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(54) **HOT-ROLLED STEEL PLATE**

(57) This hot-rolled steel sheet has a predetermined chemical composition, has a microstructure including, by area%, residual austenite of less than 3.0%, ferrite of 15.0% or more and less than 60.0%, and pearlite of less than 5.0%, in which an entropy value obtained by analyzing an SEM image of the microstructure using a gray-level co-occurrence matrix method is 10.7 or more, an inverse difference normalized value is 1.020 or more, a cluster shade value is -8.0×10^5 to 8.0×10^5, and a standard deviation of an Mn concentration is 0.60 mass% or less, and has a tensile strength of 980 MPa or more.

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Description

[Technical Field of the Invention]

[0001] The present invention relates to a hot-rolled steel sheet. Specifically, the present invention relates to a hot-rolled steel sheet that is used by being formed into various shapes by press working or the like, and particularly to a hot-rolled steel sheet that has a high strength, a high limit fracture sheet thickness reduction ratio, and excellent ductility and shearing property.

[0002] Priority is claimed on Japanese Patent Application No. 2021-166958, filed on October 11, 2021, the content of which is incorporated herein by reference.

[Background Art]

[0003] In recent years, from the viewpoint of protecting the global environment, efforts have been made to reduce the amount of carbon dioxide gas emitted in many fields. Vehicle manufacturers have also actively developed techniques for reducing the weight of vehicle bodies for the purpose of reducing fuel consumption. However, it is not easy to reduce the weight of vehicle bodies since the emphasis is placed on improvement in collision resistance to secure the safety of the occupants.

[0004] In order to achieve both vehicle body weight reduction and collision resistance, an investigation has been conducted to make a member thin by using a high strength steel sheet. Therefore, there is a strong demand for a steel sheet having both a high strength and excellent formability, and several techniques have been proposed to meet this demand. Since there are various working methods for vehicle members, the required formability differs depending on members to which the working methods are applied, but among these, the limit fracture sheet thickness reduction ratio and ductility are placed as important indices for formability. The limit fracture sheet thickness reduction ratio is a value that is obtained from the sheet thickness of a tensile test piece before breaking and the minimum value of the sheet thickness of the tensile test piece after breaking. It is not preferable that the limit fracture sheet thickness reduction ratio be low since breaking is likely to occur in an early stage when tensile strain is applied during press forming.

[0005] Vehicle members are formed by press forming, and the press-formed blank sheets are often manufactured by highly productive shearing working. A blank sheet manufactured by shearing working needs to be excellent in terms of the end surface accuracy after shearing working.

[0006] For example, when a secondary sheared surface consisting of a sheared surface, a fractured surface, and a sheared surface again is generated in the appearance of the end surface after shearing working (sheared end surface), the accuracy of the sheared end surface significantly deteriorates.

[0007] For example, Patent Document 1 discloses a hot-rolled steel sheet as a material for a cold-rolled steel sheet that has excellent surface properties after press working and in which the Mn segregation degree and the P segregation degree are controlled at a center portion of the sheet thickness.

[0008] However, in Patent Document 1, the limit fracture sheet thickness reduction ratio and shearing property of the hot-rolled steel sheet are not considered.

[Prior Art Document]

[Patent Document]

[0009] [Patent Document 1] PCT International Publication No. WO2020/044445

[Non-Patent Documents]

[0010]

[Non-Patent Document 1] J. Webel, J. Gola, D. Britz, F. Mucklich, Materials Characterization 144 (2018) 584-596
[Non-Patent Document 2] D. L. Naik, H. U. Sajid, R. Kiran, Metals 2019, 9, 546
[Non-Patent Document 3] K. Zuiderveld, Contrast Limited Adaptive Histogram Equalization, Chapter VIII. 5, Graphics Gems IV. P. S. Heckbert (Eds.), Cambridge, MA, Academic Press, 1994, pp. 474-485

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0011] The present invention is contrived in view of the above-described circumstances, and an object of the present invention is to provide a hot-rolled steel sheet that has a high strength, a high limit fracture sheet thickness reduction ratio, and excellent ductility and shearing property.

[Means for Solving the Problem]

[0012] The gist of the present invention is as follows.

(1) A hot-rolled steel sheet according to an aspect of the present invention containing, as a chemical composition, by mass%:

C: 0.050% to 0.250%;
Si: 0.05% to 3.00%;
Mn: 1.00% to 4.00%;
sol. Al: 0.001% to 2.000%;
P: 0.100% or less;
S: 0.0300% or less;
N: 0.1000% or less;
O: 0.0100% or less;
Ti: 0% to 0.500%;
Nb: 0% to 0.500%;
V: 0% to 0.500%;
Cu: 0% to 2.00%;
Cr: 0% to 2.00%;
Mo: 0% to 1.00%;
Ni: 0% to 2.00%;
B: 0% to 0.0100%;
Ca: 0% to 0.0200%;
Mg: 0% to 0.0200%;
REM: 0% to 0.1000%;
Bi: 0% to 0.0200%;
As: 0% to 0.100%;
Zr: 0% to 1.00%;
Co: 0% to 1.00%;
Zn: 0% to 1.00%;
W: 0% to 1.00%;
Sn: 0% to 0.05%; and
a remainder: Fe and impurities,
in which Expressions (A) and (B) are satisfied,
a microstructure includes, by area%,

residual austenite of less than 3.0%,
ferrite of 15.0% or more and less than 60.0%, and
pearlite of less than 5.0%,
in which an entropy value represented by Expression (1), obtained by analyzing an SEM image of the microstructure using a gray-level co-occurrence matrix method, is 10.7 or more,
an inverse difference normalized value represented by Expression (2) is 1.020 or more,
a cluster shade value represented by Expression (3) is -8.0×10^5 to 8.0×10^5, and
a standard deviation of an Mn concentration is 0.60 mass% or less, and

a tensile strength is 980 MPa or more,

$$0.060\% \leq \mathrm{Ti} + \mathrm{Nb} + \mathrm{V} \leq 0.500\% \ \ldots \ (\mathrm{A})$$

$$Zr + Co + Zn + W \leq 1.00\% \ldots (B)$$

where each element symbol in Expressions (A) and (B) represents an amount of the corresponding element by mass%, and 0% is substituted in a case where the corresponding element is not contained,
here, P(i, j) in Expressions (1) to (5) is a gray-level co-occurrence matrix, L in Expression (2) is the number of grayscale levels that can be taken in the SEM image, i and j in Expressions (2) and (3) are natural numbers of 1 to L, and μ_x and μ_y in Expression (3) are each represented by Expressions (4) and (5).

$$Entropy = -\sum_i \sum_j P(i,j).\log\left(P(i,j)\right) \quad \cdots (1)$$

$$Inverse\ difference\ normalized = \sum_i \sum_j \frac{P(i,j)}{1+\frac{|i-j|}{L}} \quad \cdots (2)$$

$$Cluster\ Shade = \sum_i \sum_j \left(i+j-\mu_x-\mu_y\right)^3 P(i,j) \quad \cdots (3)$$

$$\mu_x = \sum_i \sum_j i\left(P(i,j)\right) \quad \cdots (4)$$

$$\mu_y = \sum_i \sum_j j\left(P(i,j)\right) \quad \cdots (5)$$

(2) In the hot-rolled steel sheet according to (1), an average crystal grain size of a surface layer may be less than 3.0 μm.
(3) In the hot-rolled steel sheet according to (1) or (2), the chemical composition may contain, by mass%, one or two or more selected from the group consisting of

Ti: 0.001% to 0.500%,
Nb: 0.001% to 0.500%,
V: 0.001% to 0.500%,
Cu: 0.01% to 2.00%,
Cr: 0.01% to 2.00%,
Mo: 0.01% to 1.00%,
Ni: 0.01% to 2.00%,
B: 0.0001% to 0.0100%,
Ca: 0.0001% to 0.0200%,
Mg: 0.0001% to 0.0200%,
REM: 0.0001% to 0.1000%,
Bi: 0.0001% to 0.0200%,
As: 0.001% to 0.100%,
Zr: 0.01% to 1.00%,
Co: 0.01% to 1.00%,
Zn: 0.01% to 1.00%,
W: 0.01% to 1.00%, and
Sn: 0.01% to 0.05%.

[Effects of the Invention]

[0013] In the aspect according to the present invention, it is possible to obtain a hot-rolled steel sheet that has a high strength, a high limit fracture sheet thickness reduction ratio, and excellent ductility and shearing property. In addition, in the preferable aspect according to the present invention, it is possible to obtain a hot-rolled steel sheet that has the above various properties and, furthermore, suppresses the occurrence of inside bend cracking, that is, has excellent inside bend cracking resistance.

[0014] The hot-rolled steel sheet according to the aspect of the present invention is suitable as an industrial material used for vehicle members, mechanical structural members, and building members.

[Brief Description of the Drawings]

[0015]

FIG. 1 is an example of a sheared end surface of a hot-rolled steel sheet according to a present invention example.

FIG. 2 is an example of a sheared end surface of a hot-rolled steel sheet according to a comparative example.

[Embodiments of the Invention]

[0016] Hereinafter, the chemical composition and microstructure of a hot-rolled steel sheet according to the present embodiment will be described in greater detail. However, the present invention is not limited to configuration disclosed in the present embodiment, and various modifications can be made without departing from the gist of the present invention.

[0017] The numerical limit range described below with "to" in between includes the lower limit and the upper limit. Numerical values indicated as "less than" or "more than" do not fall within the numerical range. In the following description, % regarding the chemical composition is mass% unless otherwise specified.

Chemical Composition

[0018] Hereinafter, the chemical composition of the hot-rolled steel sheet according to the present embodiment will be described in detail.

C: 0.050% to 0.250%

[0019] C increases the area ratio of a hard phase and increases the strength of ferrite by bonding to a precipitation hardening element such as Ti, Nb, or V. In a case where the C content is less than 0.050%, it is not possible to obtain a desired strength. Therefore, the C content is set to 0.050% or more. The C content is preferably 0.060% or more, more preferably 0.070% or more, and even more preferably 0.080% or more or 0.090% or more.

[0020] Meanwhile, in a case where the C content is more than 0.250%, the ductility of the hot-rolled steel sheet decreases due to a decrease in area ratio of ferrite. Therefore, the C content is set to 0.250% or less. The C content is preferably 0.200% or less, 0.150% or less, or 0.120% or less.

Si: 0.05% to 3.00%

[0021] Si acts to promote the formation of ferrite, thereby improving the ductility of a hot-rolled steel sheet, and to solid solution strengthen ferrite, thereby increasing the strength of the hot-rolled steel sheet. In addition, Si acts to achieve soundness of steel by deoxidation (suppressing the occurrence of defects such as blowholes in the steel). In a case where the Si content is less than 0.05%, it is not possible to obtain the effects of the actions. Therefore, the Si content is set to 0.05% or more. The Si content is preferably 0.50% or more, and more preferably 0.80% or more, 1.00% or more, 1.20% or more, or 1.40% or more.

[0022] However, in a case where the Si content is more than 3.00%, the surface properties, chemical convertibility, ductility, and weldability of a steel sheet significantly deteriorate, and the A_3 transformation point is significantly increased. Therefore, it becomes difficult to perform hot rolling in a stable manner. In addition, austenite is likely to remain after cooling, thereby reducing the limit fracture sheet thickness reduction ratio. Therefore, the Si content is set to 3.00% or less. The Si content is preferably 2.70% or less, and more preferably 2.50% or less, 2.20% or less, 2.00% or less, or 1.80% or less.

