improve properties, segregation of the alloying elements and non-uniformity of the microstructure are caused, resulting in inferior bending workability. In particular, in a steel with high hardenability, the change in microstructure during cooling is sensitive, so a low-temperature transformation structure is formed non-uniformly, which makes it difficult to obtain higher bending workability.

(Patent Document 1) Korean Patent Laid-Open Publication No. 10-2023-0085173

40 (Patent Document 2) International Patent Laid-Open Publication No. WO 2020-026593

Disclosure of Invention**Technical Problem**

45 **[0007]** An aspect of the present disclosure is to provide a hot-rolled steel sheet excellent in bending workability, strength, and hardness, and a method for manufacturing the same.

[0008] The objects of the present disclosure are not limited to the above-mentioned matters. Additional objects of the present disclosure are described in the overall content of the specification, and a person of ordinary skill in the art to which the present disclosure pertains will have no difficulty in understanding the additional objects of the present disclosure from the contents described in the specification of the present disclosure.

Solution to Problem

55 **[0009]** An aspect of the present disclosure provides a hot-rolled steel sheet comprising, by weight %, C: 0.17 to 0.26%, Si: 0.01 to 0.5%, Mn: 0.4 to 2.2%, Cr: 0.005 to 0.6%, Mo: 0.005 to 0.3%, Nb: 0.001 to 0.01%, Ti: 0.005 to 0.08%, V: 0.005 to 0.05%, Al: 0.01 to 0.5%, P: 0.003 to 0.05%, S: 0.001 to 0.01%, N: 0.001 to 0.01%, B: 0.0005 to 0.003%, with the remainder being Fe and other unavoidable impurities, and satisfying the following Formula 1,

wherein a surface layer microstructure up to 10 μm from a surface comprises, by area fraction, 5 to 40% of ferrite and 2 to 10% of twinned martensite, and

a central portion microstructure comprises, by area fraction, 80% or more (including 100%) of martensite and auto-tempered martensite, and 20% or less (including 0%) of one or more of pearlite and bainite.

[Formula 1]

$$30 \leq T \leq 100$$

$$T = (([C]/10)^{0.5}) \times (0.7 \times [Si] + 1) \times (5 \times [Mn] + 1) \times (2.5 \times [Cr] + 1) \times (5 \times [Mo] + 1) \times 25$$

[0010] In Formula 1, [C], [Si], [Mn], [Cr], and [Mo] denote the content (by weight %) of the corresponding alloying elements, and a value of 0 is substituted if these elements are not intentionally added.

[0011] The central portion microstructure may have a prior austenite aspect ratio of 1 to 10.

[0012] The hot-rolled steel sheet may have a central portion cross-sectional hardness of 400 HV or more and a width-direction tensile strength of 1300 MPa or more.

[0013] The hot-rolled steel sheet may have a bendability (R/t) of 4.0 or less.

[0014] In the hot-rolled steel sheet, a difference between original bendability and bendability may be greater than 0.5.

[0015] Another aspect of the present disclosure provides a method for manufacturing a hot-rolled steel sheet, the method comprising: heating a steel slab comprising, by weight %, C: 0.17 to 0.26%, Si: 0.01 to 0.5%, Mn: 0.4 to 2.2%, Cr: 0.005 to 0.6%, Mo: 0.005 to 0.3%, Nb: 0.001 to 0.01%, Ti: 0.005 to 0.08%, V: 0.005 to 0.05%, Al: 0.01 to 0.5%, P: 0.003 to 0.05%, S: 0.001 to 0.01%, N: 0.001 to 0.01%, B: 0.0005 to 0.003%, with the remainder being Fe and other unavoidable impurities, and satisfying the following Formula 1, to a temperature range of 1150 to 1350°C;

performing rough rolling on the heated steel slab at a roughing delivery temperature (RDT) of the following Formula 2 to obtain a bar plate;

performing finish rolling on the bar plate at a finishing delivery temperature (FDT) of the following Formula 3 to obtain a hot-rolled steel sheet;

performing first cooling on the hot-rolled steel sheet at a first average cooling rate of 60 to 90°C/sec to a first cooling stop temperature of 150 to 350°C;

performing second cooling after the first cooling at a second average cooling rate of 1 to 50°C/sec to a coiling temperature (CT) of 50 to 200°C; and

coiling after the second cooling.

[Formula 1]

$$30 \leq T \leq 100$$

$$T = (([C]/10)^{0.5}) \times (0.7 \times [Si] + 1) \times (5 \times [Mn] + 1) \times (2.5 \times [Cr] + 1) \times (5 \times [Mo] + 1) \times 25$$

[0016] In Formula 1, [C], [Si], [Mn], [Cr], and [Mo] denote the content (by weight %) of the corresponding alloying elements, and a value of 0 is substituted if these elements are not intentionally added.

[Formula 2]

$$RDT \text{ (}^{\circ}\text{C)} \leq (FT + 80 + \text{bar plate thickness} \times 3.8)$$

$$FT = 907 + 239[Al] - 10.3[Cr] - 25.8[Mn] + 17.9[Mo] + 30.9[Si] - 254[C]$$

[0017] In Formula 2, [Al], [Cr], [Mn], [Mo], [Si], and [C] denote the content (by weight %) of the corresponding alloying elements, a value of 0 is substituted if these elements are not intentionally added, and the thickness of the bar plate is in mm.

[Formula 3]

$$FDT \text{ (}^{\circ}\text{C)} \geq FT$$

[0018] The method may further comprise, after obtaining the bar plate, descaling and surface-cooling the entire width of the bar plate with a water pressure of 150 bar or more.

[0019] The thickness of the bar may satisfy the following Formula 4.

$$\text{bar plate thickness (mm)} \geq \text{hot-rolled steel sheet thickness (mm)} \times 10 \quad [\text{Formula 4}]$$

[0020] The rough rolling may be performed in a temperature range of 900 to 1100°C.

Advantageous Effects of Invention

[0021] According to an aspect of the present disclosure, it is possible to provide a hot-rolled steel sheet excellent in bendability and hardness, and a method for manufacturing the same.

[0022] The various and beneficial advantages and effects of the present disclosure are not limited to the above-described contents, and may be more easily understood in the course of describing specific embodiments of the present disclosure.

Brief Description of Drawings

[0023] FIG. 1 is a graph showing the relationship between the central portion tensile strength (TS) and the bendability (R/t) of inventive examples and comparative examples in an embodiment.

Best Mode for the Invention

[0024] The terms used in this specification are for the purpose of describing the present disclosure and are not intended to limit the present disclosure. In addition, the singular forms used in this specification include the plural forms unless the relevant definition clearly indicates the contrary.

[0025] The meaning of "comprising" used in the specification specifies a configuration and does not exclude the presence or addition of other configurations.

