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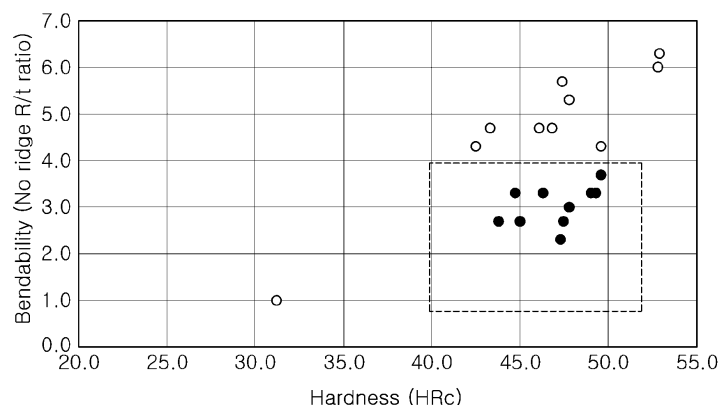
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(54) **HOT-ROLLED STEEL SHEET, AND METHOD FOR MANUFACTURING SAME**

(57) Provided are a hot-rolled steel sheet and a method for manufacturing same. The present invention provides a hot-rolled steel sheet and a method for manufacturing same, the hot-rolled steel sheet satisfying a

core section hardness of 40-50 Hrc and having excellent bendability (the bending radius at which surface ridges do not form during 90° bending/steel sheet thickness ratio is low).

[Fig. 1]



Description

Technical Field

5 **[0001]** The present disclosure relates to a high-strength hot-rolled steel sheet having high hardness and bendability, which is mainly used for a frame to protect a battery of an eco-friendly vehicle, and a method for manufacturing the same.

Background Art

10 **[0002]** Conventionally, high-strength hot-rolled steel sheets have mainly utilized a martensitic microstructure to achieve high strength and hardness. However, due to poor bendability associated with high strength, there is a disadvantage in that processing is limited, such that the steel sheets are used only through roll forming or minimal processing. This acts as a similar limiting factor in wear-resistant steel that primarily utilizes martensite, and various
15 technologies have been proposed to overcome this.

[0003] Patent Document 1 attempts to improve bendability by limiting the alloying elements of steel, such as C, Si, and Mn, and varying the microstructure composition according to the position in the thickness direction.

[0004] In addition, Patent Document 2 aims to improve bendability by configuring a high-strength steel sheet with tempered martensite in the center portion of the plate thickness and primarily ferrite and pearlite in the soft surface
20 layer portion.

[0005] However, Patent Document 1 defines the surface layer portion as the portion up to a 100 μm position of the steel sheet thickness, without considering the microstructure of the extreme surface layer (10 μm) where deformation is concentrated. It merely introduced a soft structure and only achieved a degree of bendability that can be easily obtained in a relatively low strength range.

25 **[0006]** Furthermore, in Patent Document 2, the soft surface layer portion is composed of an excessively soft structure of ferrite and pearlite compared to the core, which is the center of the thickness. This results in low hardness, and during bending, deformation is concentrated in the soft surface layer portion, leading to the disadvantage of rapid fracture.

[0007] In addition, while alloying elements such as Si, Mn, Mo, Cr, Cu, and Ni, which are mainly used to manufacture
30 such high-strength steels, are effective in improving the hardness and formability of the hot-rolled steel sheet, adding a large amount of these alloying elements to improve such properties causes segregation of the alloying elements and non-uniformity of the microstructure, leading to poor bendability. In particular, for steels with high hardenability, the change in microstructure during cooling is sensitive, resulting in the non-uniform formation of a low-temperature transformation structure phase, which makes it difficult to obtain higher bendability.

35 [Prior Art Document]

[Patent Document]

40 **[0008]**

(Patent Document 1) Japanese Patent Laid-Open No. 2013-117068

(Patent Document 2) Korean Patent Laid-Open No. 2021-0088646

45 Disclosure of Invention

Technical Problem

50 **[0009]** An object of the present disclosure is to provide a hot-rolled steel sheet that satisfies a core section hardness of 40-50 HrC and has excellent bendability (a small ratio of bending radius to steel sheet thickness at which surface unevenness do not occur during 90° bending), and a method for manufacturing the same.

Solution to Problem

55 **[0010]** Accordingly, one 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: 0.3 to 2.0%, Cr: 0.005 to 0.5%, Mo: 0.005 to 0.3%, Nb: 0.001 to 0.01%, Ti: 0.005 to 0.08%, V: 0.005 to 0.2%, 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 0.005%, a balance of Fe and unavoidable impurities, and satisfying the following Relational Expression 1, wherein a microstructure of the steel sheet comprises: a surface layer portion to a depth of 10 μm from a surface of the steel sheet, the surface layer portion comprising, by area%, ferrite: 15 to 50%, twinned martensite: 2 to 15%, and a remainder of bainite, martensite, and auto-tempered martensite; and a core portion at a t/4 position of the steel sheet, the core portion comprising, by area%, a sum of martensite and auto-tempered martensite: 90% or more, and at least one of ferrite and bainite: 10% or less, and wherein the core portion has a prior austenite aspect ratio of 10 or less.

[Relational Expression 1]

$$30 \leq T \leq 80$$

$$T = (([C]/10)^{0.5} \times 1.07) \times (0.7 \times [Si] + 1) \times (5 \times [Mn] + 1) \times (2.16 \times [Cr] + 1) \times (3 \times [Mo] + 1) \times 25.4$$

*In the above Relational Expression 1, C, Si, Mn, Cr, and Mo represent the content in weight% of the corresponding alloying elements. A value of 0 is substituted in the case of non-addition.

[0011] In addition, another aspect of the present disclosure provides:

a method for manufacturing a hot-rolled steel sheet, comprising: heating a slab to 1150 to 1350°C, the slab comprising, by weight%, C: 0.17 to 0.26%, Si: 0.01 to 0.5%, Mn: 0.3 to 2.0%, Cr: 0.005 to 0.5%, Mo: 0.005 to 0.3%, Nb: 0.001 to 0.01%, Ti: 0.005 to 0.08%, V: 0.005 to 0.2%, 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 0.005%, a balance of Fe and unavoidable impurities, and satisfying the following Relational Expression 1;

finishing rough rolling on the heated slab at a rough rolling temperature (RDT) of 900 to 1100°C based on a 1/2t position, where t is a thickness of the steel material, to obtain a bar;

performing surface cooling while descaling an entire width of the bar at least three times;

finishing finish hot-rolling on the cooled bar at a finish hot-rolling temperature (FDT) of 800°C to ST+50°C, which satisfies the following Relational Expression 2, based on a 1/2t position (where t is the thickness of the steel material), to obtain a hot-rolled steel sheet;

primarily cooling the hot-rolled steel sheet to a primary cooling stop temperature of Ms to Ms+50°C at a first average cooling rate of 60 to 90°C/sec; and

secondarily cooling the primarily cooled hot-rolled steel sheet to a coiling temperature (CT) of 50°C to Ms-50°C at a second average cooling rate of 1 to 50°C/sec, and then coiling the sheet.

[Relational Expression 1]

$$30 \leq T \leq 80$$

$$T = (([C]/10)^{0.5} \times 1.07) \times (0.7 \times [Si] + 1) \times (5 \times [Mn] + 1) \times (2.16 \times [Cr] + 1) \times (3 \times [Mo] + 1) \times 25.4$$

*In the above Relational Expression 1, C, Si, Mn, Cr, and Mo represent the content in weight% of the corresponding alloying elements. A value of 0 is substituted in the case of non-addition.