Mn: 1.00% to 4.00%

[0023] Mn acts to suppress ferritic transformation, thereby increasing the strength of the hot-rolled steel sheet. In a case where the Mn content is less than 1.00%, it is not possible to obtain a desired strength. Therefore, the Mn content is set to 1.00% or more. The Mn content is preferably 1.30% or more, and more preferably 1.50% or more or 1.80% or more.
[0024] Meanwhile, in a case where the Mn content is more than 4.00%, the hard phase has a periodic band-like form due to the segregation of Mn and it becomes difficult to obtain desired shearing property. Therefore, the Mn content is set to 4.00% or less. The Mn content is preferably 3.70% or less or 3.50% or less, and more preferably 3.20% or less, 3.00% or less, or 2.60% or less.
[0025] Ti: 0% to 0.500%, Nb: 0% to 0.500%, V: 0% to 0.500%

$$0.060\% \leq \mathrm{Ti} + \mathrm{Nb} + \mathrm{V} \leq 0.500\% \ ... \ (\mathrm{A})$$

[0026] Each element symbol in Expression (A) represents the amount of the corresponding element by mass%, and 0% is substituted in a case where the corresponding element is not contained.
[0027] Ti, Nb, and V are elements that are finely precipitated in steel as a carbide and a nitride and improve the strength of steel by precipitation hardening. In a case where the total amount of Ti, Nb, and V is less than 0.060%, these effects cannot be obtained. Therefore, the total amount of Ti, Nb, and V is set to 0.060% or more. That is, the value of the middle side of Expression (A) is set to 0.060% or more. Not all of Ti, Nb, and V need to be contained, and any one thereof may be contained, as long as the total amount thereof is 0.060% or more. Therefore, the lower limits of the Ti content, the Nb content, and the V content are each 0%. Each of the lower limits of the Ti content, the Nb content, and the V content may be 0.001%, 0.010%, 0.030%, or 0.050%. The total amount of Ti, Nb, and V is preferably 0.080% or more, and more preferably 0.100% or more.
[0028] Meanwhile, in a case where any one of the Ti content, the Nb content, and the V content is more than 0.500% or the total amount of Ti, Nb, and V is more than 0.500%, the workability of the hot-rolled steel sheet deteriorates. Therefore, each of the Ti content, the Nb content, and the V content is set to 0.500% or less, and the total amount of Ti, Nb, and V is set to 0.500% or less. That is, the value of the middle side of Expression (A) is set to 0.500% or less. Each of the Ti content, the Nb content, and the V content is preferably 0.400% or less or 0.300% or less, more preferably 0.250% or less, and even more preferably 0.200% or less or 0.100% or less. The total amount of Ti, Nb, and V is preferably 0.300% or less, more preferably 0.250% or less, and even more preferably 0.200% or less.

sol. Al: 0.001% to 2.000%

[0029] Similar to Si, Al acts to deoxidize steel, thereby achieving soundness of the steel, and to promote the formation of ferrite, thereby increasing the ductility of the hot-rolled steel sheet. In a case where the sol. Al content is less than 0.001%, it is not possible to obtain the effects of the actions. Therefore, the sol. Al content is set to 0.001% or more. The sol. Al content is preferably 0.010% or more, 0.030% or more, or 0.050% or more, and more preferably 0.080% or more, 0.100% or more, or 0.150% or more.
[0030] Meanwhile, in a case where the sol. Al content is more than 2.000%, the above effects are saturated, which is not economically preferable. Accordingly, the sol. Al content is set to 2.000% or less. The sol. Al content is preferably 1.700% or less or 1.500% or less, more preferably 1.300% or less, and even more preferably 1.000% or less.
[0031] The sol. Al means acid-soluble Al and refers to solid solution Al present in steel in a solid solution state.

P: 0.100% or less

[0032] P is an element that is generally contained as an impurity, but acts to increase the strength of the hot-rolled steel sheet by solid solution strengthening. The lower limit of the P content is 0%, but P may be positively contained. However, P is an element that is easily segregated. In a case where the P content is more than 0.100%, the ductility and limit fracture sheet thickness reduction ratio of the hot-rolled steel sheet attributed to boundary segregation are significantly decreased. Therefore, the P content is set to 0.100% or less. The P content is preferably 0.050% or less, 0.030% or less, 0.020% or less, or 0.015% or less. The lower limit of the P content does not need to be particularly specified, and the lower limit of the P content is 0%. From the viewpoint of the refining cost, the lower limit of the P content may be 0.001%, 0.003%, or 0.005%.

S: 0.0300% or less

[0033] S is an element that is contained as an impurity and forms a sulfide-based inclusion in steel, thereby decreasing the ductility and limit fracture sheet thickness reduction ratio of the hot-rolled steel sheet. In a case where the S content is more than 0.0300%, the ductility and limit fracture sheet thickness reduction ratio of the hot-rolled steel sheet are significantly decreased. Therefore, the S content is set to 0.0300% or less. The S content is preferably 0.0100% or less, 0.0070% or less, or 0.0050% or less. The lower limit of the S content is 0%, but may be 0.0001%, 0.0005%, 0.0010%, or 0.0020% from the viewpoint of the refining cost.

N: 0.1000% or less

[0034] N is an element that is contained in steel as an impurity and acts to decrease the ductility and limit fracture sheet thickness reduction ratio of the hot-rolled steel sheet. In a case where the N content is more than 0.1000%, the ductility and limit fracture sheet thickness reduction ratio of the hot-rolled steel sheet are significantly decreased. Therefore, the N content is set to 0.1000% or less. The N content is preferably 0.0800% or less, more preferably 0.0700% or less or 0.0300% or less, and even more preferably 0.0150% or less or 0.0100% or less. The lower limit of the N content is 0%. However, in a case where one or two or more of Ti, Nb, and V are contained to further refine the microstructure, the N content is preferably set to 0.0010% or more, and more preferably set to 0.0015% or more or 0.0020% or more in order to promote the precipitation of a carbonitride.

O: 0.0100% or less

[0035] In a case where a large amount of O is contained in steel, O forms a coarse oxide that serves as a fracture initiation point, and causes brittle fracture and hydrogen-induced cracks. Therefore, the O content is set to 0.0100% or less. The O content is preferably 0.0080% or less, and more preferably 0.0050% or less or 0.0030% or less. The lower limit of the O content is 0%, but in order to disperse a large number of fine oxides during deoxidation of molten steel, the O content may be set to 0.0005% or more or 0.0010% or more.

[0036] The hot-rolled steel sheet according to the present embodiment may contain the following elements as optional elements instead of a portion of Fe. In a case where the optional elements are not contained, the lower limit of the content thereof is 0%. Hereinafter, the optional elements will be described in detail.

[0037]

Cu: 0.01% to 2.00%
Cr: 0.01% to 2.00%
Mo: 0.01% to 1.00%
Ni: 0.01% to 2.00%
B: 0.0001% to 0.0100%

[0038] All of Cu, Cr, Mo, Ni, and B act to increase the hardenability of the hot-rolled steel sheet. In addition, Cu and Mo act to increase the strength of the hot-rolled steel sheet by being precipitated as a carbide in the steel. Furthermore, in a case where Cu is contained, Ni acts to effectively suppress the intergranular cracking of a slab caused by Cu. Therefore, one or two or more of these elements may be contained.

[0039] As described above, Cu acts to increase the hardenability of the hot-rolled steel sheet and to increase the strength of the hot-rolled steel sheet by being precipitated as a carbide in the steel at a low temperature. In order to more reliably obtain the effects of the actions, the Cu content is preferably set to 0.01% or more, and more preferably set to 0.05% or more. However, in a case where the Cu content is more than 2.00%, intergranular cracking may occur in a slab. Therefore, the Cu content is set to 2.00% or less. The Cu content is preferably 1.50% or less, and more preferably 1.00% or less, 0.70% or less, or 0.50% or less.

[0040] As described above, Cr acts to increase the hardenability of the hot-rolled steel sheet. In order to more reliably obtain the effect of the action, the Cr content is preferably set to 0.01% or more, and more preferably set to 0.05% or more. However, in a case where the Cr content is more than 2.00%, the chemical convertibility of the hot-rolled steel sheet is significantly decreased. Therefore, the Cr content is set to 2.00% or less. The Cr content is preferably 1.50% or less, and more preferably 1.00% or less, 0.70% or less, or 0.50% or less.

[0041] As described above, Mo acts to increase the hardenability of the hot-rolled steel sheet and to increase the strength of the hot-rolled steel sheet by being precipitated as a carbide in the steel. In order to more reliably obtain the effects of the actions, the Mo content is preferably set to 0.01% or more, and more preferably set to 0.02% or more. However, from the economic perspective, it is not preferable that the Mo content be set to more than 1.00% since the effects of the actions are saturated. Therefore, the Mo content is 1.00% or less. The O content is preferably 0.50% or less, and more preferably 0.20% or less or 0.10% or less.

[0042] As described above, Ni acts to increase the hardenability of the hot-rolled steel sheet. In addition, in a case where Cu is contained, Ni acts to effectively suppress the intergranular cracking of a slab caused by Cu. In order to more reliably obtain the effects of the actions, the Ni content is preferably set to 0.01% or more. Since Ni is an expensive element, it is not economically preferable to contain a large amount of Ni. Therefore, the Ni content is set to 2.00% or less. The Ni content is preferably 1.50% or less, and more preferably 1.00% or less, 0.70% or less, or 0.50% or less.

[0043] As described above, B acts to increase the hardenability of the hot-rolled steel sheet. In order to more reliably obtain the effect of the action, the B content is preferably set to 0.0001% or more, and more preferably set to 0.0002% or more. However, in a case where the B content is more than 0.0100%, the formability of the hot-rolled steel sheet is significantly decreased, and thus the B content is set to 0.0100% or less. The B content is preferably 0.0050% or less or 0.0025% or less.

[0044]

Ca: 0.0001% to 0.0200%
Mg: 0.0001% to 0.0200%
REM: 0.0001% to 0.1000%
Bi: 0.0001% to 0.0200%
As: 0.001 % to 0.100%

[0045] All of Ca, Mg, and REM act to increase the ductility of the hot-rolled steel sheet by adjusting the shape of inclusions in steel to a preferable shape. In addition, Bi acts to increase the ductility of the hot-rolled steel sheet by refining the solidification structure. Therefore, one or two or more of these elements may be contained. In order to more reliably obtain the effects of the actions, the amount of any one or more of Ca, Mg, REM, and Bi is preferably set to 0.0001% or more. However, in a case where the Ca content or Mg content is more than 0.0200% or the REM content is more than 0.1000%, an inclusion is excessively formed in steel, and thus the ductility of the hot-rolled steel sheet may be conversely decreased. In addition, from the economic perspective, it is not preferable that the Bi content be set to more than 0.0200% since the effects of the actions are saturated. Therefore, the Ca content and the Mg content are set to 0.0200% or less, the REM content is set to 0.1000% or less, and the Bi content is set to 0.0200% or less. The Ca content, Mg content, and Bi content are preferably 0.0100% or less, and more preferably 0.0070% or less or 0.0040% or less. The REM content is preferably 0.0070% or less or 0.0040% or less. As refines prior austenite grains by lowering an austenite single-phase formation temperature, thereby contributing to an improvement in ductility of the hot-rolled steel sheet. In order to reliably obtain the effects, the As content is preferably set to 0.001% or more. Meanwhile, since the above effects are saturated even in a case where a large amount of As is contained, the As content is set to 0.100% or less.

[0046] Here, REM refers to a total of 17 elements consisting of Sc, Y, and lanthanoids, and the REM content refers to the total amount of these elements. Lanthanoids are industrially added in the form of misch metal.

[0047] Zr: 0.01% to 1.00%, Co: 0.01% to 1.00%, Zn: 0.01% to 1.00%, W: 0.01% to 1.00%

$$\mathrm{Zr} + \mathrm{Co} + \mathrm{Zn} + \mathrm{W} \leq 1.00\% \ ... \ (\mathrm{B})$$

[0048] Each element symbol in Expression (B) represents the amount of the corresponding element by mass%, and 0% is substituted in a case where the corresponding element is not contained.

Sn: 0.01% to 0.05%

[0049] Regarding Zr, Co, Zn, and W, the present inventors have confirmed that, even in a case where these elements are contained in an amount of 1.00% or less in total, the effects of the hot-rolled steel sheet according to the present embodiment are not impaired. Therefore, one or two or more of Zr, Co, Zn, and W may be contained in an amount of 1.00% or less in total. That is, the value of the left side of Expression (B) may be set to 1.00% or less, 0.50% or less, 0.10% or less, or 0.05% or less. Each of the Zr content, the Co content, the Zn content, the W content, and the Sn content may be set to 0.50% or less, 0.10% or less, or 0.05% or less. Since Zr, Co, Zn, and W do not have to be contained, the amount of each of Zr, Co, Zn, and W may be 0%. In order to improve the strength by solid solution strengthening of the steel sheet, each of the Zr content, the Co content, the Zn content, and the W content may be 0.01% or more.

[0050] In addition, the present inventors have confirmed that, even in a case where Sn is contained in a small amount, the effects of the hot-rolled steel sheet according to the present embodiment are not impaired. However, in a case where a large amount of Sn is contained, a defect may be generated during hot rolling, and thus the Sn content is set to 0.05% or less. Since Sn does not have to be contained, the Sn content may be 0%. In order to increase the corrosion resistance of the hot-rolled steel sheet, the Sn content may be 0.01% or more.

[0051] The remainder of the chemical composition of the hot-rolled steel sheet according to the present embodiment may consist of Fe and impurities. In the present embodiment, the impurities mean substances incorporated from ore as a raw material, a scrap, manufacturing environment, or the like and/or substances permitted to an extent that the hot-rolled steel sheet according to the present embodiment is not adversely affected.

[0052] The chemical composition of the above hot-rolled steel sheet may be measured by a general analytical method. For example, the chemical composition may be measured using inductively coupled plasma-atomic emission spectrometry (ICP-AES). sol. Al may be measured by ICP-AES using a filtrate obtained by heating and decomposing a sample with an acid. In addition, C and S may be measured using a combustion-infrared absorption method, N may be measured using an inert gas fusion-thermal conductivity method, and O may be measured using an inert gas fusion-non-dispersive infrared absorption method.

[0053] In a case where the hot-rolled steel sheet is provided with a plating layer on the surface, the chemical composition may be analyzed after removing the plating layer by mechanical grinding or the like, as necessary.

Microstructure of Hot-Rolled Steel Sheet

[0054] Next, the microstructure of the hot-rolled steel sheet according to the present embodiment will be described.