[0026] Unless otherwise defined, all terms, including technical and scientific terms, used in this specification have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. Pre-defined terms are to be interpreted as having a meaning consistent with the related technical literature and the presently disclosed content.

[0027] The inventors of the present disclosure have conducted in-depth research on the changes in the cross-sectional hardness of the central portion, bendability, and original bendability after milling the surface according to the characteristics of the composition, manufacturing process, and microstructure for different steels with various compositions and microstructures in order to solve the problems of the prior art. As a result, it was confirmed that the detailed characteristics of each configuration of the surface layer (surface portion) and the core (central portion) and the original bendability are correlated with the cross-sectional hardness of the central portion and the bending characteristics, and as a result of in-depth research on a plan to implement this, the present disclosure was derived by exploring the steel composition and microstructure of the hot-rolled steel sheet and a plan to manufacture the same.

[0028] First, an example of the hot-rolled steel sheet of the present disclosure will be described in detail. Hereinafter,

the alloy composition and range of the hot-rolled steel sheet will be described. The content of the alloy composition described below means % by weight unless otherwise specified.

Carbon (C): 0.17 to 0.26%

[0029] C is the most economical and effective element for strengthening steel, and has a great influence on strength and hardness. As its added amount increases, the hardenability increases, making it easier to form hard phases such as bainite and martensite in the microstructure, thereby increasing the tensile strength. In addition, because C has a property of accumulating in austenite rather than ferrite, ferrite is formed in the surface layer, and when C accumulated in austenite transforms into martensite, it provides a mechanism for changing to twinned martensite. However, when the content of C exceeds 0.26%, the hardness of martensite increases excessively, which causes a problem of deterioration of bending workability with an excessive increase in strength, and it may be difficult to secure sufficient weldability. On the other hand, when the content of C is less than 0.17%, it is difficult to obtain a sufficient strengthening effect. Therefore, it is preferable that the content of C is in the range of 0.17 to 0.26%. The lower limit of the C content is more preferably 0.175%, still more preferably 0.18%, and most preferably 0.185%. The upper limit of the C content is more preferably 0.25%, still more preferably 0.24%, and most preferably 0.23%.

Silicon (Si): 0.01 to 0.5%

[0030] Si is an element that deoxidizes molten steel, exhibits a solid-solution strengthening effect, and is advantageous for improving formability by delaying the formation of coarse carbides. When the content of Si is less than 0.01%, the solid-solution strengthening effect and the formability improving effect cannot be sufficiently obtained. On the other hand, when the content of Si exceeds 0.5%, it is not easy to remove red scale formed on the surface of the steel sheet during hot rolling, which may result in very poor surface quality of the steel sheet. In addition, there is a problem that ductility and weldability are also deteriorated. Therefore, it is preferable that the content of Si is in the range of 0.01 to 0.5%. The lower limit of the Si content is more preferably 0.012%, still more preferably 0.015%, and most preferably 0.02%. The upper limit of the Si content is more preferably 0.4%, still more preferably 0.35%, and most preferably 0.3%.

Manganese (Mn): 0.4 to 2.2%

[0031] Mn is an element that is effective in solid-solution strengthening steel, similar to Si, and increases the hardenability of the steel to facilitate the formation of bainite and martensite, which are hard phases, during cooling after hot rolling. In addition, when ferrite is formed in the surface layer, it is concentrated in austenite, and when it subsequently transforms into martensite, it provides a mechanism for changing to twinned martensite. When the content of Mn is less than 0.4%, the effects of solid-solution strengthening and formation of bainite and martensite cannot be sufficiently obtained. On the other hand, when the content of Mn exceeds 2.2%, grain boundaries become brittle, causing problems such as low-temperature cracking. In addition, it may be difficult to secure sufficient formability due to an excessive increase in strength, a segregated portion is largely developed at the center of the thickness during slab casting in a continuous casting process, and a non-uniform microstructure is formed in the thickness direction during cooling after hot rolling, resulting in inferior bending workability. In particular, it is difficult to uniformly manufacture the microstructure during cooling even in the overall length and overall width of the hot-rolled steel sheet. Therefore, it is preferable that the content of Mn is in the range of 0.4 to 2.2%. The lower limit of the Mn content is more preferably 0.45%, still more preferably 0.5%, and most preferably 0.55%. The upper limit of the Mn content is more preferably 2.1%, still more preferably 2.05%, and most preferably 2.0%.

Chromium (Cr): 0.005 to 0.6%

[0032] Cr serves to solid-solution strengthen steel and delay ferrite phase transformation during cooling to help form martensite and bainite. When the content of Cr is less than 0.005%, the effects of solid-solution strengthening and formation of martensite and bainite cannot be sufficiently obtained. On the other hand, when the content of Cr exceeds 0.6%, a segregated portion at the center of the thickness is largely developed, similar to Mn, and the microstructure in the thickness direction becomes non-uniform, thereby deteriorating bending workability. Therefore, it is preferable that the content of Cr is in the range of 0.005 to 0.6%. The lower limit of the Cr content is more preferably 0.007%, still more preferably 0.008%, and most preferably 0.01%. The upper limit of the Cr content is more preferably 0.5%, still more preferably 0.45%, and most preferably 0.4%.

Molybdenum (Mo): 0.005 to 0.3%

[0033] Mo increases the hardenability of steel to facilitate the formation of martensite and bainite. When the content of Mo is less than 0.005%, the above-described effects cannot be sufficiently obtained. On the other hand, when the content of Mo exceeds 0.3%, martensite is formed in the surface layer due to an excessive increase in hardenability, so that bending workability is rapidly deteriorated, which is economically disadvantageous, and it may be difficult to secure sufficient weldability. In addition, a ferrite structure cannot be formed on the surface layer due to excessively high hardenability. Therefore, it is preferable that the content of Mo is in the range of 0.005 to 0.3%. The lower limit of the Mo content is more preferably 0.01%, still more preferably 0.02%, and most preferably 0.03%. The upper limit of the Mo content is more preferably 0.25%, still more preferably 0.2%, and most preferably 0.15%.

Niobium (Nb): 0.001 to 0.01%

[0034] Nb is a representative precipitation-strengthening element along with Ti and V, and is precipitated as a precipitate during hot rolling to exhibit a grain refinement effect due to recrystallization delay, thereby being effective in improving the strength and impact toughness of steel. When the content of Nb is less than 0.001%, the above-described effects cannot be sufficiently obtained. On the other hand, when the content of Nb exceeds 0.01%, coarse composite precipitates are formed during hot rolling, which deteriorates bending workability. In addition, it has the effect of excessively increasing the aspect ratio of the parent austenite before the martensitic transformation. Therefore, it is preferable that the content of Nb is in the range of 0.001 to 0.01%.