[Relational Expression 2]

800°C to ST+50°C

$$ST = 800 + 140 [C] - 145 [Si] + 80 [Mn] - 30 [Cr] + 10 [Mo]$$

*In the above Relational Expression 2, C, Si, Mn, Cr, and Mo represent the content in weight% of the corresponding alloying elements. A value of 0 is substituted in the case of non-addition.

Advantageous Effects of Invention

[0012] The present disclosure with the configuration as described above can effectively provide a high-strength hot-rolled steel sheet that satisfies a bendability (R/t) of less than 4 by controlling the hardness difference between the steel sheet surface and the t/4 core section, the aspect ratio of the core microstructure, and the composition of the surface layer microstructure, resulting in excellent bendability (a small ratio of bending radius to steel sheet thickness at which surface unevenness do not occur during 90° bending).

Brief Description of Drawings

[0013]

FIG. 1 is a graph showing the relationship between the t/4 core section hardness and the bendability (R/t) of inventive examples and comparative examples in an embodiment of the present disclosure.

FIG. 2 is a transmission electron microscope (TEM) image of twinned martensite formed in the surface layer of Inventive Example 1.

FIG. 3 is a transmission electron microscope (TEM) image of ferrite formed in the surface layer of Inventive Example 1.

FIG. 4 is an electron microscope image showing the cross-sectional microstructure distribution of the surface layer portion of Inventive Example 1 and Comparative Example 3.

FIG. 5 is a photograph showing carbides within the core microstructure (auto-tempered martensite) of Inventive Example 1.

FIG. 6 is an optical microscope image of a surface where unevenness occurred (bending radius 9 mm) and a sound surface without unevenness (bending radius 7 mm) during a bending test of Inventive Example 1.

Best Mode for the Invention

[0014] Hereinafter, the present disclosure will be described.

[0015] The inventors of the present disclosure investigated the changes in core section hardness and bendability according to the characteristics of composition, manufacturing process, and microstructure for various steels with different compositions and microstructures in order to solve the problems of the prior art described above. As a result, it was confirmed that the detailed characteristics of each composition of the surface layer and the core and the hardness difference are correlated with the core section hardness and bendability, and from this, the following Relational Expression 1 and Relational Expression 2 were derived. And based on the derived relational expressions, it was confirmed that when the microstructure of the steel is configured such that the core primarily consists of a martensite phase with an aspect ratio (major axis/minor axis) in the range of 1 to 10 based on the grain boundaries of prior austenite, and the microstructure of the surface layer to a depth of 10 μm includes ferrite and twinned martensite at a certain fraction, the surface hardness and core section hardness difference satisfies a range of 9-25%, and the core hardness satisfies 40-50 HrC, making it possible to manufacture a hot-rolled steel sheet with excellent bendability relative to its core section hardness, thereby presenting the present invention.

[0016] Hereinafter, the constituent components of the hot-rolled steel sheet of the present disclosure and the reasons for limiting their content will be described, wherein "%" means % by weight unless otherwise specified.

C: 0.17 to 0.26%

[0017] C is the most economical and effective element for strengthening steel and has a great influence on strength

and hardness. As its content increases, hardenability increases, making it easier to form hard phases such as bainite and martensite in the microstructure, which increases tensile strength. In addition, because C has a property of accumulating in austenite rather than ferrite, when ferrite is formed in the surface layer, the C accumulated in the austenite forms a mechanism that transforms it into twinned martensite during the martensitic transformation. However, if the content of C exceeds 0.26%, the strength of martensite increases excessively, causing problems of excessive strength increase and deterioration of bendability, and weldability also becomes poor. On the other hand, if 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%. More preferably, the content of C is limited to the range of 0.18 to 0.24%.

Si: 0.01 to 0.5%

[0018] 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. If the content of Si is less than 0.01%, the above-mentioned effects cannot be sufficiently obtained. On the other hand, if the content of Si exceeds 0.5%, a red scale due to Si is formed on the surface of the steel sheet during hot rolling, which not only severely deteriorates the surface quality of the steel sheet but also causes problems of reduced ductility and weldability. Therefore, it is preferable that the content of Si is in the range of 0.01 to 0.5%. More preferably, the content of Si is limited to the range of 0.05 to 0.4%.

Mn: 0.3 to 2.0%

[0019] Mn, like Si, is an effective element for solid solution strengthening of steel and increases the hardenability of steel to facilitate the formation of hard phases such as bainite and martensite during cooling after hot rolling. In addition, when ferrite is formed in the surface layer, it is concentrated in the austenite and subsequently forms a mechanism that transforms it into twinned martensite when it undergoes a phase transformation to martensite. If the content of Mn is less than 0.3%, the above-mentioned effects cannot be sufficiently obtained. On the other hand, if the content of Mn exceeds 2.0%, grain boundaries become brittle, causing problems such as low temperature cracking. In addition, there are problems of excessive strength increase and deterioration of formability, and during the continuous casting process, a segregated zone develops significantly in the center of the slab thickness. After hot rolling, during cooling, the microstructure is formed non-uniformly in the thickness direction, leading to poor bendability. In particular, it becomes difficult to uniformly produce the microstructure during cooling over the entire length and width of the hot-rolled steel sheet. Therefore, it is preferable that the content of Mn is in the range of 0.3 to 2.0%. More preferably, the content of Mn is limited to the range of 0.5 to 1.8%.

Sol. Al: 0.01 to 0.5%

[0020] Al is an element added mainly for deoxidation. If the content of Al is less than 0.01%, the above-mentioned effect cannot be sufficiently obtained. On the other hand, if the content of Al exceeds 0.5%, excessive AlN is formed by combining with nitrogen, which tends to cause corner cracks in the slab during continuous casting, and defects due to inclusion formation 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 even more preferably 0.02%. The upper limit of the Al content is more preferably 0.1%, even more preferably 0.08%, and most preferably 0.05%.

Cr: 0.005 to 0.5%

[0021] Cr serves to solid-solution-strengthen the steel and delays the ferrite phase transformation during cooling, thereby assisting in the formation of martensite and bainite. If the content of Cr is less than 0.005%, the above-mentioned effects cannot be sufficiently obtained. On the other hand, if the content of Cr exceeds 0.5%, similar to Mn, the segregated zone at the center of the thickness develops significantly, and the microstructure in the thickness direction becomes non-uniform, leading to a decrease in bendability. In addition, due to excessively high hardenability, a ferrite structure cannot be formed in the surface layer. Therefore, it is preferable that the content of Cr is in the range of 0.005 to 0.5%. More preferably, the content of Cr is limited to the range of 0.08 to 0.4%.

Mo: 0.005 to 0.3%

[0022] Mo increases the hardenability of steel, facilitating the formation of martensite and bainite. If the content of Mo is less than 0.005%, the above-mentioned effects cannot be sufficiently obtained. On the other hand, if the content

of Mo exceeds 0.3%, bendability deteriorates sharply due to an excessive increase in hardenability, and it is also economically disadvantageous and detrimental to weldability. In addition, due to excessively high hardenability, a ferrite structure cannot be formed in the surface layer. Therefore, it is preferable that the content of Mo is in the range of 0.005 to 0.3%. More preferably, the content of Mo is limited to the range of 0.01 to 0.25%.