[0055] The hot-rolled steel sheet according to the present embodiment has a microstructure including, by area%, residual austenite of less than 3.0%, ferrite of 15.0% or more and less than 60.0%, and pearlite of less than 5.0%, in which an entropy value represented by Expression (1), obtained by analyzing an SEM image of the microstructure using a gray-level co-occurrence matrix method, is 10.7 or more, an inverse difference normalized value represented by Expression (2) is 1.020 or more, a cluster shade value represented by Expression (3) is -8.0×10^5 to 8.0×10^5, and a standard deviation of an Mn concentration is 0.60 mass% or less.

[0056] Therefore, the hot-rolled steel sheet according to the present embodiment can obtain excellent ductility and shearing property while having a high strength and a high limit fracture sheet thickness reduction ratio. In the present embodiment, the microstructural fraction, entropy value, inverse difference normalized value, cluster shade value, and standard deviation of the Mn concentration are specified in the microstructure in a cross section parallel to the rolling direction at a depth position 1/4 of the sheet thickness away from the surface (a region ranging from a depth of 1/8 of the sheet thickness from the surface to a depth of 3/8 of the sheet thickness from the surface) at a center position in the sheet width direction. The reason therefor is that the microstructures at the position indicate typical microstructures of the steel sheet.

[0057] The surface mentioned here refers to the interface between a plating layer and the steel sheet in a case where the hot-rolled steel sheet is provided with the plating layer.

Area Ratio of Residual Austenite: less than 3.0%

[0058] Residual austenite is a microstructure that is present as a face-centered cubic lattice even at room temperature. Residual austenite acts to increase the ductility of the hot-rolled steel sheet by transformation-induced plasticity (TRIP). Meanwhile, residual austenite transforms into high-carbon martensite during shearing working, which inhibits the stable occurrence of cracking and causes the formation of a secondary sheared surface and the decrease of a limit fracture sheet thickness reduction ratio. In a case where the area ratio of the residual austenite is 3.0% or more, the action is actualized, and the shearing property of the hot-rolled steel sheet deteriorates. Therefore, the area ratio of the residual austenite is set to less than 3.0%. The area ratio of the residual austenite is preferably less than 1.5%, and more preferably less than 1.0%. Since residual austenite is preferably as little as possible, the area ratio of the residual austenite may be 0%.

[0059] As a method of measuring the area ratio of the residual austenite, methods by X-ray diffraction, electron back scatter diffraction image (EBSP, electron back scattering diffraction pattern) analysis, and magnetic measurement and the like are known. In the present embodiment, the area ratio of the residual austenite is measured by X-ray diffraction that makes it relatively easy to obtain accurate measurement results and is hardly affected by polishing, since it is less susceptible to polishing (when affected by polishing, the residual austenite may be converted into another phase such as martensite, so that the true area ratio may not be measured).

[0060] In the measurement of the area ratio of the residual austenite by X-ray diffraction in the present embodiment, first, the integrated intensities of a total of 6 peaks of $\alpha(110)$, $\alpha(200)$, $\alpha(211)$, $\gamma(111)$, $\gamma(200)$, and $\gamma(220)$ are obtained in a sheet thickness-directional cross section parallel to the rolling direction at a 1/4 depth position of the sheet thickness (a region ranging from a depth of 1/8 of the sheet thickness from the surface to a depth of 3/8 of the sheet thickness from the surface) at a center position in the sheet width direction of the hot-rolled steel sheet using Co-Kα rays, and the volume percentage of the residual austenite is obtained by calculation using the strength averaging method. The obtained volume percentage of the residual austenite is regarded as the area ratio of the residual austenite.

Area Ratio of Ferrite: 15.0% or more and less than 60.0%

[0061] Ferrite is a structure formed when fcc transforms into bcc at a relatively high temperature. Since ferrite has a high work hardening rate, the ferrite acts to increase the balance between the strength and ductility of the hot-rolled steel sheet. In order to obtain the above action, the area ratio of the ferrite is set to 15.0% or more. The area ratio of the ferrite is preferably 20.0% or more, more preferably 25.0% or more, and even more preferably 30.0% or more.
[0062] Meanwhile, since ferrite has a low strength, a desired strength cannot be obtained when the area ratio is excessive. Therefore, the area ratio of the ferrite is set to less than 60.0%. The area ratio of the ferrite is preferably 50.0% or less, and more preferably 45.0% or less or 40.0% or less.

Area Ratio of Pearlite: less than 5.0%

[0063] Pearlite is a lamellar microstructure in which cementite is precipitated in layers between ferrite and is a soft microstructure as compared with bainite and martensite. In a case where the area ratio of the pearlite is 5.0% or more, carbon is consumed by cementite that is contained in pearlite, the strengths of martensite and bainite, that are the remainder in microstructure, decrease, and a desired strength cannot be obtained. Therefore, the area ratio of the pearlite is set to less than 5.0%. The area ratio of the pearlite is preferably 3.0% or less, 2.0% or less, or 1.0% or less.
[0064] In order to improve the stretch flangeability of the hot-rolled steel sheet, the area ratio of the pearlite is preferably reduced as much as possible, and the area ratio of the pearlite is more preferably 0%.
[0065] The hot-rolled steel sheet according to the present embodiment contains a hard structure consisting of one or two or more of bainite, martensite, and tempered martensite in a total area ratio of more than 32.0% and 85.0% or less as the remainder in microstructure other than residual austenite, ferrite, and pearlite. The lower limit of the total area ratio of the remainder in microstructure may be 36.0%, 40.0%, 44.0%, 48.0%, 52.0%, or 55.0%, and the upper limit thereof may be 82.0%, 78.0%, 74.0%, 70.0%, or 66.0%. The remainder in microstructure other than residual austenite, ferrite, and pearlite may include one or two or more of bainite, martensite, and tempered martensite.
[0066] The measurement of the area ratio of the microstructure is conducted by the following method. A sheet thickness-directional cross section parallel to the rolling direction is mirror-finished and, furthermore, polished at room temperature with colloidal silica not containing an alkaline solution for 8 minutes, thereby removing strain introduced into the surface layer of a sample. In a random position of the sample cross section in a longitudinal direction, a 50 μm-long region at a depth position 1/4 of the sheet thickness away from the surface (a region ranging from a depth of 1/8 of the sheet thickness from the surface to a depth of 3/8 of the sheet thickness from the surface) at a center position in the sheet width direction is measured by an electron backscatter diffraction method at a measurement interval of 0.1 μm to obtain crystal orientation information. For the measurement, an EBSD analyzer composed of a thermal field emission scanning electron microscope (JSM-7001F manufactured by JEOL) and an EBSD detector (DVC5 type detector manufactured by TSL) is used. In this case, the degree of vacuum inside the EBSD analyzer is set to 9.6×10^{-5} Pa or less, the acceleration voltage is set to 15 kV, the irradiation current level is set to 13, and the electron beam irradiation level is set to 62. The observation area is set to 40,000 μm^2.
[0067] Furthermore, a reflected electron image is captured in the same visual field. First, crystal grains in which ferrite and cementite are precipitated in layers are specified from the reflected electron image and the area ratio of the crystal grains is calculated to obtain an area ratio of pearlite. After that, for crystal grains determined to have a body-centered cubic lattice structure among crystal grains except the crystal grains determined as pearlite, from the obtained crystal orientation information, regions where the grain average misorientation value is 1.0° or less are determined as ferrite using a "Grain Average Misorientation" function mounted in software "OIM Analysis (registered trademark)" included in the EBSD analyzer. In that case, the grain tolerance angle is set to 15° and the area ratio of the regions determined as ferrite is obtained to obtain an area ratio of ferrite.
[0068] Next, the area ratio of regions except the regions determined as pearlite or ferrite is measured to obtain an area ratio of the remainder in microstructure (that is, bainite, martensite, and tempered martensite). In a case where it is desired to measure the area ratio of bainite and the total area ratio of martensite and tempered martensite, these area ratios can be measured by the following method. Specifically, with respect to the remainder regions, when the maximum value of "Grain Average IQ" of the ferrite regions is represented by $I\alpha$, regions where "Grain Average IQ" becomes more than $I\alpha/2$ are extracted (determined) as bainite, and regions where "Grain Average IQ" becomes $I\alpha/2$ or less are extracted (determined) as "martensite or tempered martensite". The area ratio of the regions extracted (determined) as bainite is calculated to obtain the area ratio of bainite. In addition, the area ratio of the regions extracted (determined) as martensite or tempered martensite is calculated to obtain the total area ratio of martensite and tempered martensite.
[0069] In the present embodiment, since the area ratios of the structures are measured by X-ray diffraction and EBSD analysis, the total of the area ratios of the structures obtained by the measurement may not be 100.0%. In a case where the total of the area ratios of the structures obtained by the above method does not reach 100.0%, the area ratios of the structures are converted so that the total of the area ratios of the structures reaches 100.0%. For example, in a case

where the total of the area ratios of the structures is 103.0%, the area ratio of each structure is multiplied by "100.0/103.0" to obtain the area ratio of each structure.

[0070] Entropy Value: 10.7 or more, Inverse Difference Normalized Value: 1.020 or more

In order to suppress the generation of a secondary sheared surface, it is important to form a fractured surface after a sheared surface is sufficiently formed, and there is a need to suppress the early occurrence of cracking from the cutting edge of a tool during shearing working. In order for that, it is important that the periodicity of the microstructure is low and the uniformity of the microstructure is high. In the present embodiment, the generation of a secondary sheared surface is suppressed by controlling the entropy value (E value) representing the periodicity of the microstructure and the inverse difference normalized value (I value) representing the uniformity of the microstructure.

[0071] The E value represents the periodicity of the microstructure. In a case where the brightness is periodically arranged due to an influence of the formation of a band-like structure or the like, that is, the periodicity of the microstructure is high, the E value decreases. In the present embodiment, since there is a need to make the microstructure poorly periodic, it is necessary to increase the E value. In a case where the E value is less than 10.7, a secondary sheared surface is likely to be generated. From periodically arranged structures as initiation points, cracking occurs from the cutting edge of a shearing tool in an extremely early stage of shearing working to form a fractured surface, and then a sheared surface is formed again. It is presumed that this makes it likely for a secondary sheared surface to be generated. Therefore, the E value is set to 10.7 or more. The E value is preferably 10.8 or more, and more preferably 11.0 or more. The E value is preferably as high as possible, and the upper limit is not particularly specified and may be set to 13.0 or less, 12.5 or less, or 12.0 or less.

[0072] The I value represents the uniformity of the microstructure, and increases as the area of a region having certain brightness increases. A high I value means that the uniformity of the microstructure is high. In the hot-rolled steel sheet according to the present embodiment that has a microstructure with an area ratio of ferrite of 15.0% or more and less than 60.0%, it is necessary to make the microstructure highly uniform. Therefore, in the present embodiment, it is necessary to increase the I value. In a case where the I value is less than 1.020, due to an influence of the hardness distribution attributed to precipitates in crystal grains and an element concentration difference, cracking occurs from the cutting edge of a shearing tool in an extremely early stage of shearing working to form a fractured surface, and then a sheared surface is formed again. It is presumed that this makes it likely for a secondary sheared surface to be generated. Therefore, the I value is set to 1.020 or more. The 1 value is preferably 1.025 or more, and more preferably 1.030 or more. The I value is preferably as high as possible, and the upper limit is not particularly specified and may be set to 1.200 or less, 1.150 or less, or 1.100 or less.

Cluster Shade Value: -8.0×10^5 to 8.0×10^5

[0073] The Cluster shade value (CS value) represents the degree of strain of the microstructure. The CS value becomes a positive value in a case where there are many points having higher brightness than an average value of brightness in an image obtained by photographing the microstructure, and the CS value becomes a negative value in a case where there are many points having lower brightness than the average value.

[0074] In a secondary electron image of a scanning electron microscope, the brightness is high at places where the surface unevenness of a target to be observed is large, and the brightness is low at places where the unevenness is small. The surface unevenness of the target to be observed is greatly affected by the grain size and the strength distribution in the microstructure. In the present embodiment, in a case where the variation in strength of the microstructure is large or the structural unit is small, the CS value is large, and in a case where the variation in strength is small or the structural unit is large, the CS value is small.

[0075] In the present embodiment, it is important to keep the CS value within a desired range close to zero. In a case where the CS value is less than -8.0×10^5, the limit fracture sheet thickness reduction ratio of the hot-rolled steel sheet is decreased. The reason for this is presumed to be that there are crystal grains having a large grain size in the microstructure and the crystal grains preferentially fracture during ultimate deformation. Therefore, the CS value is set to -8.0×10^5 or more. The CS value is preferably -7.5×10^5 or more, and more preferably -7.0×10^5 or more.

[0076] Meanwhile, in a case where the CS value is more than 8.0×10^5, the limit fracture sheet thickness reduction ratio of the hot-rolled steel sheet is decreased. The reason for this is presumed to be that the variation in microscopic strength is large in the microstructure, strain is locally concentrated during ultimate deformation, and thus fracture is likely to occur. Therefore, the CS value is set to 8.0×10^5 or less. The CS value is preferably 7.5×10^5 or less, and more preferably 7.0×10^5 or less.

[0077] The E value, the I value, and the CS value can be obtained by the following method.