Titanium (Ti): 0.005 to 0.08%

[0035] Ti is a representative precipitation-strengthening element along with Nb and V, and forms coarse TiN through strong affinity with nitrogen. The TiN has an effect of suppressing the growth of crystal grains during a heating process for hot rolling. In addition, the remaining Ti after reacting with nitrogen is dissolved in the steel and combined with carbon to form TiC precipitates, which is a useful component for improving the strength of the steel. When the content of Ti is less than 0.005%, the effects of suppressing crystal grain growth and improving strength cannot be sufficiently obtained. On the other hand, when the content of Ti exceeds 0.08%, coarse TiN is generated, and precipitates are coarsened, which deteriorates bending workability during forming. Therefore, it is preferable that the content of Ti is in the range of 0.005 to 0.08%. The lower limit of the Ti content is more preferably 0.01%, still more preferably 0.015%, and most preferably 0.02%. The upper limit of the Ti content is more preferably 0.07%, still more preferably 0.06%, and most preferably 0.045%.

Vanadium (V): 0.005 to 0.05%

[0036] V is a representative precipitation-strengthening element along with Nb and Ti, and hardly precipitates during hot rolling, but forms precipitates after high-temperature coiling, cooling, or tempering to improve the strength of steel. Therefore, it is effective in improving additional strength without increasing deformation resistance and rolling load due to recrystallization delay during hot rolling. When the content of V is less than 0.005%, the effect of improving strength cannot be sufficiently obtained. On the other hand, when the content of V exceeds 0.05%, coarse precipitates are formed to deteriorate bending workability, and like Nb, the aspect ratio of the parent austenite cannot be kept low, which is economically disadvantageous. Therefore, it is preferable that the content of V is in the range of 0.005 to 0.05%. The lower limit of the V content is more preferably 0.006%, still more preferably 0.008%, and most preferably 0.01%. The upper limit of the V content is more preferably 0.04%, still more preferably 0.03%, and most preferably 0.02%.

Aluminum (Al): 0.01 to 0.5%

[0037] Al is an element added mainly for deoxidation. In this case, Al means Sol-Al. When the content of Al is less than 0.01%, a sufficient deoxidation effect cannot be obtained. On the other hand, when the content of Al exceeds 0.5%, excessive AlN is formed by combining with nitrogen, so that corner cracks are likely to occur in a slab during continuous casting, and defects due to the formation of inclusions are likely to occur. Therefore, it is preferable that the content of Al is in the range of 0.01 to 0.5%. The lower limit of the Al content is more preferably 0.015%, and still more preferably 0.02%. The upper limit of the Al content is more preferably 0.1%, still more preferably 0.08%, and most preferably 0.05%.

Phosphorus (P): 0.003 to 0.05%

[0038] P has both solid-solution strengthening and ferrite transformation promoting effects, similar to Si. However, in order to control the content of P to less than 0.003%, a large amount of manufacturing cost is required, which is economically disadvantageous and insufficient to obtain strength. On the other hand, when the content of P exceeds 0.05%, embrittlement due to grain boundary segregation may occur, fine cracks are likely to occur during bending, and ductility and impact resistance are greatly deteriorated. Therefore, it is preferable that P is in the range of 0.003 to 0.05%. The lower limit of the P content is more preferably 0.005%, still more preferably 0.007%, and most preferably 0.01%. The upper limit of the P content is more preferably 0.03%.

Sulfur (S): 0.001 to 0.01%

[0039] S is an impurity present in steel, and when its content exceeds 0.01%, it combines with Mn and the like to form non-metallic inclusions, which causes a problem in that fine cracks are likely to occur during bending of the steel and the impact resistance is greatly reduced. In the present disclosure, the lower limit of the S content is not particularly limited, but in order to control it to less than 0.001%, a long time is required during steelmaking operation, resulting in a decrease in productivity. Therefore, considering this, the lower limit of the S content may be limited to 0.001%. Therefore, it is preferable that the content of S is in the range of 0.001 to 0.01%. The lower limit of the S content is more preferably 0.002%. The upper limit of the S content is more preferably 0.008%, still more preferably 0.006%, and most preferably 0.005%.

Nitrogen (N): 0.001 to 0.01%

[0040] N is a representative solid-solution strengthening element along with C, and forms coarse precipitates along with Ti, Al, and the like. When the content of N is less than 0.001%, it is difficult to sufficiently obtain the effects of solid-solution strengthening and precipitate formation, and in order to control the content of N to less than 0.001%, a long time is required during steelmaking operation, resulting in a decrease in productivity. On the other hand, in general, the solid-solution strengthening effect of N is superior to that of carbon, but when the content of N exceeds 0.01%, there is a problem that toughness is greatly reduced. Therefore, it is preferable that the content of N is in the range of 0.001 to 0.01%. The lower limit of the N content is more preferably 0.002%, and still more preferably 0.003%. The upper limit of the N content is more preferably 0.008%, still more preferably 0.007%, and most preferably 0.006%.

Boron (B): 0.0005 to 0.003%

[0041] When B exists in a solid solution state in steel, it is mainly segregated at grain boundaries and stabilizes the grain boundaries to improve the brittleness of the steel, and stabilizes solute N to suppress the formation of coarse AlN nitrides. In addition, it is effective in forming bainite and martensite, which are hard phases, by delaying the ferrite phase transformation. When the content of B is less than 0.0005%, the effects of improving brittleness, suppressing the formation of coarse AlN nitrides, and forming bainite and martensite cannot be sufficiently obtained. On the other hand, when the content of B exceeds 0.003%, the above-described effects no longer increase, and there is a disadvantage in that ductility is reduced and thus formability is deteriorated. Therefore, it is preferable that the content of B is in the range of 0.0005 to 0.003%. The lower limit of the B content is more preferably 0.0006%, still more preferably 0.0008%, and most preferably 0.001%. The upper limit of the B content is more preferably 0.0025%, and still more preferably 0.002%.

[0042] The remaining component is iron (Fe), and may include some unintentional and unavoidable impurities mixed in during the manufacturing process. Since these impurities can be known to any person skilled in the art of a conventional manufacturing process, all of their contents are not particularly mentioned in this specification.

[0043] The hot-rolled steel sheet preferably satisfies the following Formula 1.

[Formula 1]

$$30 \leq T \leq 100$$

$$T = (([C]/10)^{0.5}) \times (0.7 \times [Si] + 1) \times (5 \times [Mn] + 1) \times (2.5 \times [Cr] + 1) \times (5 \times [Mo] + 1) \times 25$$

[0044] In Formula 1, [C], [Si], [Mn], [Cr], and [Mo] denote the content (by weight %) of the corresponding alloying

elements, and a value of 0 is substituted if these elements are not intentionally added.