P: 0.003 to 0.05%

[0023] P, like Si, has both solid solution strengthening and ferrite transformation promoting effects. However, controlling the content of P to less than 0.003% requires high manufacturing costs, making it economically disadvantageous and insufficient for obtaining strength. On the other hand, if the content of P exceeds 0.05%, embrittlement due to grain boundary segregation may occur, micro-cracks are likely to occur during bending, and ductility and impact properties are significantly reduced. 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%, even more preferably 0.007%, and most preferably 0.01%. The upper limit of the P content is more preferably 0.03%.

S: 0.001 to 0.01%

[0024] S is an impurity existing in steel, and if its content exceeds 0.01%, it combines with Mn and the like to form nonmetallic inclusions, which causes a problem in that micro-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 the steelmaking operation, which reduces productivity. Considering this, the lower limit of the S content can be limited to 0.001%. Therefore, it is preferable that the content of S is in the range of 0.001 to 0.01%.

N: 0.001 to 0.01%

[0025] N is a representative solid-solution strengthening element along with C, and it forms coarse precipitates with Ti, Al, and the like. If the content of N is less than 0.001%, it is not only difficult to sufficiently obtain the above-mentioned effects, but also controlling the N content to less than 0.001% requires a long time during the steelmaking operation, leading to a decrease in productivity. On the other hand, although the solid-solution strengthening effect of N is generally superior to that of carbon, if 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%.

Ti: 0.005 to 0.08%

[0026] Ti, along with Nb and V, is a representative precipitation-strengthening element and forms coarse TiN in steel due to its strong affinity with N. TiN has the effect of suppressing grain growth during the heating process for hot rolling. In addition, the remaining Ti that has reacted with nitrogen is dissolved in the steel and combines with carbon to form TiC precipitates, which is a useful component for improving the strength of the steel. However, if the content of Ti is less than 0.005%, the above effects cannot be obtained, and if the Ti content exceeds 0.08%, there is a problem that the formation of coarse TiN and the coarsening of precipitates deteriorate bendability during forming. Therefore, in the present disclosure, it is preferable to limit the Ti content to 0.005 to 0.08%. More preferably, the content of Ti is limited to the range of 0.01 to 0.06%.

Nb: 0.001 to 0.01%

[0027] Nb, along with Ti and V, is a representative precipitation-strengthening element and is effective in improving the strength and impact toughness of steel through the effect of grain refinement by delaying recrystallization by precipitating during hot rolling. However, if the content of Nb is less than 0.001%, the above effect cannot be obtained, and if the Nb content exceeds 0.01%, there is a problem that the formation of coarse complex precipitates during hot rolling deteriorates bendability. Furthermore, if it exceeds 0.01%, it has the effect of excessively increasing the aspect ratio of the parent austenite before the martensitic transformation, making it impossible to achieve the low aspect ratio aimed for in the present disclosure. Therefore, in the present disclosure, it is preferable to limit the Nb content to 0.001 to 0.01%. More preferably, the content of Nb is limited to the range of 0.005 to 0.01%.

V: 0.005 to 0.05%

[0028] V, along with Nb and Ti, is a representative precipitation-strengthening element, and it hardly precipitates

during hot rolling but forms precipitates after high-temperature coiling, thereby improving the strength of the steel. Therefore, it is effective for further improving strength without increasing deformation resistance and rolling load due to recrystallization delay during hot rolling. In the present disclosure, in order to obtain this effect, it is preferable to include 0.005% or more of V. However, if the content is excessive, there is a problem that the formation of coarse precipitates deteriorates bendability, and like Nb, the aspect ratio of the parent austenite cannot be kept low, and it is also economically disadvantageous. Therefore, in the present disclosure, it is preferable to limit the upper limit to 0.05%, and more preferably to 0.03%.

B: 0.0005 to 0.005%

[0029] When B exists in a solid solution state in steel, it mainly segregates at grain boundaries, which has the effect of stabilizing the grain boundaries and improving the brittleness of the steel. Furthermore, it plays a role in stabilizing solute N to suppress the formation of coarse AlN nitrides. It is also effective in forming hard phases such as bainite and martensite by delaying the ferrite phase transformation. In the present disclosure, the content must be 0.0005% or more to have the above effects, and if the content exceeds 0.005%, the effect does not increase any further, and ductility decreases, leading to a problem of poor formability. Therefore, in the present disclosure, it is preferable to limit its upper limit to 0.005%.

[0030] The remainder, other than the above-mentioned composition, is Fe. However, in a normal manufacturing process, unavoidable impurities that are not intended from raw materials or the surrounding environment may be incorporated, so these cannot be excluded. Since these impurities are something that anyone with ordinary skill in this technical field would know, all of their details are not specifically mentioned in this specification. Meanwhile, the addition of effective components other than the above composition is not excluded.

Relational Expression 1

[0031] Meanwhile, in the present disclosure, for a steel material having the component range as described above, it is preferable to control the value of the following Relational Expression 1, which is composed of C, Si, Mn, Cr, and Mo, to be from 30 to 80. The following Relational Expression 1 is a factorization of the combination of alloying elements that can maintain the formation of hard phases, such as bainite and lath martensite, in the steel microstructure of the present disclosure at an appropriate level. That is, the larger the "T" value of the following Relational Expression 1, the more the formation of hard phases such as bainite and lath martensite increases, and the hardness value of each hard phase also increases. Therefore, if the value defined by the following Relational Expression 1 is less than 10, the hardness value of the steel sheet decreases. Thus, a larger value is advantageous for securing strength and hardness, but if it exceeds 80, ferrite and twinned martensite cannot be formed in the surface layer, leading to poor bendability of the steel and an increase in material deviation over the entire length and width of the hot-rolled steel sheet.

[Relational Expression 1]

$$30 \leq T \leq 80$$

$$T = (([C]/10)^{0.5} \times 1.07) \times (0.7 \times [Si] + 1) \times (5 \times [Mn] + 1) \times (2.16 \times [Cr] + 1) \times (3 \times [Mo] + 1) \times 25.4$$

*In the above Relational Expression 1, C, Si, Mn, Cr, and Mo represent the content in weight% of the corresponding alloying elements. A value of 0 is substituted in the case of non-addition.

[0032] Hereinafter, the microstructure of the high-hardness hot-rolled steel sheet of the present disclosure will be described.

[0033] The steel sheet proposed in the present disclosure is characterized in that the microstructure of the t/4 core comprises, by area%, a sum of martensite (lath, twinned) and auto-tempered martensite: 90% or more, and at least one of bainite and ferrite: 10% or less, and the microstructure of the surface layer to a depth of 10 μ m comprises, by area%, ferrite: 15 to 50%, twinned martensite: 2 to 15%, and a remainder of bainite, martensite, and auto-tempered martensite.

[0034] Twinned martensite is classified as martensite in a broad category, but it is distinguished from lath martensite, which has a plate-like substructure with a width of several micrometers, and auto-tempered martensite, which contains

epsilon carbides as fine carbides, in that it has a twin substructure of a fine thickness (several tens of nm) in a crystallographic twinning relationship.

[0035] Furthermore, the steel sheet of the present disclosure can satisfy an aspect ratio, calculated as the major axis/minor axis of the prior austenite grain size of the core martensite, in the range of 1 to 10.

[0036] When the microstructure of the steel sheet satisfies the above-mentioned range, the target core section hardness is 40-50 HrC, and the difference between the surface section hardness and the core section hardness can satisfy 9-25% relative to the core section hardness. Therefore, the bendability is excellent relative to the core section hardness, and an R/t of 4 or less can be satisfied.

[0037] However, if the ferrite amount in the surface layer is too small, the surface layer, which is mostly composed of a hard phase, has insufficient deformation resistance during bending, leading to the disadvantage that surface unevenness is easily formed and eventually fracture occurs. On the other hand, if there is too much ferrite, the deformation that should be distributed throughout the entire thickness is concentrated only in the limited surface layer, and surface unevenness can be formed even with a large bending radius.