[0078] In the present embodiment, a region where an SEM image (a secondary electron image of a scanning electron microscope) is captured to calculate the E value, the I value, and the CS value is set in a sheet thickness-directional cross section parallel to the rolling direction at a depth position 1/4 of the sheet thickness away from the surface (a region ranging from a depth of 1/8 of the sheet thickness from the surface to a depth of 3/8 of the sheet thickness from the surface) at a center position in the sheet width direction. The SEM image is captured using an SU-6600 Schottky electron gun manufactured by Hitachi High-Technologies Corporation with a tungsten emitter and an acceleration voltage of 1.5 kV. Based on the above settings, the SEM image is output at a magnification of 1,000 times in 256 grayscale levels.

[0079] Next, on an image obtained by cutting out the obtained SEM image into an 880 × 880-pixel region (the observation region is 160 μm × 160 μm in actual size), a smoothing treatment described in Non-Patent Document 3, in which the contrast-enhanced limit magnification is set to 2.0 and the tile grid size is 8 × 8 is performed. The smoothed SEM image is rotated counterclockwise from 0 degrees to 179 degrees in increments of 1 degree, excluding 90 degrees, and an image is created at each angle, thereby obtaining a total of 179 images. Next, from each of these 179 images, the frequency values of brightness between adjacent pixels are sampled in a matrix form using the GLCM method described in Non-Patent Document 1.

[0080] 179 matrixes of the frequency values sampled by the above method are expressed as p_k (k = 0 ··· 89, 91, ··· 179) where k is a rotation angle from the original image. p_k's generated for the individual images are summed for all k's (k = 0 ··· 89, 91, ··· 179), and then 256 × 256 matrixes P standardized such that the total of individual components becomes 1 are calculated. Furthermore, the E value, the I value, and the CS value are each calculated using Expressions (1) to (5) described in Non-Patent Document 2.

[0081] P(i, j) in Expressions (1) to (5) is a gray-level co-occurrence matrix, and the value at the i-th row in the j-th column of the matrix P is expressed as P (i, j). The calculation is performed using the 256 × 256 matrixes P as described above, and thus in a case where it is desired to emphasize this point, Expressions (1) to (5) can be corrected to Expressions (1') to (5').

[0082] Here, L in Expression (2) is the number of grayscale levels (quantization levels of grayscale) that can be taken in the SEM image. In the present embodiment, since the SEM image is output in 256 grayscale levels as described above, L is 256. i and j in Expressions (2) and (3) are natural numbers of 1 to L, and μ_x and μ_y in Expression (3) are each represented by Expressions (4) and (5).

[0083] In Expressions (1') to (5'), the value at the i-th row in the j-th column of the matrix P is expressed as P_{ij}.

$$Entropy = -\sum_i \sum_j P(i,j).\log(P(i,j)) \quad \cdots (1)$$

$$Inverse\ difference\ normalized = \sum_i \sum_j \frac{P(i,j)}{1+\frac{|i-j|}{L}} \quad \cdots (2)$$

$$Cluster\ Shade = \sum_i \sum_j (i+j-\mu_x-\mu_y)^3 P(i,j) \quad \cdots (3)$$

$$\mu_x = \sum_i \sum_j i(P(i,j)) \quad \cdots (4)$$

$$\mu_y = \sum_i \sum_j j(P(i,j)) \quad \cdots (5)$$

$$Entropy = -\sum_{i=1,j=1}^{i=256,j=256} P_{ij} \log P_{ij} \quad \cdots (1')$$

$$\text{Inverse difference normalized} = \sum_{i=1,j=1}^{i=256,j=256} P_{ij} / \left(1 + |i - j| / 256\right) \quad \cdots (2')$$

$$\text{Cluster Shade} = \sum_{i=1,j=1}^{i=256,j=256} \left(i + j - \mu_x - \mu_y\right)^3 P_{ij} \quad \cdots (3')$$

$$\mu_x = \sum_{i=1,j=1}^{i=256,j=256} i\left(P_{ij}\right) \quad \cdots (4')$$

$$\mu_y = \sum_{i=1,j=1}^{i=256,j=256} j\left(P_{ij}\right) \quad \cdots (5')$$

Standard Deviation of Mn Concentration: 0.60 mass% or less

[0084] The standard deviation of the Mn concentration at a depth position 1/4 of the sheet thickness away from the surface (a region ranging from a depth of 1/8 of the sheet thickness from the surface to a depth of 3/8 of the sheet thickness from the surface) of the hot-rolled steel sheet according to the present embodiment at a center position in the sheet width direction is 0.60 mass% or less. This makes it possible to uniformly disperse the hard phase and makes it possible to prevent the occurrence of cracking from the cutting edge of a shearing tool in an extremely early stage of shearing working. As a result, the generation of a secondary sheared surface can be suppressed. The standard deviation of the Mn concentration is preferably 0.55 mass% or less or 0.50 mass% or less, and more preferably 0.47 mass% or less or 0.45 mass% or less. The value of the lower limit of the standard deviation of the Mn concentration is desirably as small as possible from the viewpoint of suppressing excessively large burrs, but the substantial lower limit is 0.10 mass% due to restrictions in the manufacturing process. The lower limit thereof may be set to 0.20 mass% or 0.28 mass% as necessary.

[0085] After a sheet thickness-directional cross section parallel to the rolling direction of the hot-rolled steel sheet is mirror-polished, a depth position 1/4 of the sheet thickness away from the surface (a region ranging from a depth of 1/8 of the sheet thickness from the surface to a depth of 3/8 of the sheet thickness from the surface) at a center position in the sheet width direction is measured with an electron probe microanalyzer (EPMA) to measure the standard deviation of the Mn concentration. As measurement conditions, the acceleration voltage is set to 15 kV, the magnification is set to 5,000 times, and the distribution image of a range that is 20 μm long in the sample rolling direction and 20 μm long in the sample sheet thickness direction is measured. More specifically, the measurement interval is set to 0.1 μm, and the Mn concentrations are measured at 40,000 or more points. Next, the standard deviation is calculated based on the Mn concentrations obtained from all of the measurement points, thereby obtaining the standard deviation of the Mn concentration.

Average Crystal Grain Size of Surface Layer: less than 3.0 μm

[0086] Inside bend cracking can be suppressed in the hot-rolled steel sheet by making the crystal grain size of the surface layer fine. The higher the strength of the hot-rolled steel sheet, the more likely the cracking is to occur from the inside bend during bending (hereinafter, referred to as inside bend cracking). The mechanism of inside bend cracking is presumed as follows. At the time of bending, compressive stress is generated in the inside bend. In the beginning, the working proceeds while the entire inside bend is uniformly deformed; however, as the amount of the working increases, only uniform deformation is no longer sufficient to carry deformation, and the deformation proceeds as strain concentrates locally (generation of a shear deformation band). As this shear deformation band further grows, cracking occurs along the shear band from the surface of the inside bend and propagate. The reason for the inside bend cracking to be more likely to occur in association with high-strengthening is presumed to be that deterioration of work hardening capability in association with high-strengthening makes it difficult for uniform deformation to proceed and makes it easy for bias of deformation to be caused, which generates a shear deformation band in an early stage of the working (or under loose working conditions).

[0087] The present inventors found from studies that inside bend cracking becomes significant in steel sheets having a 980 MPa or more-grade tensile strength. In addition, the present inventors found that, as the crystal grain size of the surface layer of the hot-rolled steel sheet becomes finer, local strain concentration is further suppressed, and it becomes more unlikely that inside bend cracking occurs. In order to obtain the above action, the average crystal grain size of the surface layer of the hot-rolled steel sheet is preferably set to less than 3.0 μm. Therefore, in the present embodiment, the average crystal grain size of the surface layer may be set to less than 3.0 μm. The average crystal grain size of the surface layer is more preferably 2.7 μm or less or 2.5 μm or less. The lower limit of the average crystal grain size of the surface layer region is not particularly specified and may be set to 0.5 μm or 1.0 μm.

[0088] In the present embodiment, the surface layer is a region ranging from the surface of the hot-rolled steel sheet to a position at a depth of 50 μm from the surface. As described above, the surface mentioned here refers to the interface between a plating layer and the steel sheet in a case where the hot-rolled steel sheet is provided with the plating layer.

[0089] The crystal grain size of the surface layer is measured using an EBSP-OIM (electron back scatter diffraction pattern-orientation image microscopy) method. The EBSP-OIM method is performed using a device obtained by combining a scanning electron microscope and an EBSP analyzer and OIM Analysis (registered trademark) manufactured by AMETEK, Inc. The analyzable area of the EBSP-OIM method is a region that can be observed with the SEM. The EBSP-OIM method makes it possible to analyze a region with a minimum resolution of 20 nm, which varies depending on the resolution of the SEM.

[0090] In a region in a cross section parallel to the rolling direction of the hot-rolled steel sheet, ranging from the surface of the hot-rolled steel sheet to a position at a depth of 50 μm from the surface, at a center position in the sheet width direction, analysis is performed in at least 5 visual fields at a magnification of 1,200 times and a region of 40 μm × 30 μm. A place where an angle difference between adjacent measurement points is 5° or more is defined as a crystal grain boundary, and an area-averaged crystal grain size is calculated. The obtained area-averaged crystal grain size is regarded as the average crystal grain size of the surface layer.

[0091] Residual austenite is not a structure formed by phase transformation at 600°C or lower and has no dislocation accumulation effect. Accordingly, in the present measurement method (the method of measuring the average crystal grain size of the surface layer), residual austenite is not regarded as a target to be analyzed. In a case where the area ratio of residual austenite is 0%, there is no need to exclude the residual austenite from the target to be analyzed. However, in a case where there is a possibility of affecting the measurement of the average crystal grain size of the surface layer, residual austenite having an fee crystal structure is excluded for measurement from the target to be analyzed in the EBSP-OIM method.

Tensile Strength Properties

[0092] Among the mechanical properties of the hot-rolled steel sheet, the tensile strength properties (tensile strength, total elongation) are evaluated according to JIS Z 2241: 2011. As a test piece, a No. 5 test piece of JIS Z 2241: 2011 is used. As a position where a tensile test piece is collected, a 1/4 portion extending from the end portion in the sheet width direction may be set, and a direction perpendicular to the rolling direction may be set as a longitudinal direction.

[0093] In the hot-rolled steel sheet according to the present embodiment, the tensile strength (TS) is 980 MPa or more. The tensile strength is preferably 1,000 MPa or more. In a case where the tensile strength is less than 980 MPa, an applicable component is limited, and the contribution to vehicle body weight reduction is small. The upper limit does not need to be particularly limited and may be set to 1,780 MPa from the viewpoint of suppressing the wearing of a die.

[0094] In addition, the total elongation of the hot-rolled steel sheet according to the present embodiment is preferably set to 10.0% or more, and the product of the tensile strength and the total elongation (TS × El) is preferably set to 13,000 MPa·% or more. The total elongation is more preferably set to 11.0% or more, and even more preferably set to 13.0% or more. In addition, the product of the tensile strength and the total elongation is more preferably set to 14,000 MPa·% or more, and even more preferably 15,000 MPa·% or more. The total elongation set to 10.0% or more and the product of the tensile strength and the total elongation set to 13,000 MPa·% or more significantly contribute to vehicle body weight reduction without limiting applicable components. The upper limit of the product of the tensile strength and the total elongation does not need to be set and may be set to 22,000 MPa·% or 18,000 MPa·%. The upper limit of the total elongation does not need to be set and may be set to 30.0%, 25.0%, or 22.0%.

Sheet Thickness

[0095] The sheet thickness of the hot-rolled steel sheet according to the present embodiment is not particularly limited and may be set to 0.5 to 8.0 mm. In a case where the sheet thickness of the hot-rolled steel sheet is less than 0.5 mm, it may become difficult to secure the rolling finishing temperature and the rolling force may become excessive, which may make hot rolling difficult. Therefore, the sheet thickness of the hot-rolled steel sheet according to the present embodiment may be set to 0.5 mm or more. The sheet thickness is preferably 1.2 mm or more, 1.4 mm or more, or 1.8 mm or more. Meanwhile, in a case where the sheet thickness is more than 8.0 mm, it becomes difficult to refine the microstructure, and it may be difficult to obtain the above-described microstructure. Therefore, the sheet thickness may be set to 8.0 mm or less. The sheet thickness is preferably 6.0 mm or less, 5.0 mm or less, or 4.0 mm or less.

Plating Layer

[0096] The hot-rolled steel sheet according to the present embodiment having the above-described chemical composition and microstructure may be provided with a plating layer on the surface for the purpose of improving corrosion resistance and the like and thereby made into a surface-treated steel sheet. The plating layer may be an electro plating layer or a hot-dip plating layer. As the electro plating layer, electrogalvanizing, electro Zn-Ni alloy plating, and the like are exemplary examples. As the hot-dip plating layer, hot-dip galvanizing, hot-dip galvannealing, hot-dip aluminizing, hot-dip Zn-Al alloy plating, hot-dip Zn-Al-Mg alloy plating, hot-dip Zn-Al-Mg-Si alloy plating, and the like are exemplary examples. The plating adhesion amount is not particularly limited and may be the same as before. In addition, it is also possible to further increase the corrosion resistance by performing an appropriate chemical conversion treatment (for example, application and drying of a silicate-based chromium-free chemical conversion liquid) after plating.