[0045] Formula 1 is a factorization of a combination of alloying elements that can maintain bainite, which is a hard phase, and lath martensite in the center of the steel microstructure of the present disclosure, and ferrite, twinned martensite, and bainite in the surface layer at an appropriate level. As the "T" value of Formula 1 below increases, the formation of bainite and lath martensite, which are hard phases, increases, and the hardness value of each hard phase also increases. Therefore, the larger this value is, the more advantageous it is for securing strength and hardness, but if it is excessive, ferrite and twinned martensite cannot be formed on the surface layer, which deteriorates the bending workability of the steel and increases the material variation in the overall length and overall width of the hot-rolled steel sheet. To this end, it is preferable to manage the value of Formula 1 from 30 to 100.

[0046] The surface layer microstructure up to 10 μm from the surface of the hot-rolled steel sheet may include, by area fraction, 5 to 40% of ferrite and 2 to 10% of twinned martensite. The twinned martensite is classified as martensite in a broad category, but is distinguished from lath martensite, which has a plate-like substructure with a width of several tens of nm, and auto-tempered martensite, which includes epsilon carbide as fine carbides, and is a martensite having a twin substructure with a fine thickness (several tens of nm) in a crystallographically twin relationship. Since the phase of the twinned martensite is difficult to distinguish on an FE-SEM image, it can be read using a high-resolution transmission electron microscope (TEM). Meanwhile, the TEM measurement can be evaluated by collecting a specimen based on a cross-section parallel to the rolling direction at a position of 10 μm from the surface of the hot-rolled steel sheet.

[0047] When the ferrite in the surface layer is too small, the surface layer, which is mostly composed of a hard phase, has a problem in that surface irregularities are easily formed due to insufficient deformation resistance during bending, eventually leading to fracture. On the other hand, when there is too much ferrite, the deformation that should be dispersed over the entire thickness is concentrated only on the limited surface layer, so that surface irregularities can be formed despite a large bending radius.

[0048] The twinned martensite in the surface layer serves to buffer a rapid change in strength between the ferrite in the surface layer and the martensite in the deep layer, and serves to prevent excessive concentration of deformation only in the surface layer. Therefore, an effective effect of improving bendability can be obtained through an appropriate ratio of the ferrite and the twinned martensite, and it is possible to prevent excessive concentration of deformation and secure appropriate workability by including 2% or more of twinned martensite formed by the influence of carbon and hardenability elements concentrated in not only the ferrite of the surface layer but also untransformed austenite. However, when there is too much twinned martensite in the surface layer, there is a problem in that it becomes vulnerable to deformation of the surface, so that cracks are easily generated.

[0049] Meanwhile, the remainder of the surface layer is preferably a hard structure. Specifically, it may be bainite, tempered bainite, martensite, tempered martensite, or the like.

[0050] The central portion microstructure of the hot-rolled steel sheet has martensite as a primary phase, and carbides such as tempered martensite (auto-tempered martensite in which epsilon carbide is observed) due to a self-tempering effect may be observed depending on the control of the coiling temperature. Specifically, it may include, by area fraction, 80% or more (including 100%) of martensite and auto-tempered martensite, and 20% or less (including 0%) of one or more of pearlite and bainite. Typically, the central portion microstructure targets a point at 1/4 of the thickness of the steel sheet.

[0051] By sufficiently securing the martensite and auto-tempered martensite, excellent strength and hardness can be secured.

[0052] In the hot-rolled steel sheet, prior austenite elongated in the rolling direction can be observed. This can be observed through an SEM. At this time, the aspect ratio of the prior austenite may be 1 to 10. It can be confirmed that the effect of improving bending workability is exhibited when the aspect ratio is in the range of 1 to 10. This is because the bending line during bending is parallel to the rolling direction, so the deformation is a form of elongation perpendicular to the rolling direction. At this time, it can be determined that the microstructure elongated in the rolling direction has a very small grain size when viewed perpendicular to the rolling direction, resulting in a decrease in deformation resistance.

[0053] The hot-rolled steel sheet may have a central portion cross-sectional hardness of 400 HV or more and a width-direction tensile strength of 1300 MPa or more.

[0054] In addition, since the bendability (R/t) is 4 or less and the difference between the original bendability (r/t) and the bendability is 0.5 or more, it is possible to have excellent strength and hardness, and at the same time, to have an effect of improving bendability, particularly, the bendability of the surface. Meanwhile, it is preferable that the original bendability (r/t) is 6.0 or less.

[0055] The bendability (R/t) evaluation is, for example, performed by a 90-degree bending process in which a die having a 90-degree bending angle and a specific V-shaped bending radius is placed at the bottom and pressed with a die corresponding thereto at the top. It is defined as the ratio of the bending radius (R) at which surface irregularities do not occur during processing to the thickness of the steel sheet (t), and the original bendability is measured by the

same method after milling the surface by 0.1 to 0.5 mm.

[0056] Next, an embodiment of a method for manufacturing a hot-rolled steel sheet of the present disclosure will be described in detail.

[0057] First, the manufacturing method may include heating, hot rolling, cooling, and coiling a steel slab satisfying the above-described alloy composition and Formula 1.

Steel Slab Heating

[0058] A steel slab satisfying the above-described alloy composition and Formula 1 is heated to a temperature range of 1150 to 1350°C. When the steel slab heating temperature is less than 1150°C, precipitates are not sufficiently redissolved, so that the formation of precipitates in a process after hot rolling is reduced, coarse TiN remains, and it is difficult to uniformly control the temperature of the steel sheet during hot rolling because the slab is not sufficiently soaked. On the other hand, when the slab heating temperature exceeds 1350°C, the strength is lowered by abnormal grain growth of austenite crystal grains. Therefore, it is preferable that the slab heating temperature is in the range of 1150 to 1350°C. The lower limit of the slab heating temperature is more preferably 1155°C, and still more preferably 1160°C. The upper limit of the slab heating temperature is more preferably 1340°C, still more preferably 1330°C, and most preferably 1320°C.

Hot Rolling

[0059] The heated steel slab is subjected to rough rolling at a roughing delivery temperature (RDT) of the following Formula 2 to obtain a bar plate. The roughing delivery temperature (RDT) is preferably performed on the basis of $t/2$ (t : thickness of the steel material). At this time, the thickness of the steel material is preferably the thickness of the bar plate. The rough rolling may be performed in a temperature range of 900 to 1100°C.