[0038] Meanwhile, the present inventors have confirmed that among the microstructural features of the steel material, not only the fraction of surface ferrite but also the fraction of twinned martensite, which is formed under the influence of carbon and hardenability elements concentrated in the untransformed austenite during ferrite formation, is an important influencing factor.

[0039] The presence of twinned martensite can be said to be essential for preventing excessive deformation concentration and securing appropriate workability. Since it is difficult to distinguish the phase of the twinned martensite on an FE-SEM, it can be identified using a high-resolution transmission electron microscope as shown in FIG. 2. Meanwhile, TEM measurement was evaluated by collecting a specimen based on a cross-section parallel to the rolling direction at a position 10 μm from the surface of the hot-rolled steel sheet.

[0040] In addition, the above-mentioned core microstructure primarily consists of a martensite phase, and carbides along with tempered martensite can be observed due to the auto (self) tempering effect depending on the coiling temperature control. Furthermore, during SEM observation, prior austenite grains elongated in the rolling direction can be observed, and it was confirmed that the effect of improving bendability is exhibited when the aspect ratio is in the range of 1 to 10. This is because the bending line during bending is placed parallel to the rolling direction, so the deformation is in a form that elongates perpendicular to the rolling direction. At this time, it can be judged that the microstructure elongated in the rolling direction has a very small grain size when viewed perpendicular to the rolling direction, resulting in lower deformation resistance. When all of these microstructural characteristics are combined, excellent bendability can be exhibited.

[0041] Next, the method for manufacturing the high-strength hot-rolled steel sheet of the present disclosure will be described in detail.

[0042] The method for manufacturing a hot-rolled steel sheet of the present disclosure comprises the steps of: heating a slab satisfying the above-mentioned composition and Relational Expression 1 to 1150-1350°C; finishing rough rolling on the heated slab at a rough rolling temperature (RDT) of 900-1100°C based on a $1/2t$ position (where t is the thickness of the steel material) to obtain a bar; performing surface cooling while descaling the entire width of the bar at least three times; finishing finish hot-rolling on the cooled bar at a finish hot-rolling temperature (FDT) of 800°C to $ST+50^\circ\text{C}$, which satisfies the following Relational Expression 2, based on a $1/2t$ position (where t is the thickness of the steel material) to obtain a hot-rolled steel sheet; primarily cooling the hot-rolled steel sheet to a primary cooling stop temperature of M_s to $M_s+50^\circ\text{C}$ at a first average cooling rate of 60-90°C/sec; and secondarily cooling the primarily cooled hot-rolled steel sheet to a coiling temperature (CT) of 50°C to $M_s-50^\circ\text{C}$ at a second average cooling rate of 1-50°C/sec, and then coiling the sheet.

[0043] First, in the present disclosure, a steel slab satisfying the above-mentioned composition and Relational Expression 1 is reheated to 1150-1350°C. At this time, if the reheating temperature is less than 1150°C, precipitates are not sufficiently redissolved, and the formation of precipitates in the process after hot rolling is reduced. In addition, coarse TiN remains, and due to insufficient soaking of the slab, it becomes difficult to uniformly control the temperature of the steel sheet during hot rolling. On the other hand, if the temperature exceeds 1350°C, the strength decreases due to abnormal grain growth of austenite grains, so it is preferable to limit the reheating temperature to 1150-1350°C.

[0044] Subsequently, in the present disclosure, rough rolling is finished on the heated slab at a rough rolling temperature (RDT) of 900-1100°C based on a $1/2t$ position (where t is the thickness of the steel material) to obtain a bar.

[0045] And in the present disclosure, surface cooling is performed while descaling the entire width of the bar at least three times, and subsequently, finish hot-rolling is finished on the bar at a finish hot-rolling temperature (FDT) defined by the following Relational Expression 2, based on a $1/2t$ position (where t is the thickness of the steel material).

[Relational Expression 2]

800°C to ST+50°C

$$ST = 800 + 140 [C] - 145 [Si] + 80 [Mn] - 30 [Cr] + 10 [Mo]$$

*In the above Relational Expression 2, C, Si, Mn, Cr, and Mo represent the content in weight% of the corresponding alloying elements. A value of 0 is substituted in the case of non-addition.

[0046] At this time, the surface temperature of the steel is controlled to be lower than the core temperature while performing descaling using a water spray device. This is to form some ferrite while maintaining a low temperature for the surface portion during the cooling stage after rolling, whereby carbon released from the ferrite accumulates in the untransformed austenite, which is then induced to transform into twinned martensite during the steel cooling process.

[0047] In order to improve bendability relative to hardness, the microstructure composition and hardness difference between the surface and the core are essential, and the aspect ratio, calculated as the major axis/minor axis of the prior austenite grain size of the core martensite, must be controlled within a predetermined range. To satisfy all of these conditions, the core temperature FDT at the finish hot-rolling stage has a temperature limit according to the above Calculation Formula 2, which is composed of the steel components. Specifically, if the finish hot-rolling temperature is higher than that of Relational Expression 2, the formation of the microstructure of the surface layer portion and the core portion cannot be induced to the desired composition, resulting in a conventional martensitic high-strength steel with poor bendability. On the other hand, if the finish hot-rolling temperature is lower than that of the above Relational Expression 2, the aspect ratio of the core structure does not achieve the desired value, which also adversely affects bendability.

[0048] And in the present disclosure, the finish hot-rolled steel sheet is primarily cooled to a temperature range of Ms+50°C to Ms at an average cooling rate of 50-100°C/sec. Here, Ms can be defined by the following Relational Expression 3.

$$Ms = 430 - 380*[C] - 13.5*[Si] - 47.5*[Mn] - 16*[Cr] - 24*[Mo] \quad \text{[Relation Expression 3]}$$

*In the above Relational Expression 3, C, Si, Mn, Cr, and Mo represent the content in weight% of the corresponding alloying elements.

[0049] The said cooling temperature is a condition for forming sufficient core portion martensite and surface layer portion ferrite + twinned martensite in a balanced manner. If the primary cooling is stopped at a temperature higher than Ms+50°C and switched to slow cooling, the cooling will be insufficient, preventing the formation of enough martensite in the core, resulting in insufficient core section hardness. Therefore, the desired high-strength steel sheet cannot be obtained. On the other hand, if rapid cooling is performed to a temperature lower than the Ms temperature, the combination of ferrite + twinned martensite in the surface layer portion cannot be obtained, making it impossible to achieve bendability.

[0050] Not only the cooling temperature but also the cooling rate plays a role; an excessive cooling rate forms the surface layer portion structure differently from what is intended, and an insufficient cooling rate forms the core portion structure differently from what is intended.

[0051] In the present disclosure, it is preferable to control the first cooling rate to a range of 60-90°C/sec.

[0052] Finally, in the present disclosure, the primarily cooled hot-rolled steel sheet is secondarily cooled to a coiling temperature (CT) of 50°C to Ms-50°C at a second average cooling rate of 1-50°C/sec, and then coiled.

[0053] Lowering the cooling rate compared to the primary cooling is recommended because once martensite has already formed in the core, any further rapid cooling deteriorates the shape quality of the sheet; therefore, switching to slow cooling is recommended from a productivity perspective. Excessive rapid cooling hinders the formation of ferrite in the surface layer portion, so it is advisable to introduce slow cooling as much as possible.