Manufacturing Conditions

[0097] A suitable manufacturing method of the hot-rolled steel sheet according to the present embodiment having the above-described chemical composition and microstructure is as follows.

[0098] In the suitable manufacturing method of the hot-rolled steel sheet according to the present embodiment, the following steps (1) to (10) are sequentially performed. The temperature of a slab and the temperature of a steel sheet in the present embodiment refer to the surface temperature of the slab and the surface temperature of the steel sheet. In addition, stress refers to tension that is loaded in the rolling direction of the steel sheet.

[0099]

(1) A slab is held in a temperature range of 700°C to 850°C for 900 seconds or longer, then, further heated, and held in a temperature range of 1,100°C or higher for 6,000 seconds or longer.

(2) Hot rolling is performed so that the sheet thickness is reduced by a total of 90% or more in a temperature range of 850°C to 1,100°C.

(3) Stress of 170 kPa or more is loaded to the steel sheet after rolling one stage before the final stage of the hot rolling and before the final stage rolling.

(4) The rolling reduction at the final stage of the hot rolling is set to 8% or more, and the hot rolling is finished so that the rolling finishing temperature Tf becomes 900°C or higher and lower than 1,010°C.

(5) Stress that is loaded to the steel sheet after the final stage rolling of the hot rolling and until the steel sheet is cooled to 800°C is set to less than 200 kPa.

(6) The steel sheet is cooled to a temperature range of the hot rolling finishing temperature Tf - 50°C or lower within 1 second after the finishing of the hot rolling, and then accelerated cooling is performed to a temperature range of 600°C to 730°C at an average cooling rate of 50 °C/s or faster. Here, the cooling to the temperature range of the hot rolling finishing temperature Tf - 50°C or lower within 1 second after the finishing of the hot rolling is a more preferable cooling condition.

(7) Slow cooling at an average cooling rate of slower than 5 °C/s is performed in a temperature range of 600°C to 730°C for 2.0 seconds or longer.

(8) After the end of the slow cooling, cooling is performed so that the average cooling rate in a temperature range of 450°C to 600°C is 30 °C/s or faster and slower than 50 °C/s.

(9) Cooling is performed so that the average cooling rate in a temperature range of the coiling temperature to 450°C is 50 °C/s or faster.

(10) Coiling is performed in a temperature range of 350°C or lower.

[0100] A hot-rolled steel sheet having a microstructure that has a high strength, a high limit fracture sheet thickness reduction ratio, and excellent ductility and shearing property can be stably manufactured by employing the above-described manufacturing method. That is, by appropriately controlling the slab heating conditions and the hot rolling conditions, the reduction of Mn segregation and equiaxed austenite before transformation are achieved, and, in cooperation with the cooling conditions after the hot rolling to be described later, a hot-rolled steel sheet having a desired microstructure can be stably manufactured.

(1) Slab, Slab Temperature When Subjected to Hot Rolling, and Holding Time

[0101] As the slab to be subjected to hot rolling, a slab obtained by continuous casting, a slab obtained by casting and blooming, and the like can be used. In addition, a slab obtained by additionally performing hot working or cold working on the above-described slab can be used as necessary.

[0102] The slab to be subjected to hot rolling is preferably held in a temperature range of 700°C to 850°C for 900 seconds or longer during slab heating, then, further heated, and held in a temperature range of 1,100°C or higher for 6,000 seconds or longer. During the holding in a temperature range of 700°C to 850°C, the steel sheet temperature may be fluctuated or be maintained constant in this temperature range. Furthermore, during the holding in a temperature range of 1,100°C or higher, the steel sheet temperature may be fluctuated or be maintained constant in a temperature range of 1,100°C or higher.

[0103] In austenite transformation in the temperature range of 700°C to 850°C, Mn is distributed between ferrite and austenite, and Mn can be diffused into the ferrite region by extending the transformation time. Accordingly, the Mn micro segregation unevenly distributed in the slab can be eliminated, and the standard deviation of the Mn concentration can be significantly reduced. In addition, by holding the steel sheet in the temperature range of 1,100°C or higher for 6,000 seconds or longer, it is possible to make the austenite grains during slab heating uniform.

[0104] In the hot rolling, it is preferable to use a reverse mill or a tandem mill for multi-pass rolling. Particularly, from the viewpoint of industrial productivity and of stress loading on the steel sheet during rolling, at least the final two stages are more preferably hot rolling in which a tandem mill is used.

(2) Rolling Reduction of Hot Rolling: Sheet Thickness Reduction by Total of 90% or More in Temperature Range of 850°C to 1,100°C

[0105] By performing hot rolling so that the sheet thickness is reduced by a total of 90% or more in a temperature range of 850°C to 1,100°C, recrystallized austenite grains are mainly refined, and accumulation of strain energy into unrecrystallized austenite grains is promoted. In addition, the recrystallization of austenite is promoted, and the atomic diffusion of Mn is promoted, which makes it possible to reduce the standard deviation of the Mn concentration. Therefore, it is preferable to perform the hot rolling so that the sheet thickness is reduced by a total of 90% or more in a temperature range of 850°C to 1,100°C.

[0106] The sheet thickness reduction in a temperature range of 850°C to 1,100°C can be expressed as $\{(t_0 - t_1)/t_0\} \times 100$ (%) where t_0 represents an inlet sheet thickness before the first rolling in the rolling in the above temperature range and t_1 represents an outlet sheet thickness after the final stage rolling in the rolling in the above temperature range.

(3) Stress After Rolling One Stage Before Final Stage of Hot Rolling and Before Final Stage Rolling: 170 kPa or more

[0107] The stress that is loaded to the steel sheet after rolling one stage before the final stage of hot rolling and before the final stage rolling is preferably set to 170 kPa or more. This makes it possible to reduce the number of crystal grains having a {h110}<001> crystal orientation in the recrystallized austenite after the rolling one stage before the final stage. Since recrystallization is difficult to occur in the {h110}<001> crystal orientation, recrystallization by the final stage rolling can be effectively promoted by suppressing the formation of this crystal orientation. As a result, the band-like structure of the hot-rolled steel sheet is improved, the periodicity of the microstructure is reduced, and the E value increases.

[0108] In a case where the stress that is loaded to the steel sheet is less than 170 kPa, it may be impossible to achieve a desired E value. The stress that is loaded to the steel sheet is more preferably 190 kPa or more.

[0109] The stress that is loaded to the steel sheet can be controlled by adjusting the roll rotation speed during tandem rolling, and can be obtained by dividing the load in the rolling direction measured in a rolling stand by the cross-sectional area of the passing sheet.

(4) Rolling Reduction at Final Stage of Hot Rolling: 8% or more, Hot Rolling Finishing Temperature Tf: 900°C or Higher and Lower than 1,010°C

[0110] It is preferable that the rolling reduction at the final stage of the hot rolling is set to 8% or more and the hot rolling finishing temperature Tf is set to 900°C or higher. By setting the rolling reduction at the final stage of the hot rolling to 8% or more, it is possible to promote recrystallization caused by the final stage rolling. As a result, the band-like structure of the hot-rolled steel sheet is improved, the periodicity of the microstructure is reduced, and the E value increases. By setting the hot rolling finishing temperature Tf to 900°C or higher, it is possible to suppress an excessive increase in number of ferrite nucleation sites in austenite. As a result, the formation of ferrite in the final structure (the microstructure of the manufactured hot-rolled steel sheet) is suppressed, and a high-strength hot-rolled steel sheet can be obtained. In addition, by setting the hot rolling finishing temperature Tf to lower than 1,010°C, the coarsening of the austenite grain size can be suppressed, and a desired E value can be obtained due to the reduced periodicity of the microstructure.

(5) Stress After Final Stage Rolling of Hot Rolling and Until Steel Sheet is Cooled to 800°C: Less than 200 kPa

[0111] Stress that is loaded to the steel sheet after the final stage rolling of the hot rolling and until the steel sheet is cooled to 800°C is preferably set to less than 200 kPa. By setting the stress (tension) that is loaded in the rolling direction of the steel sheet to less than 200 kPa, the recrystallization of austenite preferentially proceeds in the rolling direction, and an increase in periodicity of the microstructure can be suppressed. As a result, a desired E value can be obtained. The stress that is loaded to the steel sheet is more preferably 180 kPa or less. The stress that is loaded in the rolling direction of the steel sheet can be controlled by adjusting the rotation speeds of the rolling stand and the coiling device, and can be obtained by dividing the measured load in the rolling direction by the cross-sectional area of the passing sheet.

(6) Cooling to Temperature Range of Hot Rolling Finishing Temperature Tf - 50°C or lower Within 1 Second After Finishing of Hot Rolling, And Then Accelerated Cooling to Temperature Range of 600°C to 730°C at Average Cooling Rate of 50 °C/s or Faster

[0112] In order to suppress the growth of austenite crystal grains refined by the hot rolling, the steel sheet is more preferably cooled by 50°C or more within 1 second after the finishing of the hot rolling. In order to cool the steel sheet to a temperature range of the hot rolling finishing temperature Tf - 50°C or lower within 1 second after the finishing of the hot rolling, cooling may be performed at a fast average cooling rate immediately after the finishing of the hot rolling. For example, cooling water may be sprayed to the surface of the steel sheet. By cooling the steel sheet to a temperature range of Tf - 50°C or lower within 1 second after the finishing of the hot rolling, it is possible to refine the crystal grain size of the surface layer and to increase the inside bend cracking resistance of the hot-rolled steel sheet.

[0113] In addition, by performing accelerated cooling to a temperature range of 730°C or lower at an average cooling rate of 50 °C/s or faster after the cooling, it is possible to suppress the formation of ferrite and pearlite with a small amount of precipitation hardening. Accordingly, the strength of the hot-rolled steel sheet is improved. The average cooling rate mentioned here refers to a value obtained by dividing the temperature drop width of the steel sheet from the start of the accelerated cooling (when introducing the steel sheet into cooling equipment) to the finishing of the accelerated cooling (when deriving the steel sheet from the cooling equipment) by the time required from the start of the accelerated cooling to the finishing of the accelerated cooling.

[0114] The upper limit of the cooling rate is not particularly specified, but in a case where the cooling rate is increased, the cooling equipment becomes large and the equipment cost increases. Therefore, considering the equipment cost, the cooling rate is preferably 300 °C/s or lower. In addition, the cooling stop temperature of the accelerated cooling may be set to 600°C or higher in order to perform slow cooling to be described later.

(7) Slow Cooling at Average Cooling Rate of Slower Than 5 °C/s Being Performed in Temperature Range of 600°C to 730°C for 2.0 Seconds or Longer

[0115] By performing slow cooling at an average cooling rate of slower than 5 °C/s in a temperature range of 600°C to 730°C for 2.0 seconds or longer, it is possible to sufficiently precipitate the precipitation-hardened ferrite. This makes it possible to achieve both the strength and ductility of the hot-rolled steel sheet.

[0116] The average cooling rate mentioned here refers to a value obtained by dividing the temperature drop width of the steel sheet from the cooling stop temperature of the accelerated cooling to the stop temperature of the slow cooling by the time required from the stop of the accelerated cooling to the stop of the slow cooling.

[0117] The slow cooling time is preferably 3.0 seconds or longer. The upper limit of the slow cooling time is determined by the equipment layout, and may be shorter than approximately 10.0 seconds. In addition, although the lower limit of the average cooling rate of the slow cooling is not particularly set, raising the temperature without cooling may require a large investment in equipment. Therefore, the lower limit may be set to 0 °C/s or faster.

(8) After End of Slow Cooling, Cooling Being Performed So That Average Cooling Rate in Temperature Range of 450°C to 600°C is 30 °C/s or Faster And Slower Than 50 °C/s

[0118] After the end of the slow cooling, it is preferable to perform cooling so that the average cooling rate in a temperature range of 450°C to 600°C is 30 °C/s or faster and slower than 50 °C/s. By setting the average cooling rate in the temperature range to 30 °C/s or faster and slower than 50 °C/s, a desired CS value can be obtained. In a case where the average cooling rate is faster than 50 °C/s, a flat lath-like structure having low brightness is likely to be formed, and the CS value becomes less than -8.0×10^5. In a case where the average cooling rate is slower than 30 °C/s, the concentration of carbon in an untransformed part is promoted, the strength of the hard structure increases, and the difference in strength from the soft structure increases. Therefore, the CS value becomes more than 8.0×10^5.

[0119] The average cooling rate mentioned here refers to a value obtained by dividing the temperature drop width of the steel sheet from the cooling stop temperature of the slow cooling where the average cooling rate is slower than 5 °C/s to the cooling stop temperature of the cooling where the average cooling rate is 30 °C/s or faster and slower than 50 °C/s by the time required from the stop of the slow cooling where the average cooling rate is slower than 5 °C/s to the stop of the cooling where the average cooling rate is 30 °C/s or faster and slower than 50 °C/s.