[Formula 2]

$$\text{RDT } (^{\circ}\text{C}) \leq (\text{FT} + 80 + \text{bar plate thickness} \times 3.8)$$

$$\text{FT} = 907 + 239[\text{Al}] - 10.3[\text{Cr}] - 25.8[\text{Mn}] + 17.9[\text{Mo}] + 30.9[\text{Si}] - 254[\text{C}]$$

[0060] In Formula 1, [Al], [Cr], [Mn], [Mo], [Si], and [C] denote the content (by weight %) of the corresponding alloying elements, a value of 0 is substituted if these elements are not intentionally added, and the thickness of the bar plate is in mm.

[0061] A hot-rolled steel sheet is obtained by performing finish rolling on the bar plate at a finishing delivery temperature (FDT) of the following Formula 3. The finishing delivery temperature (FDT) is preferably performed on the basis of $t/2$ (t : thickness of the steel material). At this time, the thickness of the steel material is preferably the thickness of the hot-rolled steel sheet.

[Formula 3]

$$\text{FDT } (^{\circ}\text{C}) \geq \text{FT}$$

[0062] In order to improve the bending workability with respect to hardness, a difference in microstructure and hardness between the surface layer and the central portion is essential, and it is preferable that the degree of elongation of the prior austenite of the central portion martensite is limited to satisfy the characteristics of the above-described microstructure. To this end, the temperatures RDT and FDT at the end of the rough rolling and finish rolling have different temperature limits according to Formulas 2 and 3, which are composed of the steel composition and the thickness of the bar plate. When the RDT is higher than the formula calculated by Formula 2, the microstructure of the surface layer and the central portion cannot be induced to a desired configuration, resulting in a conventional martensitic high-strength steel, which may deteriorate the bending workability. When the FDT is lower than the formula calculated by Formula 3, the aspect ratio of the central portion structure does not achieve a desired value, which may also adversely affect the bending workability.

[0063] After obtaining the bar plate, descaling and surface cooling of the entire width of the bar plate may be further performed with a water pressure of 150 bar or more. By performing the descaling, the effect of quenching the surface can be added, and additional surface cooling can facilitate the formation of a soft structure in the surface layer.

[0064] The thickness of the bar plate preferably satisfies the following Formula 4. It is necessary that the surface layer portion cools faster than the central portion during rolling. At this time, if the thickness of the bar plate is too thin, heat conduction to the central portion occurs rapidly, so that a temperature difference between the surface layer portion and the central portion cannot occur. Therefore, it is preferable to satisfy the condition of Formula 4.

bar plate thickness (mm) $\geq$ hot-rolled steel sheet thickness (mm) $\times 10$ [Formula 4]

Cooling

[0065] After the hot-rolled steel sheet is manufactured, the hot-rolled steel sheet is first-cooled at a first average cooling rate of 60 to 90°C/sec to a first cooling stop temperature of 150 to 350°C.

[0066] After the first cooling above, the hot-rolled steel sheet is second-cooled to a coiling temperature (CT) of 50 to 200°C at a second average cooling rate of 1 to 50°C/sec.

[0067] The first cooling is performed at an average cooling rate of 50 to 100°C/sec to a temperature range of 150 to 350°C. This is to form a sufficient balance of central portion martensite and surface layer ferrite and twinned martensite. At this time, it is preferable to avoid an excessively high cooling rate because it may deteriorate the coil shape.

[0068] The first-cooled steel sheet is subjected to second cooling at an average cooling rate of 1 to 40°C/sec to a temperature in the range of 50 to 200°C. At this time, the cooling rate is preferably 1°C/sec or more in order to form the intended microstructure, and since excessive high-speed cooling may deteriorate the shape quality of the sheet and has no further advantages, the cooling rate is preferably in the above range. On the other hand, it is advantageous to switch to low-speed cooling in terms of productivity, so it is preferable to introduce low-speed cooling as much as possible.

Coiling

[0069] After the second cooling, coiling is performed in the range of 50 to 200°C. The coiling is for obtaining an auto-tempering effect, and when the time for staying at a temperature at which carbides can be formed, which is generally equal to or lower than the temperature at which the martensitic transformation starts, is long, a microstructure including epsilon carbide, which is called a transition carbide, can be formed without a separate heat treatment process of heating. A method of implementing this in a hot rolling process utilizes a phenomenon in which the time for cooling the coil is lengthened to 1 hour or more when coiling is performed in a specific temperature range higher than room temperature. To this end, in the present disclosure, the coiling is preferably performed at 50°C or higher and 200°C or lower. At a too low temperature, an auto-tempering effect cannot be obtained, and when the coiling temperature is too high, the auto-tempering effect is excessive, so that strength and bendability may be deteriorated.

Pickling and Oiling

[0070] After the coiling, the method may further include pickling and oiling the coiled hot-rolled steel sheet. In the present disclosure, the pickling and oiling process is not particularly limited, and any method commonly used in the art may be used.

Mode for the Invention

[0071] Hereinafter, embodiments of the present disclosure will be described. It is a matter of course that the following embodiments can be variously modified by a person of ordinary skill in the art to which the present disclosure pertains, as long as they do not depart from the scope of the present disclosure. The following embodiments are for understanding the present disclosure, and the scope of rights of the present disclosure should not be limited to the following embodiments, but should be defined by the claims to be described later as well as their equivalents.

(Example)

[0072] Steel slabs having the compositions shown in Table 1 below (unit: wt%, the remainder being Fe and unavoidable impurities) were prepared. In Table 1 below, T was calculated by Formula 1 below.

[Formula 1]

$$30 \leq T \leq 100$$

$$T = \left(\left([C] / 10 \right)^{0.5} \right) \times (0.7 \times [Si] + 1) \times (5 \times [Mn] + 1) \times (2.5 \times [Cr] + 1) \times (5 \times [Mo] + 1) \times 25$$

[0073] In Formula 1, [C], [Si], [Mn], [Cr], and [Mo] denote the content (by weight %) of the corresponding alloying elements, and a value of 0 is substituted if these elements are not intentionally added.