[0054] On the other hand, hot-rolled high-strength steels of giga-grade or higher are typically manufactured in the form of tempered martensite containing cementite through heat treatment to overcome poor workability. However, if heat treatment is omitted for productivity, there is a disadvantage of poor bendability. Therefore, in the present disclosure, the coiling temperature is limited to Ms-50°C to 50°C to add an auto (self) tempering effect to the core

portion martensite. The steel sheet of the present disclosure manufactured through this process allows for the observation of fine epsilon carbides, enabling auto-tempered martensite to be obtained without a separate heat treatment process.

[0055] Furthermore, the present disclosure may further include a step of pickling and oiling the coiled steel sheet after the secondary cooling.

MODE FOR CARRYING OUT THE INVENTION

[0056] Steel slabs having the compositions shown in Table 1 below were prepared. Then, hot-rolled steel sheets were manufactured from each of the prepared steel slabs using the manufacturing conditions shown in Table 2 below. In Table 2, RDT is the roughing delivery core temperature, FDT is the finish delivery core temperature, FSB is the number of descaling passes in finish rolling, CT is the coiling temperature, and ST is the temperature defined by Relational Expression 2.

[Table 1]

Catego ry	Remark	C	Si	Mn	Cr	Mo	Nb	Ti	V	Al	P	S	N	B	T (Harde nability)
Inv. Ex. 1	Inv. Steel	0.21	0.05	1.3	0.2	0.01	0.005	0.03	0.01	0.03	0.01	0.002	0.004	0.0015	45.09
Inv. Ex. 2		0.19	0.2	0.9	0.3	0.02	0.003	0.02	0.02	0.03	0.01	0.002	0.004	0.002	41.03
Inv. Ex. 3		0.22	0.03	1.1	0.01	0.15	0.005	0.02	0.02	0.03	0.01	0.002	0.005	0.002	39.63
Inv. Ex. 4		0.2	0.05	1.2	0.3	0.02	0.007	0.04	0.01	0.03	0.01	0.005	0.006	0.002	48.64
Inv. Ex. 5		0.19	0.02	0.7	0.2	0.2	0.005	0.03	0.02	0.02	0.02	0.003	0.004	0.002	39.17
Inv. Ex. 6		0.25	0.03	0.8	0.2	0.05	0.007	0.03	0.01	0.02	0.00 5	0.003	0.003	0.002	36.13
Inv. Ex. 7		0.23	0.02	1.7	0.02	0.01	0.005	0.02 5	0.02	0.03	0.01 5	0.004	0.005	0.0025	42.66
Inv. Ex. 8		0.18	0.05	1.6	0.01	0.25	0.003	0.02 5	0.01	0.03	0.01 5	0.004	0.005	0.003	60.72
Inv. Ex. 9		0.24	0.15	1.3	0.02	0.05	0.002	0.04 5	0.03	0.02	0.01	0.004	0.005	0.002	41.86
Inv. Ex. 10		0.21	0.01	1.6	0.01	0.02	0.005	0.03	0.01	0.04	0.01	0.002	0.005	0.002	38.65
Comp. Ex. 1	Camp. Steel	0.19	0.2	1.7	0.2	0.1	0.005	0.02	0.01	0.02	0.01	0.003	0.004	0.002	75.53
Comp. Ex. 2		0.19	0.2	1.7	0.2	0.1	0.005	0.03	0.01	0.04	0.01 5	0.005	0.003	0.003	75.53
Comp. Ex. 3		0.2	0.2	2.4	0.7	0.5	0.005	0.04	0.01	0.03	0.01 5	0.005	0.006	0.002	357.72
Comp. Ex. 4		0.18	0.05	0.9	0.00 5	0.1	0.01	0.03	0.01	0.04	0.01	0.004	0.006	0.001	27.28
Comp. Ex. 5		0.21	0.05	1.2	0.1	0.2	0.01	0.02 5	0.01	0.04	0.01 5	0.003	0.004	0.0025	55.52
Comp. Ex. 6		0.2	0.02	1.7	0.4	0.02	0.005	0.02	0.02	0.04	0.01 5	0.002	0.004	0.001	73.16
Comp. Ex. 7		0.25	0.03	0.8	0.25	0.2	0.018	0.02	0.01	0.04	0.01	0.003	0.003	0.0028	54.05
Comp. Ex. 8		0.28	0.02	1.8	0.5	0.1	0.025	0.03	0.01	0.03	0.01 5	0.001	0.005	0.0025	124.69
Comp. Ex. 9		0.3	0.06	1	0.4	0.4	0.02	0.04	0.03	0.03	0.02	0.002	0.005	0.0015	120.69
Comp. Ex. 10		0.19	0.1	1.6	0.3	0.1	0.005	0.02	0.01	0.02	0.01	0.003	0.004	0.002	77.29

[0057] *In Table 1, the unit for each component content is weight%, and the remaining component is Fe and unavoidable impurities. Also, in Table 1, T represents the T value defined by Relational Expression 1.

[0058] The microstructure and physical properties of each hot-rolled steel sheet manufactured as described above were analyzed in detail and are shown in Table 3 below. The Aspect Ratio is the aspect ratio calculated as the major axis/minor axis of the prior austenite grain size of the core martensite. Microstructure observation was performed using both a transmission electron microscope and a general electron microscope at magnifications of 1000x and 3000x, respectively, and measurements were taken when distinction was possible. The surface hardness and core section hardness are Rockwell C hardness. The surface hardness was measured at the surface, and the core section hardness was measured at a thickness of t/4 of the core section. R/t represents bendability and is the ratio of the bending radius to the steel sheet thickness, expressed based on the minimum bending radius at which no unevenness occur on the surface even after 90° bending. At this time, the bending specimen was processed to be long in the direction perpendicular to the rolling direction, and bending was performed so that the bending line was parallel to the rolling direction. YS and TS are the yield strength and tensile strength measured during a tensile test in a direction perpendicular to the rolling direction, the unit is MPa, and the tensile test standard used was a JIS No. 5 standard test piece.

[Table 2]

Categ ory	Slab Heating Temp. (°C)	RDT (°C)	FDT (°C)	FSB (times)	ST (°C)	Ms (°C)	1st Cooling Rate (°C/s)	1st Cooling Stop Temp. (°C)	2nd Cooling Rate (°C/s)	CT (°C)
Inv. Ex. 1	1231	1011	936	3	920	284	79	295	16	122
Inv. Ex. 2	1160	933	864	2	861	307	86	326	24	94
Inv. Ex. 3	1217	1002	931	3	916	290	73	308	30	51
Inv. Ex. 4	1216	1010	916	3	908	291	68	310	22	53
Inv. Ex. 5	1195	980	905	3	876	316	67	337	24	106
Inv. Ex. 6	1180	979	889	2	889	292	64	312	24	138
Inv. Ex. 7	1275	1061	986	3	965	261	76	288	30	88
Inv. Ex. 8	1269	1059	963	2	948	279	82	292	24	148
Inv. Ex. 9	1227	1000	919	3	916	274	77	286	23	65
Inv. Ex. 10	1261	1036	971	2	956	273	70	288	21	105
Comp. Ex. 1	1229	1017	932	1	929	269	72	294	16	340
Comp. Ex. 2	1256	1039	958	1	929	269	76	293	22	280
Comp. Ex. 3	1283	1065	985	3	975	214	66	232	18	66
Comp. Ex. 4	1188	985	909	1	891	316	82	335	22	139
Comp. Ex. 5	1216	1007	923	0	920	279	78	292	18	93
Comp. Ex. 6	1312	1089	1019	3	949	266	82	277	17	56
Comp. Ex. 7	1204	979	898	1	889	288	72	299	28	99
Comp. Ex. 8	1280	1077	992	1	966	227	79	247	26	135
Comp. Ex. 9	1240	1011	928	1	905	252	79	269	21	111
Comp. Ex. 10	1240	1030	949	1	932	273	120	120	0.5	94