(9) Average Cooling Rate in Temperature Range of Coiling Temperature to 450°C: 50 °C/s or Faster

[0120] In order to suppress the area ratio of pearlite and residual austenite and obtain a desired strength and desired formability, the average cooling rate in a temperature range of the coiling temperature to 450°C is preferably set to 50 °C/s or faster. In such a case, the primary phase structure can be made hard.

[0121] The average cooling rate mentioned here refers to a value obtained by dividing the temperature drop width of the steel sheet from the cooling stop temperature of the cooling where the average cooling rate is 30 °C/s or faster and slower than 50 °C/s to the coiling temperature by the time required from the stop of the cooling where the average cooling rate is 30 °C/s or faster and slower than 50 °C/s to the coiling.

(10) Coiling Temperature: 350°C or Lower

[0122] The coiling temperature is set to 350°C or lower. In a case where the coiling temperature is set to 350°C or lower, the amount of an iron carbide precipitated is reduced, and the variation in hardness distribution in the hard phase can be reduced. As a result, the I value can be increased and the generation of a secondary sheared surface can be suppressed.

[Examples]

[0123] Next, the effects of one aspect of the present invention will be described in more detail using examples. However, conditions in the examples are merely exemplary to confirm the feasibility and the effects of the present invention, and the present invention is not limited to these condition examples. The present invention may employ various conditions to achieve the object of the present invention without departing from the gist of the present invention.

[0124] Steels having a chemical composition shown in Tables 1 and 2 were melted and continuously cast to manufacture slabs having a thickness of 240 to 300 mm. The obtained slabs were used to obtain hot-rolled steel sheets shown in Tables 5 and 6 under the manufacturing conditions shown in Tables 3 and 4.

[0125] The average cooling rate of slow cooling was set to slower than 5 °C/s. In addition, since the measurement lower limit of the coiling temperature shown in Table 4 is 50°C, the actual coiling temperatures in the examples written as 50°C are 50°C or lower.

[0126] The area ratio of the microstructure, the E value, the I value, the CS value, the standard deviation of the Mn concentration, the average crystal grain size of the surface layer, the tensile strength TS, and the total elongation El of each of the obtained hot-rolled steel sheets were obtained by the above methods. The obtained measurement results are shown in Tables 5 and 6.

[0127] The remainder in microstructure was one or two or more of bainite, martensite, and tempered martensite.

Methods of Evaluating Properties of Hot-Rolled Steel Sheets

Tensile Properties

[0128] In a case where the tensile strength (TS) was 980 MPa or more, the total elongation (El) was 10.0% or more, and the tensile strength (TS) × total elongation (El) was 13,000 MPa·% or more, the hot-rolled steel sheet was considered to have a high strength and excellent ductility, and determined as acceptable. In a case where any one was not satisfied, the hot-rolled steel sheet was not considered to have a high strength and excellent ductility, and determined as unacceptable.

Limit Fracture Sheet Thickness Reduction Ratio

[0129] The limit fracture sheet thickness reduction ratio of the hot-rolled steel sheet was evaluated by a tensile test.

[0130] The tensile test was performed by the same method as in the evaluation of the tensile properties. The value of $(t1 - t2) \times 100/t1$ was calculated, where t1 represents the sheet thickness before the tensile test and t2 represents the minimum value of the sheet thickness at a center portion in the width direction of the tensile test piece after fracture, to obtain the limit fracture sheet thickness reduction ratio. In order to obtain the limit fracture sheet thickness reduction ratio, the tensile test was performed five times, and the average value was calculated by taking the mean of three values, excluding the maximum limit fracture sheet thickness reduction ratio and the minimum limit fracture sheet thickness reduction ratio.

[0131] In a case where the limit fracture sheet thickness reduction ratio was 60.0% or more, the hot-rolled steel sheet was considered to have a high limit fracture sheet thickness reduction ratio, and determined as acceptable. Meanwhile, in a case where the limit fracture sheet thickness reduction ratio was less than 60.0%, the hot-rolled steel sheet was not considered to have a high limit fracture sheet thickness reduction ratio, and determined as unacceptable.

Shearing property (Secondary Sheared Surface Evaluation)

[0132] The shearing property of the hot-rolled steel sheet was evaluated by a punching test.

[0133] Three punched holes were produced in each example with a hole diameter of 10 mm, a clearance of 10%, and a punching speed of 3 m/s. Next, of the punched hole, a cross section perpendicular to the rolling direction and a cross section parallel to the rolling direction were each embedded in a resin, and the cross-sectional profile was photographed with a scanning electron microscope. In the obtained observation photographs, the sheared end surfaces as shown in FIG. 1 or FIG. 2 can be observed. FIG. 1 is an example of a sheared end surface of a hot-rolled steel sheet according to a present invention example, and FIG. 2 is an example of a sheared end surface of a hot-rolled steel sheet according to a comparative example. FIG. 1 shows a sheared end surface with a shear droop, a sheared surface, a fractured surface, and a burr. FIG. 2 shows a sheared end surface with a shear droop, a sheared surface, a fractured surface, a sheared surface, a fractured surface, and a burr. Here, the shear droop is an R-like smooth surface region, the sheared surface is a region of a punched end surface separated by shear deformation, the fractured surface is a region of a punched end surface separated by cracking occurring from the vicinity of the cutting edge, and a burr is a surface having projections protruding from the lower surface of the hot-rolled steel sheet.

[0134] In a case where, for example, a sheared surface, a fractured surface, and a sheared surface as shown in FIG. 2 appeared on two surfaces perpendicular to the rolling direction and two surfaces parallel to the rolling direction in the obtained sheared end surface, it was determined that a secondary sheared surface was formed. 4 surfaces for each punched hole, that is, a total of 12 surfaces were observed. In a case where there was no surface on which a secondary sheared surface appeared, the hot-rolled steel sheet was considered to have excellent shearing property, and determined as acceptable, and a value "Absent" was entered into the table. Meanwhile, in a case where even a single secondary sheared surface was formed, the hot-rolled steel sheet was not considered to have excellent shearing property, and determined as unacceptable, and a value "Present" was entered into the table.

Inside Bend Cracking Resistance

[0135] The inside bend cracking resistance was evaluated by the following bending test.

[0136] A 100 mm × 30 mm strip-shaped test piece was cut out from a 1/2 position in the width direction of the hot-rolled steel sheet to obtain a bending test piece. A test was performed according to the V-block method of JIS Z 2248: 2006 (the bending angle θ is 90°) for both bending where the bending ridge was parallel to the rolling direction (L direction) (L-axis bending) and bending where the bending ridge was parallel to a direction perpendicular to the rolling direction (C direction) (C-axis bending). As a result, a minimum bend radius at which no cracking would occur was obtained, and the inside bend cracking resistance was investigated. A value obtained by dividing the average value of the minimum bend radii in the L axis and in the C axis by the sheet thickness was regarded as the limit bending R/t and used as an index value of inside bend cracking resistance. In a case where R/t was 2.5 or less, the hot-rolled steel sheet was determined to be excellent in inside bend cracking resistance.

[0137] Here, regarding the presence or absence of cracks, a cross section obtained by cutting the test piece after the test on a surface parallel to the bending direction and perpendicular to the sheet surface was mirror-polished, cracks were then observed with an optical microscope, and a case where the lengths of cracks observed in the inside bend of the test piece exceeded 30 μm was determined as cracks being present.

[Table 1]

Steel No.	Mass%, Remainder Consists of Fc and Impurities												Remarks
	C	Si	Mn	Ti	Nb	V	Ti+Nb+V	sol. Al	P	s	N	O	
A	0.077	0.73	1.78	0.126			0.126	0.371	0.013	0.0026	0.0043	0.0046	Present Invention Steel
B	0.075	1.52	1.87	0.127			0.127	0.341	0.002	0.0045	0.0032	0.0041	Present Invention Steel
C	0.216	1.47	1.13	0.135			0.135	0.308	0.015	0.0009	0.0036	0.0035	Present Invention Steel
D	0.138	0.15	1.97	0.119			0.119	1.460	0.014	0.0048	0.0049	0.0037	Present Invention Steel
E	0.153	2.80	1.36	0.124			0.124	0.009	0.021	0.0043	0.0032	0.0025	Present Invention Steel
F	0.065	1.66	2.64	0.121			0.121	0.342	0.016	0.0044	0.0037	0.0025	Present Invention Steel
G	0.090	2.66	1.75	0.132			0.132	0.030	0.021	0.0025	0.0047	0.0028	Present Invention Steel
H	0.051	1.38	3.81	0.126			0.126	1.790	0.009	0.0024	0.0027	0.0021	Present Invention Steel
I	0.075	1.85	2.23	0.061	0.013		0.074	0.370	0.015	0.0033	0.0031	0.0039	Present Invention Steel
J	0.075	1.38	1.75			0.156	0.156	0.313	0.021	0.0063	0.0046	0.0030	Present Invention Steel
K	0.088	1.57	1.80		0.082		0.082	0.299	0.020	0.0036	0.0026	0.0028	Present Invention Steel
L	0.086	1.42	1.96	0.092	0.015	0.037	0.144	0.336	0.010	0.0042	0.0048	0.0021	Present Invention Steel
M	0.074	1.37	1.79	0.124			0.124	0.338	0.014	0.0033	0.0023	0.0024	Present Invention Steel
N	0.084	1.38	1.85	0.123			0.123	0.337	0.021	0.0046	0.0028	0.0038	Present Invention Steel
O	0.074	1.57	1.88	0.129			0.129	0.310	0.020	0.0047	0.0026	0.0020	Present Invention Steel
P	0.077	1.52	1.62	0.122			0.122	0.352	0.012	0.0034	0.0044	0.0026	Present Invention Steel
Q	0.037	1.54	1.84	0.135			0.135	0.324	0.019	0.0024	0.0025	0.0047	Comparative Steel
R	0.266	1.65	1.97	0.129			0.129	0.311	0.013	0.0046	0.0032	0.0034	Comparative Steel
S	0.081	3.16	1.85	0.131			0.131	0.354	0.016	0.0042	0.0025	0.0046	Comparative Steel
T	0.078	1.50	0.81	0.137			0.137	0.360	0.011	0.0038	0.0045	0.0045	Comparative Steel
U	0.083	1.62	1.89	0.053			0.053	0.372	0.009	0.0041	0.0039	0.0033	Comparative Steel
V	0.080	1.58	1.78	0.128			0.135	0.304	0.083	0.0029	0.0037	0.0047	Present Invention Steel
W	0.063	1.59	1.82	0.120			0.124	0.325	0.012	0.0108	0.0047	0.0041	Present Invention Steel
X	0.088	1.51	1.96	0.131			0.119	0.297	0.008	0.0048	0.0522	0.0038	Present Invention Steel

(continued)

Steel No.	Mass%, Remainder Consists of Fc and Impurities												Remarks
	C	Si	Mn	Ti	Nb	V	Ti+Nb+V	sol. Al	P	s	N	O	
Y	0.075	0.83	1.84	0.118			0.137	0.025	0.012	0.0026	0.0029	0.0063	Present Invention Steel

The underline indicates that the corresponding value is outside the range of the present invention.

[Table 2]

Steel No.	Mass%, Remainder Consists of Fe and Impurities																Remarks
	Cu	Cr	Mo	Ni	B	Ca	Mg	REM	Bi	As	Zr	Co	Zn	W	Sn	Zr + Co + Zn + W	
A																	Present Invention Steel
B																	Present Invention Steel
C						0.0031	0.0019										Present Invention Steel
D									0.0020								Present Invention Steel
E																	Present Invention Steel
F													0.16			0.16	Present Invention Steel
G					0.0037												Present Invention Steel
H															0.02		Present Invention Steel
I																	Present Invention Steel
J								0.0025									Present Invention Steel
K														0.17		0.17	Present Invention Steel
L											0.34					0.34	Present Invention Steel
M	0.18											0.21				0.21	Present Invention Steel
N		0.20			0.0013												Present Invention Steel
O			0.11												0.02		Present Invention Steel
P				0.31													Present Invention Steel
Q																	Comparative Steel
R																	Comparative Steel
S																	Comparative Steel
T																	Comparative Steel
U																	Comparative Steel
V																	Present Invention Steel
W																	Present Invention Steel
X										0.053							Present Invention Steel
Y																	Present Invention Steel

[Table 3]