[Table 1]

Classi ficati on	C	Si	Mn	Cr	Mo	Nb	Ti	v	Al	P	S	N	B	T
steel type 1	0.2 1	0. 1	1.2	0.3	0.0 1	0.0 01	0.0 2	0.0 1	0.0 3	0.0 05	0.0 02	0.0 04	0.00 15	50
steel type 2	0.1 8	0. 2	1.1	0.4	0.0 1	0.0 03	0.0 2	0.0 2	0.0 3	0.0 1	0.0 02	0.0 04	0.00 2	52
steel type 3	0.2 2	0. 05	0.8	0.4	0.2	0.0 05	0.0 2	0.0 2	0.0 3	0.0 1	0.0 02	0.0 05	0.00 2	77
steel type 4	0.2 3	0. 1	1	0.5	0.1	0.0 07	0.0 4	0.0 1	0.0 3	0.0 1	0.0 05	0.0 06	0.00 2	82
steel type 5	0.2	0. 02	0.8	0.3	0.0 2	0.0 07	0.0 3	0.0 2	0.0 2	0.0 2	0.0 03	0.0 04	0.00 2	35
steel type 6	0.2 5	0. 01	0.7	0.3	0.0 5	0.0 07	0.0 3	0.0 1	0.0 2	0.0 05	0.0 03	0.0 03	0.00 2	39
steel type 7	0.1 9	0. 2	1.5	0.2	0.1	0.0 05	0.0 2	0.0 1	0.0 2	0.0 1	0.0 03	0.0 04	0.00 2	75
steel type 8	0.2 3	0. 2	1.5	0.2	0.1	0.0 05	0.0 3	0.0 1	0.0 4	0.0 15	0.0 05	0.0 03	0.00 3	83
steel type 9	0.1 8	0. 02	2.3	0.6 5	0.3 5	0.0 05	0.0 4	0.0 1	0.0 3	0.0 15	0.0 05	0.0 06	0.00 2	307
steel type 10	0.1 7	0. 05	0.9	0.0 05	0.0 5	0.0 1	0.0 3	0.0 1	0.0 4	0.0 1	0.0 04	0.0 06	0.00 1	23
steel type 11	0.2 1	0. 05	1.2	0.1	0.5	0.0 1	0.0 25	0.0 1	0.0 4	0.0 15	0.0 03	0.0 04	0.00 25	115
steel type 12	0.2 2	0. 1	1.1	0.3	0.1	0.0 7	0.0 7	0.0 1	0.0 3	0.0 05	0.0 02	0.0 04	0.00 15	68
steel type 13	0.2	0. 02	1.7	0.4	0.0 2	0.0 05	0.0 2	0.0 2	0.0 4	0.0 15	0.0 02	0.0 04	0.00 1	75

[0074] The steel slabs were subjected to steel slab heating, rough rolling, finish rolling, first cooling, second cooling, and coiling under the conditions of Table 2 below. In Table 2 below, RDT is the rough rolling finishing temperature, FDT is the finish rolling finishing temperature, and is at the t/2 (t: thickness of the steel material) point. CT is the coiling temperature. It was confirmed whether these conform to Formulas 2 and 3 below. The thickness of the manufactured hot-rolled steel sheet is 3 mm.

[Formula 2]

$$RDT \text{ (}^{\circ}\text{C)} \leq (FT + 80 + \text{bar plate thickness} \times 3.8)$$

$$FT = 907 + 239[Al] - 10.3[Cr] - 25.8[Mn] + 17.9[Mo] + 30.9[Si] - 254[C]$$

[0075] In Formula 2, [Al], [Cr], [Mn], [Mo], [Si], and [C] denote the content (by weight %) of the corresponding alloying elements, a value of 0 is substituted if these elements are not intentionally added, and the thickness of the bar plate is in mm.

[Formula 3]

$$FDT \text{ (}^{\circ}\text{C)} \geq FT$$

[Table 2]

Classification	steel type	Slab heating temperature	RDT (°C)	FDT (°C)	Bar thickness (mm)	FT (°C)	first cooling rate (°C/s)	first cooling stop temperature (°C)	second cooling rate (°C/s)	CT (°C)
Inventive Example 1	steel type 1	1242	1014	843	34	830	63	228	21	80
Inventive Example 2	steel type 2	1237	1026	856	33	842	82	227	23	126
Inventive Example 3	steel type 3	1241	1026	851	37	839	72	222	29	88
Inventive Example 4	steel type 4	1236	1015	844	34	830	64	225	19	133
Inventive Example 5	steel type 5	1248	1019	846	35	838	68	226	16	67
Inventive Example 6	steel type 6	1221	1016	844	35	828	81	237	25	104
Comparative Example 1	steel type 7	1235	1023	849	33	831	55	240	27	416
Comparative Example 2	steel type 8	1221	1018	845	39	825	52	235	21	300

(continued)

Classification	steel type	Slab heat ing temperature	RDT (°C)	FDT (°C)	Bar thickness (mm)	FT (°C)	first cooling rate (°C/s)	first cooling stop temperature (°C)	second cooling rate (°C/s)	CT (°C)
Comparative Example 3	steel type 9	1206	1005	828	34	809	63	228	31	134
Comparative Example 4	steel type 10	1231	1010	838	36	853	61	227	20	71
Comparative Example 5	steel type 11	1231	1019	852	28	842	85	232	24	85
Comparative Example 6	steel type 12	1240	1029	853	34	832	72	238	20	137
Comparative Example 7	steel type 13	1253	1037	834	32	819	62	227	20	141

[0076] The microstructures of the central portion and the surface layer of the hot-rolled steel sheets manufactured according to Tables 1 and 2 were observed and are shown in Table 3 below.

[0077] The aspect ratio is an aspect ratio calculated by the major axis/minor axis of the prior austenite grain size of the central portion martensite. The microstructure observation was performed using a transmission electron microscope and a general electron microscope at magnifications of 1000x and 3000x, respectively, and measured when distinguishable.

[Table 3]

Classification	steel type	aspect ratio of prior austenite (long axis/short axis)	Bainite portion of a central portion (%)	Martensite portion of a central portion (%)	twinned martensite portion of a surface layer (%)	Ferrite portion of a surface layer (%)
Inventive Example 1	steel type 1	3	0	100	12	20
Inventive Example 2	steel type 2	4	5	95	12	25
Inventive Example 3	steel type 3	4	0	100	11	25
Inventive Example 4	steel type 4	5.4	0	100	12	20
Inventive Example 5	steel type 5	4	5	95	13	25
Inventive Example 6	steel type 6	3.4	5	95	9	25
Comparative Example 1	steel type 7	6	75	25	0	65
Comparative Example 2	steel type 8	8	85	15	0	55
Comparative Example 3	steel type 9	6	0	100	0	0
Comparative Example 4	steel type 10	3.4	25	75	8	30
Comparative Example 5	steel type 11	6	0	100	0	0
Comparative Example 6	steel type 12	14	0	100	12	25
Comparative Example 7	steel type 13	2.5	0	100	0	0

[0078] For the hot-rolled steel sheets of Table 3, hardness, physical properties, and bending workability were evaluated, and the results are shown in Table 4 below. In Table 4 below, the surface hardness and the central portion cross-sectional hardness are Vickers hardness. The surface hardness was measured on the surface, and the central portion cross-sectional hardness was measured on the cross-section at 1/2 of the thickness of the cross-section. r/t is the original bendability, R/t is the bendability, and is expressed as the ratio of the bending radius (R) to the thickness of the steel sheet (t) and is based on the minimum bending radius at which no irregularities or cracks occur on the surface even after 90-degree bending. At this time, the bending specimen was processed long in the rolling direction and the direction perpendicular to the rolling direction, and bending was performed so that the bending line was parallel to the rolling direction. The original bendability was measured after milling the surface by 0.2 to 0.5 mm. YS and TS are the yield strength and tensile strength measured during a tensile test in the width direction of the coil, which is the direction perpendicular to the rolling direction, the unit is MPa, and a JIS No. 5 standard test piece was used for the tensile test standard.