[Table 3]

Category	Aspect Ratio	Surface Hardness (HrC)	Core Section Hardness (HrC)	Hardness Diff. (%)	Bendability (R/t)	YS (MPa)	TS (MPa)	Core (Bain ite + Ferrite) (%)	Core Martensite (%)	Surface Twinned Martensite (%)	Surface Ferrite (%)
Inv. Ex. 1	4	40.9	47.3	13.5	2.3	1239	1474	2	98	12	25
Inv. Ex. 2	5	39.4	45.0	12.4	2.7	1147	1397	4	96	11	20
Inv. Ex. 3	5	41.5	47.8	13.1	3.0	1263	1510	0	100	10	25
Inv. Ex. 4	4.4	39.6	46.3	14.4	3.3	1200	1450	2	98	11	25
Inv. Ex. 5	3	37.6	43.8	14.2	2.7	1116	1367	6	94	12	30
Inv. Ex. 6	2.4	44.4	49.6	10.4	3.7	1343	1584	3	97	9	20
Inv. Ex. 7	2.2	42.3	49.3	14.2	3.3	1331	1574	0	100	9	30
Inv. Ex. 8	4	40.3	44.7	9.8	3.3	1135	1389	0	100	12	20
Inv. Ex. 9	4.4	41.4	49.0	15.5	3.3	1322	1566	0	100	7	25
Inv. Ex. 10	5	42.2	47.5	11.2	2.7	1247	1495	0	100	9	20
Comp. Ex. 1	5	38.9	42.5	8.5	4.3	1033	1320	13	82	0	11
Comp. Ex. 2	7	40.0	43.3	7.7	4.7	1084	1345	11	83	1	13
Comp. Ex. 3	5	41.5	47.8	13.2	5.3	1260	1507	0	100	0	0
Comp. Ex. 4	2.4	28.4	31.2	8.9	1.0	674	920	75	2	8	42
Comp. Ex. 5	5	45.1	46.8	3.6	4.7	1218	1468	0	100	0	8
Comp. Ex. 6	1.5	44.3	47.4	6.6	5.7	1242	1491	0	100	0	0
Comp. Ex. 7	16	44.5	49.6	10.3	4.3	1344	1585	6	94	12	30
Comp. Ex. 8	13	51.4	52.9	2.8	6.3	1535	1762	0	100	0	0
Comp. Ex. 9	14	51.1	52.8	3.2	6.0	1521	1750	0	100	0	0
Comp. Ex. 10	9	45.8	46.1	0.6	4.7	1188	1440	0	100	0	0

[0059] As shown in Tables 1 to 3 above, it can be confirmed that Inventive Examples 1-10, in which the steel composition and manufacturing process conditions satisfy the scope of the present disclosure, all have excellent mechanical properties.

[0060] In contrast, Comparative Examples 1 and 2 are composed of components that satisfy Relational Expression 1, but during the manufacturing process, cooling was finished at a high temperature exceeding the range of the coiling temperature. As a result, in the final microstructure, a large amount of martensite in the core was replaced by bainite, resulting in lower strength compared to the composition, and ferrite in the surface layer portion was also not formed in the proper range. Consequently, as the coiling temperature increased, the strength and hardness decreased, but the effect of improving bendability did not appear as the microstructural conditions were not met.

[0061] In Comparative Example 3, alloying elements were used that exceeded Relational Expression 1 related to the composition. Along with this, the T value of Relational Expression 1 was excessively high due to the composition of hardenability elements such as Mn, Cr, and Mo exceeding the inventive range. As a result, no ferrite and twinned martensite were formed in the surface layer, and although other manufacturing process conditions were satisfied and the difference between surface hardness and core hardness exceeded 10%, the result was that no improvement effect in bendability was observed.

[0062] Comparative Example 4, in direct contrast to Comparative Example 3, confirmed that a high-strength martensitic steel could not be produced because it did not satisfy the compositional relational expression 1, although the individual alloy component ranges were satisfied under conditions that fell short of the range of Relational Expression 1. The majority of the core formed a bainite structure, and accordingly, the strength and hardness were significantly lower than in other inventive/comparative examples. Of course, as the strength and hardness decreased, the workability improved, and a large amount of ferrite and twinned martensite was formed in the surface layer, resulting in very good bendability of 1.0, but it cannot be included in the inventive examples that aim to improve bendability as a high-strength steel.

[0063] Comparative Example 5 was a case where the number of uses of the FSB (finish rolling descaler water spray device), used to satisfy the microstructure composition of the surface layer and the center in the manufacturing process conditions, was insufficient at 0 times, and it was a case where the ferrite + twinned martensite structure could not be formed in the surface layer due to a lack of surface cooling. As a result, the difference between the surface and core section hardness did not fall within the required range, and consequently, the bendability also showed poor results.

[0064] Comparative Example 6 was a case where the FDT (finish hot-rolling temperature) range, calculated from the ST temperature defined in Relational Expression 2, was exceeded in the manufacturing process conditions. Similar to Comparative Example 5, this prevented the formation of the ferrite + twinned martensite structure in the surface layer. As a result, the difference between the surface and core section hardness did not fall within the required range, and consequently, the bendability also showed poor results.

[0065] Comparative Examples 7-9 were cases where the component ranges of Nb, Mo, etc., were exceeded, causing the aspect ratio of the prior austenite in the core to become excessively large and increasing the effect of microstructure refinement in a specific direction, which led to the deterioration of bendability. In addition to this, in Comparative Examples 8-9, due to the large amount of alloying elements exceeding Relational Expression 1, the microstructure composition of the surface layer was also formed differently from what was intended, resulting in even poorer bendability.

[0066] In Comparative Example 10, an excessively high cooling rate was applied for the primary cooling rate, which is related to phase transformation among the manufacturing process conditions, and in terms of microstructure, the combination of ferrite + twinned martensite in the surface layer could not be formed. As a result, despite the composition and other manufacturing process conditions all being within the range, the bendability was very poor.

[0067] Meanwhile, FIG. 1 is a graph showing the relationship between the $t/4$ core section hardness and bendability (R/t) for the inventive and comparative examples in an embodiment of the present disclosure. As shown in FIG. 1, it can be seen that as hardness increases, R/t generally increases, showing a trend of deteriorating bendability. However, the inventive examples have a relatively low R/t value for their tensile strength, deviating from the continuous line of the graph, which confirms that their bendability is superior to that of the comparative examples.

[0068] FIG. 2 is a transmission electron microscope (TEM) image of twinned martensite formed in the surface layer of Inventive Example 1.

[0069] FIG. 3 is a transmission electron microscope (TEM) image of ferrite formed in the surface layer of Inventive Example 1.

[0070] FIG. 4 is an electron microscope image showing the cross-sectional microstructure distribution of the surface layer of Inventive Example 1 and Comparative Example 3.

[0071] FIG. 5 is a photograph showing carbides within the core microstructure (auto-tempered martensite) of Inventive Example 1.

[0072] FIG. 6 is an optical microscope image of a surface where unevenness occurred (bending radius 9 mm) and a

sound surface without unevenness (bending radius 7 mm) during a bending test of Inventive Example 1.