Manufacturing No.	Steel No.	Holding Time in Temperature Range of 700°C to 850°C s	Heating Temperature °C	Holding Time in Temperature Range of 1,100°C or Higher s	Sheet Thickness Reduction at 850°C to 1,100°C %	Loaded Stress After Rolling One Stage Before Final Stage and Before Final Stage Rolling kPa	Hot Rolling Finishing Temperature Tf °C	Rolling Reduction at Final Stage %	Loaded Stress After Final Stage Rolling of Hot Rolling and Until Steel Sheet is Cooled to 800°C kPa	Remarks
1	A	1382	1215	9447	94	218	945	17	186	Present Invention Example
2	B	1232	1236	8835	96	204	972	18	186	Present Invention Example
3	B	815	1219	9403	93	209	926	17	186	Comparative Example
4	B	1340	1232	9619	88	208	930	16	178	Comparative Example
5	B	1448	1252	5630	95	224	924	14	190	Comparative Example
6	B	1266	1229	9288	95	167	943	13	178	Comparative Example
7	B	1259	1234	9517	95	213	1031	16	176	Comparative Example
8	B	1336	1261	9339	93	218	946	6	189	Comparative Example
9	B	1270	1261	9455	94	223	950	15	209	Comparative Example
10	B	1386	1253	9490	95	216	946	13	170	Present Invention Example
11	B	1287	1222	9653	95	200	966	14	187	Comparative Example
12	B	1159	1254	9011	96	217	973	15	187	Comparative Example
13	B	1155	1221	8855	93	204	941	14	175	Comparative Example
14	B	1526	1221	9065	94	215	942	14	176	Comparative Example
15	B	1133	1213	9356	94	210	933	15	180	Comparative Example
16	B	1146	1236	8950	96	208	935	16	189	Comparative Example
17	C	925	1231	9527	91	199	905	17	170	Present Invention Example
18	D	1209	1230	8915	95	205	911	40	185	Present Invention Example
19	E	1251	1215	9191	96	206	945	9	195	Present Invention Example
20	F	1856	1220	11500	96	227	904	18	175	Present Invention Example
21	G	1549	1213	9097	94	205	971	18	185	Present Invention Example
22	H	2006	1225	13642	96	238	936	18	188	Present Invention Example
23	I	1502	1175	9442	96	176	952	15	196	Present Invention Example
24	J	1506	1242	9550	93	208	980	17	195	Present Invention Example
25	K	1260	1252	9602	93	220	956	13	178	Present Invention Example
26	L	1295	1256	9009	93	191	925	13	192	Present Invention Example
27	M	1496	1233	8879	93	235	946	14	179	Present Invention Example
28	N	1416	1217	9193	95	203	930	15	186	Present Invention Example
29	O	1449	1232	9156	96	211	971	17	193	Present Invention Example
30	P	1510	1249	9560	95	200	953	14	193	Present Invention Example
31	Q	1536	1225	9188	93	199	943	16	192	Comparative Example
32	R	1438	1262	9225	93	214	920	18	187	Comparative Example
33	S	1575	1224	8950	96	232	966	18	194	Comparative Example
34	T	1157	1215	9162	93	204	955	13	194	Comparative Example
35	U	1424	1232	9660	96	205	952	13	191	Comparative Example
36	V	1469	1226	9268	96	228	936	13	187	Present Invention Example
37	W	1263	1217	9042	95	215	921	13	195	Present Invention Example
38	X	1254	1230	9381	94	218	956	14	182	Present Invention Example
39	Y	1439	1225	9121	94	217	930	17	174	Present Invention Example

The underline indicates that the corresponding condition is not a preferable manufacturing condition.

[Table 4]

Manufacturing No.	Steel No.	Cooling Amount within 1 Second After Finishing of Hot Rolling °C	Average Cooling Rate of Accelerated Cooling °C/s	Cooling Stop Temperature of Accelerated Cooling °C	Slow Cooling Time in Temperature Range of 600°C to 730°C s	Average Cooling Rate in Temperature Range of 450°C to 600°C °C/s	Average Cooling Rate in Temperature Range of Coiling Temperature to 450°C °C/s	Coiling Temperature °C	Remarks
1	A	75	104	674	3.9	37	80	50	Present Invention Example
2	B	75	92	712	3.6	39	142	50	Present Invention Example
3	B	64	108	699	4.0	41	116	50	Comparative Example
4	B	70	122	720	3.8	41	104	50	Comparative Example
5	B	61	83	715	3.6	45	146	50	Comparative Example
6	B	71	109	669	3.6	35	136	50	Comparative Example
7	B	67	106	654	4.3	42	113	50	Comparative Example
8	B	74	82	697	4.2	38	150	50	Comparative Example
9	B	61	103	718	3.8	41	88	50	Comparative Example
10	B	35	107	664	4.6	36	107	50	Present Invention Example
11	B	78	93	678	1.1	40	130	50	Comparative Example
12	B	65	38	698	3.5	45	106	50	Comparative Example
13	B	75	108	761	3.4	45	95	50	Comparative Example
14	B	72	105	672	4.3	74	140	50	Comparative Example
15	B	68	102	652	3.1	20	105	50	Comparative Example
16	B	59	82	700	3.4	39	44	50	Comparative Example
17	C	75	104	728	6.2	31	53	50	Present Invention Example
18	D	63	100	680	6.0	48	151	50	Present Invention Example
19	E	64	85	613	3.1	36	60	190	Present Invention Example
20	F	78	119	701	5.9	42	138	243	Present Invention Example
21	G	66	122	724	4.1	45	122	50	Present Invention Example
22	H	76	98	675	6.7	38	93	315	Present Invention Example
23	I	80	101	693	3.3	42	134	50	Present Invention Example
24	J	77	108	669	3.1	44	136	50	Present Invention Example
25	K	59	82	669	2.6	43	153	50	Present Invention Example
26	L	70	119	708	4.2	41	131	50	Present Invention Example
27	M	74	121	660	4.3	41	135	50	Present Invention Example
28	N	77	110	675	3.5	36	94	50	Present Invention Example
29	O	68	117	707	4.4	43	147	50	Present Invention Example
30	P	68	87	667	4.5	36	146	50	Present Invention Example
31	Q	64	89	728	3.3	37	117	50	Comparative Example
32	R	68	104	705	3.7	36	133	50	Comparative Example
33	S	80	109	672	3.0	39	143	50	Comparative Example
34	T	76	124	701	4.3	43	145	50	Comparative Example
35	U	62	120	665	3.3	45	112	50	Comparative Example
36	V	60	93	727	3.6	42	103	50	Present Invention Example
37	W	63	106	666	3.9	43	117	50	Present Invention Example
38	X	65	86	693	4.1	43	135	50	Present Invention Example
39	Y	61	92	699	3.8	45	99	50	Present Invention Example

The underline indicates that the corresponding condition is not a preferable manufacturing condition.

[Table 5]

Manufacturing No.	Steel No.	Sheet Thickness mm	Ferrite area%	Residual Austenite area%	Pearlite area%	Remainder in Microstructure area%	F Value -	I Value -	CS Value × 10^5	Mn Standard Deviation mass%	Average Crystal Grain Size of Surface Layer μm	Remarks
1	A	2.6	24.4	0.0	0.0	75.6	11.6	1.068	-4.2	0.37	2.0	Present Invention Example
2	B	2.9	43.5	0.0	0.0	56.5	11.3	1.070	0.1	0.47	2.5	Present Invention Example
3	B	2.9	37.3	0.0	0.0	62.7	11.8	1.049	-4.9	0.62	2.4	Comparative Example
4	B	2.9	42.6	0.0	0.0	57.4	11.4	1.038	-2.5	0.61	2.3	Comparative Example
5	B	2.9	31.8	0.0	0.0	68.2	11.5	1.065	2.6	0.62	2.1	Comparative Example
6	B	2.9	44.5	0.0	0.0	55.5	10.4	1.076	-1.9	0.42	2.0	Comparative Example
7	B	2.9	42.9	0.0	0.0	57.1	10.6	1.038	-0.5	0.37	2.8	Comparative Example
8	B	2.9	43.7	0.0	0.0	56.3	10.4	1.067	-5.4	0.41	2.2	Comparative Example
9	B	2.9	35.9	0.0	0.0	64.1	10.3	1.080	0.1	0.42	2.2	Comparative Example
10	B	2.9	39.9	0.0	0.0	60.1	11.6	1.063	-4.5	0.44	3.3	Present Invention Example
11	B	2.9	10.2	0.0	0.0	89.8	11.3	1.066	2.5	0.47	2.4	Comparative Example
12	B	2.9	53.0	0.0	7.5	39.5	11.3	1.050	0.4	0.39	2.5	Comparative Example
13	B	2.9	57.3	0.0	5.2	37.5	11.5	1.062	2.6	0.37	2.0	Comparative Example
14	B	2.9	40.3	0.0	0.0	59.7	11.4	1.081	-8.8	0.38	2.4	Comparative Example
15	B	2.9	33.6	0.0	9.6	56.8	11.9	1.065	9.0	0.46	2.2	Comparative Example
16	B	2.9	42.0	8.2	0.0	49.8	11.2	1.067	-3.7	0.43	2.4	Comparative Example
17	C	2.6	16.7	0.0	0.0	83.3	11.8	1.069	1.6	0.45	2.5	Present Invention Example
18	D	2.6	19.0	0.0	0.0	81.0	11.6	1.075	-2.1	0.44	2.0	Present Invention Example
19	E	2.6	51.9	2.5	0.0	45.6	11.8	1.051	2.5	0.37	2.1	Present Invention Example
20	F	1.4	22.1	0.0	0.0	77.9	11.7	1.052	-0.1	0.48	2.2	Present Invention Example
21	G	2.6	48.7	1.1	0.0	50.2	11.6	1.082	0.2	0.40	2.1	Present Invention Example
22	H	6.4	15.2	0.0	0.0	84.8	11.9	1.051	2.5	0.55	2.1	Present Invention Example
23	I	2.9	30.9	0.0	0.0	69.1	10.7	1.081	-0.9	0.44	2.0	Present Invention Example
24	J	2.9	33.7	0.0	0.0	66.3	11.2	1.063	-2.2	0.38	2.5	Present Invention Example
25	K	2.9	27.9	0.0	0.0	72.1	11.6	1.027	-1.0	0.42	2.5	Present Invention Example
26	L	2.9	42.8	0.0	0.0	57.2	11.3	1.053	-4.9	0.38	2.2	Present Invention Example
27	M	2.9	38.4	0.0	0.0	61.6	11.6	1.075	-2.9	0.40	2.2	Present Invention Example
28	N	2.9	39.9	0.0	0.0	60.1	11.8	1.066	-5.6	0.45	2.3	Present Invention Example
29	O	2.9	43.4	0.0	0.0	56.6	11.5	1.072	1.8	0.47	2.4	Present Invention Example
30	P	2.9	35.3	0.0	0.0	64.7	11.9	1.070	-4.0	0.38	2.5	Present Invention Example
31	Q	2.9	85.6	0.0	0.0	14.4	11.4	1.054	-2.4	0.44	2.5	Comparative Example
32	R	2.9	7.4	0.0	0.0	92.6	11.4	1.040	0.4	0.36	2.5	Comparative Example
33	S	2.9	63.7	6.6	0.0	29.7	11.9	1.078	1.4	0.45	3.6	Comparative Example
34	T	2.9	75.4	0.0	0.0	24.6	11.8	1.069	-3.3	0.32	2.4	Comparative Example
35	U	2.9	52.2	0.0	0.0	47.8	11.5	1.059	-3.6	0.43	2.5	Comparative Example
36	V	2.9	37.7	0.0	0.0	62.3	11.3	1.038	1.6	0.37	2.5	Present Invention Example
37	W	2.9	38.2	0.0	0.0	61.8	11.4	1.077	-5.5	0.44	2.0	Present Invention Example
38	X	2.9	28.3	0.0	0.0	71.7	11.7	1.079	-2.3	0.45	2.2	Present Invention Example
39	Y	2.9	20.3	0.0	0.0	61.5	11.8	1.056	-2.3	0.47	2.3	Present Invention Example

The underline indicates that the corresponding values are outside the range of the present invention or not preferable properties.