[0079] Meanwhile, FIG. 1 is a graph showing the relationship between the tensile strength (TS) and the bendability (R/t) according to the results of Table 4 below.

[Table 4]

Classifi cation	steel type	a surfac es hardne ss (Hv)	a central portion cross- sectional hardnes (Hv)	origi nal benda bility (r/t)	bendabi lity (R/t)	YS (MPa)	TS (MPa)
Inventiv e Example 1	steel type 1	439	474	3.7	2.7	1241	1489
Inventiv e Example 2	steel type 2	404	438	3.3	2.7	1125	1378
Inventiv e Example 3	steel type 3	446	480	3.0	2.3	1260	1507
Inventiv e Example 4	steel type 4	456	492	4.0	3.0	1301	1546
Inventiv e Example 5	steel type 5	449	484	4.0	3.0	1273	1517
Inventiv e Example 6	steel type 6	463	504	4.3	3.7	1340	1581
Comparat ive Example 1	steel type 7	255	276	2.3	3.0	636	868
Comparat ive Example 2	steel type 8	260	280	3.0	3.3	651	882
Comparat ive Example 3	steel type 9	418	457	5.3	5.3	1185	1437
Comparat ive Example 4	steel type 10	369	400	4.7	4.3	1008	1258
Comparat ive Example 5	steel type 11	433	468	4.7	4.7	1221	1471
Comparat ive Example 6	steel type 12	425	460	4.7	4.3	1195	1445
Comparat ive Example 7	steel type 13	440	475	5.7	5.7	1244	1493

[0080] As shown in Tables 1 to 4 and FIG. 1, Inventive Examples 1 to 6, which satisfy the conditions presented in the present disclosure, were all able to secure excellent strength and hardness, and at the same time, secure excellent workability. It can be confirmed that they have excellent mechanical properties.

[0081] On the other hand, referring to FIG. 1, it can be seen that in the comparative examples, as the strength increases, R/t increases, and the bending workability deteriorates.

[0082] Specifically, Comparative Examples 1 and 2 satisfied the steel composition and Formula 1 presented in the present disclosure, but the coiling temperature during the manufacturing process exceeded the range of the present disclosure, and cooling was completed at a high temperature. As a result, in the final microstructure, a large amount of martensite in the central portion was replaced by bainite, resulting in very low strength, and ferrite and twinned martensite were not formed in an appropriate range in the surface layer. As a result, sufficient hardness was not secured as the coiling temperature increased.

[0083] Comparative Example 7 satisfied the steel composition and Formula 1 presented in the present disclosure, but the RDT was excessively high during the manufacturing process, so the condition of Formula 2 was not satisfied. As a result, a combination of ferrite and twinned martensite in the surface layer was not formed in the microstructure, and the bendability was very poor.

[0084] Comparative Example 3 is a case in which Formula 1 related to hardenability elements such as Mn, Cr, and

Mo and their components exceeds the scope of the present disclosure. As a result, ferrite and twinned martensite were not formed at all in the surface layer, and even if all the manufacturing process conditions were satisfied, no improvement effect was shown in bendability.

[0085] In Comparative Example 4, unlike 3, the alloying elements were configured under the condition that the value of Formula 1 was less than the range of the present disclosure. Accordingly, it was confirmed that even if all the manufacturing process conditions presented in the present disclosure were satisfied, sufficient martensite could not be secured, so that a high-strength steel could not be made. Specifically, most of the central portion formed a bainite structure, and accordingly, the strength and hardness were also lower than those of other examples. Of course, the strength and hardness were lowered and the workability was improved, and an appropriate amount of ferrite and twinned martensite were also formed on the surface layer, but it is not suitable for the present disclosure, which aims to improve the bendability of high-strength steel.

[0086] Comparative Example 5 is a case where the content of Mo and the T value of Formula 1 are out of the range of the present disclosure, and the thickness of the bar plate during the manufacturing process is too small. Accordingly, in the hot-rolled steel sheet manufacturing process, the temperature difference between the surface and the central portion of the bar plate is small, which prevents the formation of ferrite + twinned martensite in the surface layer. As a result, sufficient bendability was not secured, and the difference between the original bendability and the bendability did not fall within the required range.

[0087] Comparative Example 6 is a case where the Nb content is excessively large, and accordingly, even if all the manufacturing process conditions presented in the present disclosure are satisfied, the aspect ratio of the prior austenite deviates from the range of the present disclosure, resulting in a deterioration of both bendability and original bendability.

Claims

1. A hot-rolled steel sheet, comprising:

by weight%, C: 0.17 to 0.26%, Si: 0.01 to 0.5%, Mn: 0.4 to 2.2%, Cr: 0.005 to 0.6%, Mo: 0.005 to 0.3%, Nb: 0.001 to 0.01%, Ti: 0.005 to 0.08%, V: 0.005 to 0.05%, Al: 0.01 to 0.5%, P: 0.003 to 0.05%, S: 0.001 to 0.01%, N: 0.001 to 0.01%, and B: 0.0005 to 0.003%, with a remainder being Fe and other unavoidable impurities, wherein the following Formula 1 is satisfied;
a surface layer microstructure up to 10 μ m from a surface of the steel sheet, the surface layer microstructure comprising, by area fraction, 5 to 40% of ferrite and 2 to 10% of twinned martensite; and
a central portion microstructure comprising, by area fraction, 80% or more (including 100%) of martensite and auto-tempered martensite, and 20% or less (including 0%) of one or more of pearlite and bainite,
wherein Formula 1 is:

$$30 \leq T \leq 100,$$

where $T = (([C]/10)^{0.5}) \times (0.7 \times [Si] + 1) \times (5 \times [Mn] + 1) \times (2.5 \times [Cr] + 1) \times (5 \times [Mo] + 1) \times 25$, and wherein [C], [Si], [Mn], [Cr], and [Mo] in Formula 1 denote a content (by weight%) of corresponding alloying elements, and a value of 0 is substituted if the elements are not intentionally added.

2. The hot-rolled steel sheet of claim 1, wherein the central portion microstructure comprises prior austenite having an aspect ratio of 1 to 10.

3. The hot-rolled steel sheet of claim 1, wherein the hot-rolled steel sheet has a central portion cross-sectional hardness of 400 HV or more and a width-direction tensile strength of 1300 MPa or more.