[0073] As described above, while the detailed description of the present disclosure has described preferred embodiments thereof, it is a matter of course that various modifications are possible for those with ordinary skill in the art to which the present disclosure pertains, without departing from the scope of the present disclosure. Therefore, the scope of rights of the present disclosure should not be limited to the described embodiments, but should be determined not only by the claims described below but also by their equivalents.

Claims

1. A hot-rolled steel sheet, comprising: by weight%, C: 0.17 to 0.26%, Si: 0.01 to 0.5%, Mn: 0.3 to 2.0%, Cr: 0.005 to 0.5%, Mo: 0.005 to 0.3%, Nb: 0.001 to 0.01%, Ti: 0.005 to 0.08%, V: 0.005 to 0.2%, 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 0.005%, a balance of Fe and unavoidable impurities, and satisfying the following Relational Expression 1,

wherein a microstructure of the steel sheet comprises: a surface layer portion to a depth of 10 μm from a surface of the steel sheet, the surface layer portion comprising, by area%, ferrite: 15 to 50%, twinned martensite: 2 to 15%, and

a remainder of bainite, martensite, and auto-tempered martensite; and a core portion at a t/4 position of the steel sheet, the core portion comprising, by area%, a sum of martensite and auto-tempered martensite: 90% or more, and at least one of ferrite and bainite: 10% or less, and wherein the core portion has a prior austenite aspect ratio of 10 or less.

$$30 \leq T \leq 80 \quad T = \left(\left(\frac{[\text{C}]}{10} \right)^{0.5} \times 1.07 \right) \times (0.7 \times [\text{Si}] + 1) \times (5 \times [\text{Mn}] + 1) \times (2.16 \times [\text{Cr}] + 1) \times (3 \times [\text{Mo}] + 1) \times 25.4 \quad [\text{Relation Expression 1}]$$

wherein, in Relational Expression 1, C, Si, Mn, Cr, and Mo represent the content in weight% of the corresponding alloying elements, and a value of 0 is substituted if an element is not added.

2. The hot-rolled steel sheet of claim 1, wherein a hardness measured at the surface of the steel sheet is 9% to 25% lower than a core section hardness measured at a t/4 position of the steel sheet.
3. The hot-rolled steel sheet of claim 1, wherein the steel sheet has a bendability (R/t) of less than 4.
4. A method for manufacturing a hot-rolled steel sheet, the method comprising: heating a slab to 1150 to 1350°C, the slab comprising, by weight%, C: 0.17 to 0.26%, Si: 0.01 to 0.5%, Mn: 0.3 to 2.0%, Cr: 0.005 to 0.5%, Mo: 0.005 to 0.3%, Nb: 0.001 to 0.01%, Ti: 0.005 to 0.08%, V: 0.005 to 0.2%, 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 0.005%, a balance of Fe and unavoidable impurities, and satisfying the following Relational Expression 1;

finishing rough rolling on the heated slab at a rough rolling temperature (RDT) of 900 to 1100°C based on a 1/2t position, where t is a thickness of a steel material, to obtain a bar; performing surface cooling while descaling an entire width of the bar at least three times;

finishing finish hot-rolling on the cooled bar at a finish hot-rolling temperature (FDT) of 800°C to ST+50°C, which satisfies the following Relational Expression 2, to obtain a hot-rolled steel sheet;

primarily cooling the hot-rolled steel sheet to a primary cooling stop temperature of Ms to Ms+50°C at a first average cooling rate of 60 to 90°C/sec; and

secondarily cooling the primarily cooled hot-rolled steel sheet to a coiling temperature (CT) of 50°C to Ms-50°C at a second average cooling rate of 1 to 50°C/sec, and then coiling the hot-rolled steel sheet.

$$30 \leq T \leq 80 \quad T = \left(\left(\frac{[\text{C}]}{10} \right)^{0.5} \times 1.07 \right) \times (0.7 \times [\text{Si}] + 1) \times (5 \times [\text{Mn}] + 1) \times (2.16 \times [\text{Cr}] + 1) \times (3 \times [\text{Mo}] + 1) \times 25.4 \quad [\text{Relation Expression 1}]$$

[Relational Expression 2]

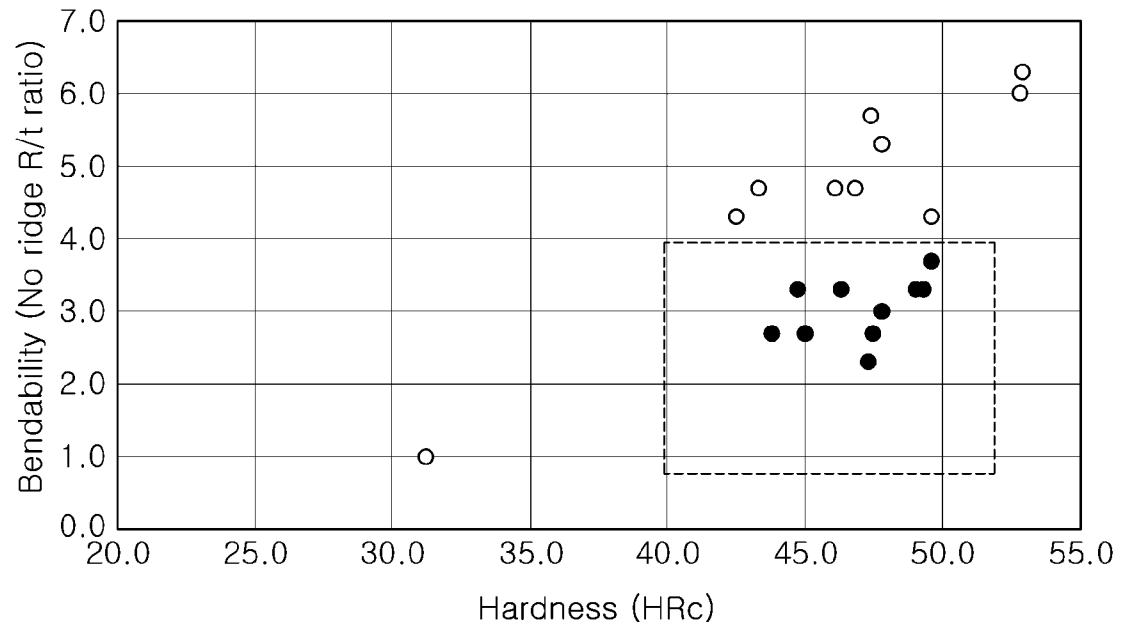
$$ST = 800 + 140 [C] - 145 [Si] + 80 [Mn] - 30 [Cr] + 10 [Mo]$$

wherein, in Relational Expression 1 and Relational Expression 2, C, Si, Mn, Cr, and Mo represent the content in weight% of the corresponding alloying elements, and a value of 0 is substituted if an element is not added.