[Table 6]

Manufacturing No.	Steel No.	Tensile Strength TS MPa	Total Elongation El %	TS × El MPa·%	Presence or Absence of Secondary Sheared surface -	Limit Fracture Sheet Thickness Reduction Ratio %	Limit Bending R/t -	Remarks
1	A	1021	14.6	14907	Absence	71.1	2.2	Present Invention Example
2	B	1035	15.4	15939	Absence	70.5	2.1	Present Invention Example
3	B	1013	15.6	15803	Presence	72.2	2.2	Comparative Example
4	B	1024	15.3	15667	Presence	72.3	2.3	Comparative Example
5	B	1007	15.9	16011	Presence	73.5	2.2	Comparative Example
6	B	998	16.2	16168	Presence	72.7	2.2	Comparative Example
7	B	1013	15.2	15398	Presence	74.3	2.5	Comparative Example
8	B	1032	15.5	15996	Presence	74.3	2.1	Comparative Example
9	B	1023	15.9	16266	Presence	72.0	2.4	Comparative Example
10	B	1039	15.4	16001	Absence	74.4	2.7	Present Invention Example
11	B	1066	11.4	12152	Absence	74.0	2.2	Comparative Example
12	B	947	13.6	12879	Absence	74.4	2.1	Comparative Example
13	B	960	13.2	12672	Absence	73.2	2.4	Comparative Example
14	B	1026	15.7	16108	Absence	57.2	2.2	Comparative Example
15	B	973	13.3	12941	Absence	53.3	2.3	Comparative Example
16	B	1007	15.6	15709	Presence	58.1	2.4	Comparative Example
17	C	1430	10.9	15587	Absence	71.1	2.3	Present Invention Example
18	D	998	14.0	13972	Absence	62.8	2.2	Present Invention Example
19	E	982	17.9	17578	Absence	60.2	2.3	Present Invention Example
20	F	1101	13.2	14533	Absence	73.8	2.1	Present Invention Example
21	G	989	17.2	17011	Absence	66.1	2.1	Present Invention Example
22	H	1348	10.3	13884	Absence	73.8	2.1	Present Invention Example
23	I	1003	15.4	15446	Absence	71.7	2.3	Present Invention Example
24	J	1000	16.3	16300	Absence	64.1	2.3	Present Invention Example
25	K	1083	13.9	15054	Absence	71.6	2.4	Present Invention Example
26	L	1008	15.6	15725	Absence	74.5	2.4	Present Invention Example
27	M	1018	15.7	15983	Absence	71.3	2.2	Present Invention Example
28	N	1014	15.8	16021	Absence	70.8	2.3	Present Invention Example
29	O	1016	15.9	16154	Absence	73.5	2.1	Present Invention Example
30	P	1029	15.1	15538	Absence	72.2	2.1	Present Invention Example
31	Q	815	21.0	17115	Absence	74.9	2.2	Comparative Example
32	R	1203	9.1	10947	Absence	73.6	2.3	Comparative Example
33	S	978	17.9	17506	Absence	50.4	2.7	Comparative Example
34	T	942	16.9	15920	Absence	74.6	2.3	Comparative Example
35	U	864	19.2	16589	Absence	71.1	2.1	Comparative Example
36	U	1007	14.6	14702	Absence	64.8	2.2	Present Invention Example
37	U	1039	13.9	14442	Absence	67.5	2.1	Present Invention Example
38	U	1025	13.0	13325	Absence	62.8	2.3	Present Invention Example
39	U	1012	14.5	14674	Absence	65.7	2.4	Present Invention Example

The underline indicates that the corresponding values are outside the range of the present invention or not preferable properties.

[0138] From Tables 5 and 6, it is found that the hot-rolled steel sheets according to the present invention examples have excellent ductility and shearing property while having a high strength and a high limit fracture sheet thickness reduction ratio. In addition, it is found that among the present invention examples, the hot-rolled steel sheets in which the average crystal grain size of the surface layer is less than 3.0 μm have the above various properties and further have excellent inside bend cracking resistance.

[0139] On the other hand, it is found that the hot-rolled steel sheets according to the comparative examples deteriorate in any one or more of strength, ductility, limit fracture sheet thickness reduction ratio, and shearing property.

[Industrial Applicability]

[0140] In the aspect according to the present invention, it is possible to provide a hot-rolled steel sheet that has a high strength, a high limit fracture sheet thickness reduction ratio, and excellent ductility and shearing property. In addition, in the preferable aspect according to the present invention, it is possible to obtain a hot-rolled steel sheet that has the above various properties and, furthermore, suppresses the occurrence of inside bend cracking, that is, has excellent inside bend cracking resistance.

[0141] The hot-rolled steel sheet according to the present invention is suitable as an industrial material used for vehicle members, mechanical structural members, and building members.

Claims

1. A hot-rolled steel sheet comprising, as a chemical composition, by mass%:

C: 0.050% to 0.250%;
Si: 0.05% to 3.00%;
Mn: 1.00% to 4.00%;
sol. Al: 0.001% to 2.000%;
P: 0.100% or less;
S: 0.0300% or less;
N: 0.1000% or less;
O: 0.0100% or less;
Ti: 0% to 0.500%;
Nb: 0% to 0.500%;
V: 0% to 0.500%;
Cu: 0% to 2.00%;
Cr: 0% to 2.00%;
Mo: 0% to 1.00%;
Ni: 0% to 2.00%;
B: 0% to 0.0100%;
Ca: 0% to 0.0200%;
Mg: 0% to 0.0200%;
REM: 0% to 0.1000%;
Bi: 0% to 0.0200%;
As: 0% to 0.100%;
Zr: 0% to 1.00%;
Co: 0% to 1.00%;
Zn: 0% to 1.00%;
W: 0% to 1.00%;
Sn: 0% to 0.05%; and
a remainder: Fe and impurities,
wherein Expressions (A) and (B) are satisfied,
a microstructure includes, by area%,

residual austenite of less than 3.0%,
ferrite of 15.0% or more and less than 60.0%, and
pearlite of less than 5.0%,
in which an entropy value represented by Expression (1), obtained by analyzing an SEM image of the microstructure using a gray-level co-occurrence matrix method, is 10.7 or more,
an inverse difference normalized value represented by Expression (2) is 1.020 or more,
a cluster shade value represented by Expression (3) is -8.0×10^5 to 8.0×10^5, and
a standard deviation of an Mn concentration is 0.60 mass% or less, and

a tensile strength is 980 MPa or more,

$$0.060\% \leq \mathrm{Ti} + \mathrm{Nb} + \mathrm{V} \leq 0.500\% \ ... \ (A)$$

$$Zr + Co + Zn + W \leq 1.00\% \ ... \ (B)$$

where each element symbol in Expressions (A) and (B) represents an amount of the corresponding element by mass%, and 0% is substituted in a case where the corresponding element is not contained,
here, P(i, j) in Expressions (1) to (5) is a gray-level co-occurrence matrix, L in Expression (2) is the number of grayscale levels that can be taken in the SEM image, i and j in Expressions (2) and (3) are natural numbers of 1 to L, and μ_x and μ_y in Expression (3) are each represented by Expressions (4) and (5).

$$Entropy = -\sum_i \sum_j P(i,j).\log(P(i,j)) \quad \cdots (1)$$

$$Inverse\ difference\ normalized = \sum_i \sum_j \frac{P(i,j)}{1 + \frac{|i-j|}{L}} \quad \cdots (2)$$

$$Cluster\ Shade = \sum_i \sum_j \left(i + j - \mu_x - \mu_y\right)^3 P(i,j) \quad \cdots (3)$$

$$\mu_x = \sum_i \sum_j i(P(i,j)) \quad \cdots (4)$$

$$\mu_y = \sum_i \sum_j j(P(i,j)) \quad \cdots (5)$$

2. The hot-rolled steel sheet according to claim 1,
wherein an average crystal grain size of a surface layer is less than 3.0 μm.

3. The hot-rolled steel sheet according to claim 1 or 2,

wherein the chemical composition contains, by mass%, one or two or more selected from the group consisting of
Ti: 0.001% to 0.500%,
Nb: 0.001% to 0.500%,
V: 0.001% to 0.500%,
Cu: 0.01% to 2.00%,
Cr: 0.01% to 2.00%,
Mo: 0.01% to 1.00%,
Ni: 0.01% to 2.00%,
B: 0.0001% to 0.0100%,
Ca: 0.0001% to 0.0200%,
Mg: 0.0001% to 0.0200%,
REM: 0.0001% to 0.1000%,
Bi: 0.0001% to 0.0200%,
As: 0.001% to 0.100%,
Zr: 0.01% to 1.00%,
Co: 0.01% to 1.00%,
Zn: 0.01% to 1.00%,
W: 0.01% to 1.00%, and
Sn: 0.01% to 0.05%.

FIG. 1

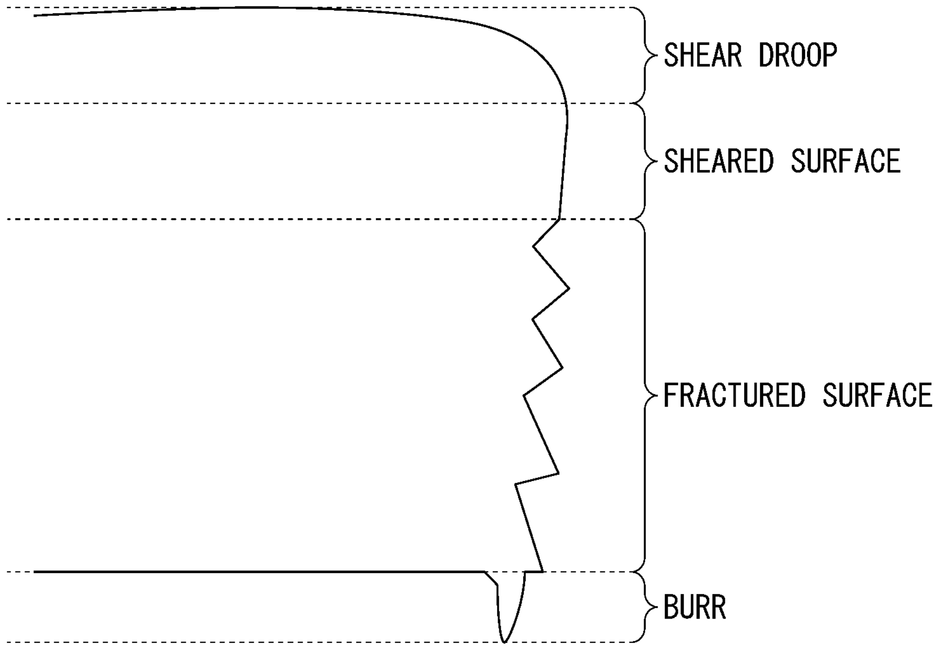
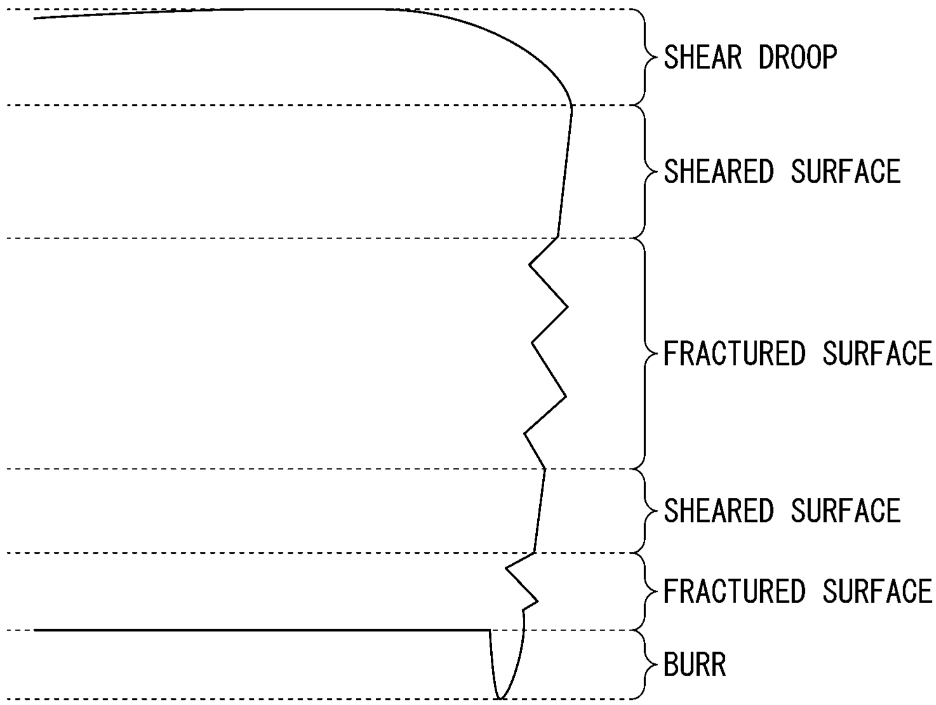

SHEAR DROOP
SHEARED SURFACE
FRACTURED SURFACE
BURR

FIG. 2


SHEAR DROOP
SHEARED SURFACE
FRACTURED SURFACE
SHEARED SURFACE
FRACTURED SURFACE
BURR

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/034395

A. CLASSIFICATION OF SUBJECT MATTER

C21D 8/02(2006.01)i; ***C21D 9/46***(2006.01)i; ***C22C 38/00***(2006.01)i; ***C22C 38/58***(2006.01)i
FI: C22C38/00 301W; C22C38/58; C22C38/00 301A; C21D9/46 T; C21D8/02 A

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)

C21D8/02; C21D9/46; C22C38/00; C22C38/58

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2022
Registered utility model specifications of Japan 1996-2022
Published registered utility model applications of Japan 1994-2022

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2020/184372 A1 (NIPPON STEEL CORP.) 17 September 2020 (2020-09-17)	1-3
A	JP 2015-214718 A (NIPPON STEEL & SUMITOMO METAL CORP.) 03 December 2015 (2015-12-03)	1-3
A	JP 2015-098629 A (NIPPON STEEL & SUMITOMO METAL CORP.) 28 May 2015 (2015-05-28)	1-3
A	WO 2014/166323 A1 (BAOSHAN IRON AND STEEL CO., LTD.) 16 October 2014 (2014-10-16)	1-3

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

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

Date of the actual completion of the international search	Date of mailing of the international search report
14 November 2022	**22 November 2022**
Name and mailing address of the ISA/JP **Japan Patent Office (ISA/JP)** **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/034395

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		CN 113366127 A	
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JP 2015-214718 A	03 December 2015	(Family: none)	
JP 2015-098629 A	28 May 2015	(Family: none)	
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Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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- **J. WEBEL ; J. GOLA ; D. BRITZ ; F. MUCKLICH.** *Materials Characterization,* 2018, vol. 144, 584-596 **[0010]**
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