4. The hot-rolled steel sheet of claim 1, wherein the hot-rolled steel sheet has a bendability (R/t) of 4.0 or less.

5. The hot-rolled steel sheet of claim 1, wherein a difference between an original bendability and a bendability of the hot-rolled steel sheet is greater than 0.5.

6. A method for manufacturing a hot-rolled steel sheet, the method comprising:

heating a steel slab to a temperature range of 1150 to 1350°C, the steel slab comprising, by weight%, C: 0.17 to 0.26%, Si: 0.01 to 0.5%, Mn: 0.4 to 2.2%, Cr: 0.005 to 0.6%, Mo: 0.005 to 0.3%, Nb: 0.001 to 0.01%, Ti:

0.005 to 0.08%, V: 0.005 to 0.05%, Al: 0.01 to 0.5%, P: 0.003 to 0.05%, S: 0.001 to 0.01%, N: 0.001 to 0.01%, and B: 0.0005 to 0.003%, with a remainder being Fe and other unavoidable impurities, and satisfying the following Formula 1;

performing rough rolling on the heated steel slab at a roughing delivery temperature (RDT) of the following Formula 2 to obtain a bar plate;

performing finish rolling on the bar plate at a finishing delivery temperature (FDT) of the following Formula 3 to obtain the hot-rolled steel sheet;

performing first cooling on the hot-rolled steel sheet at a first average cooling rate of 60 to 90°C/sec to a first cooling stop temperature of 150 to 350°C;

performing second cooling after the first cooling at a second average cooling rate of 1 to 50°C/sec to a coiling temperature (CT) of 50 to 200°C; and

coiling after the second cooling,

wherein Formulas 1, 2, and 3 are:

$$[\text{Formula 1}] \quad 30 \leq T \leq 100,$$

$$\text{where } T = ([C]/10)^{0.5} \times (0.7 \times [Si] + 1) \times (5 \times [Mn] + 1) \times (2.5 \times [Cr] + 1) \times (5 \times [Mo] + 1) \times 25,$$

$$[\text{Formula 2}] \quad \text{RDT } (^{\circ}\text{C}) \leq (FT + 80 + \text{bar plate thickness} \times 3.8),$$

$$\text{where } FT = 907 + 239[Al] - 10.3[Cr] - 25.8[Mn] + 17.9[Mo] + 30.9[Si] - 254[C],$$

$$[\text{Formula 3}] \quad \text{FDT } (^{\circ}\text{C}) \geq FT,$$

and wherein the content of each alloying element in the formulas is in weight%, a value of 0 is substituted if the element is not intentionally added, and the bar plate thickness is in mm.

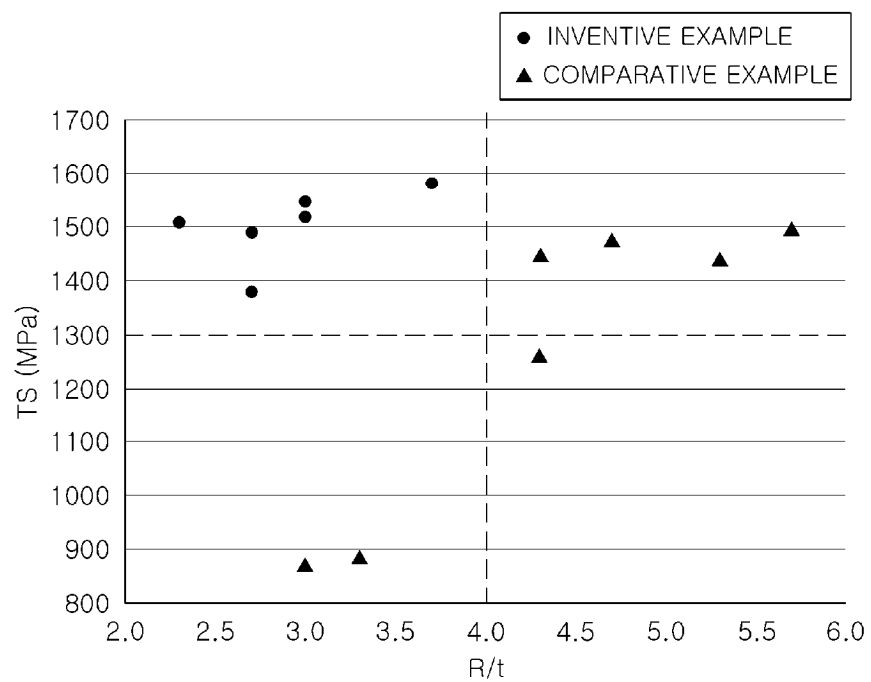
7. The method of claim 6, further comprising, after obtaining the bar plate, descaling and surface-cooling an entire width of the bar plate with a water pressure of 150 bar or more.

8. The method of claim 6, wherein a thickness of the bar satisfies the following Formula 4:

$$\text{bar plate thickness (mm)} \geq \text{hot-rolled steel sheet thickness (mm)} \times 10. \quad [\text{Formula 4}]$$

9. The method of claim 6, wherein the rough rolling is performed in a temperature range of 900 to 1100°C.

[FIG. 1]



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/019783

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/38(2006.01)i; C22C 38/28(2006.01)i; C22C 38/26(2006.01)i; C22C 38/06(2006.01)i; C22C 38/00(2006.01)i;
C22C 38/32(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 1/26(2006.01); B21C 47/02(2006.01); C21D 8/02(2006.01); C22C 38/00(2006.01);
C22C 38/14(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), 마르텐사이트(martensite), 페라이트
(ferrite), 조압연(rough rolling), 디스케일링(descaling), 냉각(cooling), 크롬(chromium), 몰리브덴(molybdenum)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-2007-0094779 A (NIPPON STEEL CORPORATION) 21 September 2007 (2007-09-21) See paragraphs [0071]-[0072], [0095], [0098] and [0103], claims 1-2 and 5 and tables 3-4.	1-9
A	WO 2020-250735 A1 (JFE STEEL CORPORATION) 17 December 2020 (2020-12-17) See claims 1 and 6.	1-9
A	KR 10-2015-0126683 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORPORATION) 12 November 2015 (2015-11-12) See paragraph [0153] and claims 1 and 9.	1-9
A	KR 10-2022-0131543 A (NIPPON STEEL CORPORATION) 28 September 2022 (2022-09-28) See paragraphs [0152]-[0153] and claims 1-3.	1-9
A	JP 2012-062558 A (JFE STEEL CORP.) 29 March 2012 (2012-03-29) See paragraphs [0041]-[0043] and claims 1-2 and 4.	1-9

☐ 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

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Date of the actual completion of the international search	Date of mailing of the international search report
11 March 2025	11 March 2025
Name and mailing address of the ISA/KR	Authorized officer
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International application No.

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