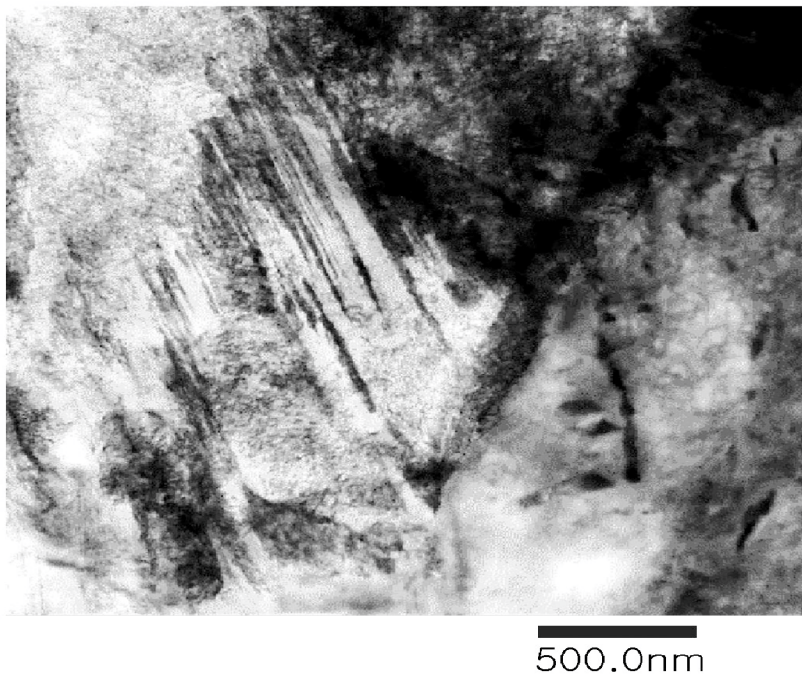
5. The method for manufacturing a hot-rolled steel sheet of claim 4, further comprising: pickling and oiling the coiled steel sheet after the secondary cooling.

6. The method for manufacturing a hot-rolled steel sheet of claim 4, wherein the coiled hot-rolled steel sheet has a microstructure, wherein a surface layer portion to a depth of 10 μ m from a surface of the steel sheet comprises, by area%, ferrite: 15 to 50%, twinned martensite: 2 to 15%, and a remainder of bainite, martensite, and auto-tempered martensite, wherein a core portion at a t/4 position of the steel sheet comprises, by area%, a sum of martensite and auto-tempered martensite: 90% or more, and at least one of ferrite and bainite: 10% or less, wherein a hardness measured at the surface of the steel sheet is 9% to 25% lower than a core section hardness measured at the t/4 position of the steel sheet, and wherein the core portion has a prior austenite aspect ratio of 10 or less.

[Fig. 1]



[Fig. 2]

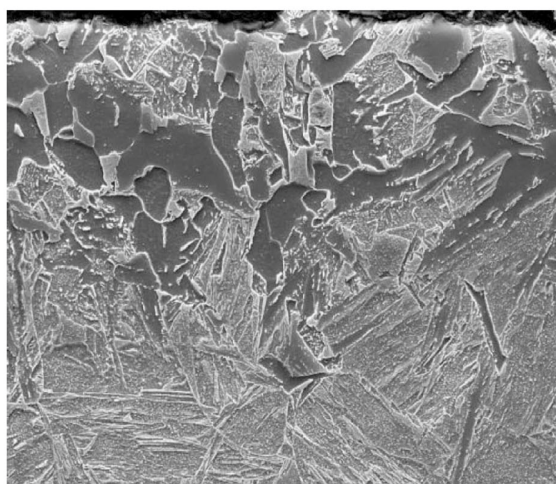


[Fig. 3]



500.0nm

[Fig. 4]

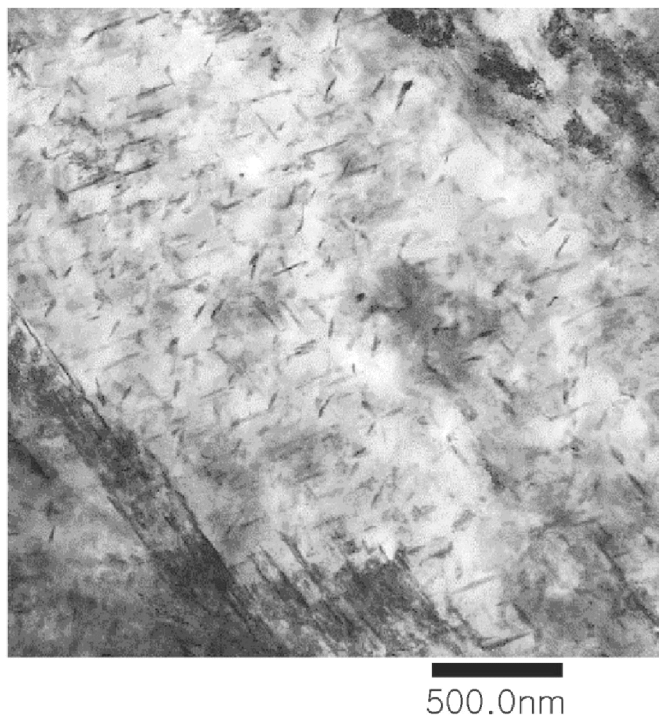


1 μ m

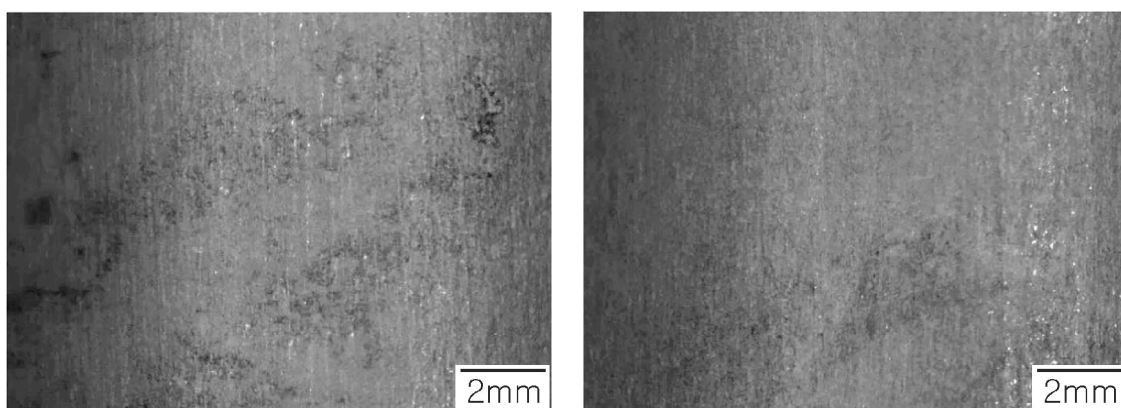


1 μ m

[Fig. 5]



[Fig. 6]



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/019780

A. CLASSIFICATION OF SUBJECT MATTER

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

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/38(2006.01); B21B 1/26(2006.01); C21D 8/02(2006.01); C21D 9/46(2006.01); C22C 38/00(2006.01);
C22C 38/04(2006.01); C22C 38/14(2006.01)

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), 페라이트(ferrite), 트윈드 마르텐사이트(twinned martensite), 베이나이트(hainite), 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 10-2021-0024135 A (JFE STEEL CORPORATION) 04 March 2021 (2021-03-04) See paragraphs [0126], [0128], [0137], [0141] and [0144], claims 1-3 and 7 and tables 2-1, 2-2 and 3-1.	1-6
A	KR 10-2015-0126683 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORPORATION) 12 November 2015 (2015-11-12) See paragraphs [0153]-[0155] and claims 1, 5 and 7.	1-6
A	JP 2006-199979 A (NIPPON STEEL CORP.) 03 August 2006 (2006-08-03) See paragraph [0021] and claims 1-2 and 8.	1-6
A	WO 2020-250735 A1 (JFE STEEL CORPORATION) 17 December 2020 (2020-12-17) See claims 1 and 6.	1-6

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

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Date of the actual completion of the international search

05 March 2025

Date of mailing of the international search report

06 March 2025

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Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/019780

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KR 10-2022-0067347 A (POSCO) 24 May 2022 (2022-05-24) See paragraph [0136] and claims 1 and 10.	1-6

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2024/019780

5	Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
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