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(54) **STEEL SHEET**

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(57) **ABSTRACT**

This steel sheet has a predetermined chemical composition, Ex. C that is obtained by Ex. C = (%C) - 12 ((%Ti*)/48 + (%V)/51 + (%Nb)/93 + (%Mo)/96 + (%W)/184} is 0.020% or less, a microstructure at a ¼ depth position of a sheet thickness from a surface contains 60% or more of ferrite, 0% to 5% of MA and a total of 0% to 5% of pearlite and cementite with a remainder of bainite in terms of area fractions, in the microstructure, the average crystal grain diameter is 10.0 μm or less, the average aspect ratio of crystal grains is 0.30 or more, the standard deviation of a Mn concentration is 0.60 mass% or less, a Ti-based carbide having a Baker-Nutting orientation relationship in the ferrite is precipitated in a semi-coherent state, and a tensile strength is 980 MPa or more.

STEEL SHEET

TECHNICAL FIELD

[0001] The present invention relates to a steel sheet.

[0002] Priority is claimed on Japanese Patent Application No. 2020-049120, filed in Japan on Mar. 19, 2020, the content of which is incorporated herein by reference.

BACKGROUND ART

[0003] In recent years, efforts have been being made to reduce carbon dioxide emission in a number of fields from the viewpoint of the global environment protection. Automobile manufacturers are also actively developing techniques for weight reduction in vehicle bodies for the purpose of fuel consumption reduction. A decrease in the weight of steel to be used, such as a decrease in the sheet thickness of a steel sheet, makes it possible to easily decrease the weight of vehicle bodies. However, in the case of automobiles, improvement in the impact resistance is also emphasized in order to ensure passenger safety, and thus weight reduction in vehicle bodies by a decrease in the weight of steel to be used or the like, which is easy, cannot be adopted, and weight reduction in vehicle bodies is not easy. Accordingly, studies are underway to thin members using high strength steel sheets in order to satisfy both weight reduction in vehicle bodies and collision resistance. Incidentally, steel sheets to be applied to vehicle components are formed into component shapes, and, normally, the formability deteriorates as the strengths of the steel sheets increase. Therefore, there is a strong desire for steel sheets to be applied to vehicle components to have both a high strength and excellent formability. Specifically, for steel sheets that are used for inner sheet members, structural members, suspension members, and the like of automobiles, stretch flanging (hole expansion) or bending is often used, and thus the steel sheets need to have a high strength and to be excellent in terms of elongation, stretch flangeability and bending workability.

[0004] For example, as described in Patent Document 1, as a steel sheet from which excellent elongation can be obtained, a dual-phase steel sheet (hereinafter, DP steel) composed of a composite structure of soft ferrite and hard martensite is known. However, the DP steel sheet is excellent in terms of elongation, but cracks occur in some cases due to the formation of voids in the interface between ferrite and martensite, which have significantly different hardness, and thus there is a case where the DP steel sheet is poor in terms of stretch flangeability or bending workability.

[0005] In addition, Patent Document 2 proposes a high strength hot-rolled steel sheet that is obtained by setting the cooling rate in a temperature range from the solidification of a slab to 1300° C. to 10 to 300° C./min and, after finish rolling, coiling the slab at 500° C. or higher and 700° C. or lower and has a steel structure composed of a ferrite single phase and a tensile strength of 1180 MPa or more. Patent Document 2 discloses that the high strength hot-rolled steel sheet is excellent in terms of the bending workability. However, the high strength hot-rolled steel sheet described in Patent Document 2 is manufactured by reheating a slab without cooling the slab to lower than 900° C. where ferrite begins to be formed and hot-rolling the slab. Therefore, there is a problem in that segregation formed during solidification is not sufficiently reduced and there is a case where the bending workability is not stable. In addition, in Patent Document 2, the stretch flangeability is not taken into account.

[0006] Patent Document 3 proposes a method for manufacturing a steel sheet having a ferrite area fraction of 80% or more and a tensile strength of 980 MPa or more by completing hot rolling within five hours after continuous casting to form a solid solution of Ti exceeding the solubility in y and precipitating fine TiC together with ferritic transformation during coiling at 550° C. or higher and 700° C. or lower and a high strength hot-rolled steel sheet that is obtained by the manufacturing method. However, even in Patent Document 3, since continuous casting through the completion of hot finish rolling is performed in an austenite region to suppress the precipitation of coarse TiC, there has been a case where the bending workability deteriorates due to Mn segregation. In addition, in Patent Document 3 as well, similar to Patent Document 2, the stretch flangeability is not taken into account.

CITATION LIST

Patent Documents

[0007] [Patent Document 1] Japanese Unexamined Patent Application, First Publication No. H6-128688

[0008] [Patent Document 2] Japanese Unexamined Patent Application, First Publication No. 2014-194053

[0009] [Patent Document 3] Japanese Unexamined Patent Application, First Publication No. 2014-208876

SUMMARY OF THE INVENTION

Problems to Be Solved by the Invention

[0010] The present invention has been made in consideration of the above-described problems, and an object of the present invention is to provide a steel sheet having a high strength and being excellent in terms of elongation, stretch flangeability and bending workability. Here, the steel sheet of the present invention also includes steel sheets having a cover such as a plating layer on the surface.

Means for Solving the Problem

[0011] The present inventors studied steel sheets that are favorable in all of the strength, the elongation, the stretch flangeability and the bending workability. As a result, it was found that a steel sheet having a high strength and being excellent in terms of elongation, stretch flangeability and bending workability can be manufactured by optimizing the chemical composition and manufacturing conditions to control the microstructure of the steel sheet and Mn segregation and controlling the precipitation form of a Ti-based carbide.

[0012] The present invention has been made based on the above-described finding, and the gist of the present invention is as described below.

[0013] [1] A steel sheet according to an aspect of the present invention contains, as a chemical composition, by mass %, C: 0.050% to 0.250%, Si: 0.005% to 2.000%, Mn: 0.10% to 3.00%, P: 0.100% or less, S: 0.0100% or less, sol. Al: 0.001% to 1.00%, Ti: 0.150% to 0.400%, N: 0.0010% to 0.0100%, Nb: 0% to 0.100%, V: 0% to 1.000%, Mo: 0% to 1.000%, Cu: 0% to 1.00%, Ni: 0% to 1.00%, Cr: 0% to 2.00%, W: 0% to 1.000%, B: 0% to 0.0020%, Ca: 0% to

0.0100%, Mg: 0% to 0.0100%, REM: 0% to 0.0100% and Bi: 0% to 0.0200% with a remainder of Fe and impurities, in which Ex. C obtained by the following formula (1) is 0.020% or less, a microstructure at a ¼ depth position of a sheet thickness from a surface contains 60% or more of ferrite, 0% to 5% of MA and a total of 0% to 5% of pearlite and cementite with a remainder of bainite in terms of area fractions, in the microstructure, the average crystal grain diameter is 10.0 μm or less, the average aspect ratio of crystal grains is 0.30 or more, the standard deviation of a Mn concentration is 0.60 mass% or less, a Ti-based carbide having a Baker-Nutting orientation relationship in the ferrite is precipitated in a semi-coherent state, and a tensile strength is 980 MPa or more.

$$\text{Ex. C} = (\%C) - 12\{(\%Ti^*)/48+(\%V)/51+(\%Nb)/93+(\%Mo)/96+(\%W)/184\} \quad \text{Formula (1)}$$

Here, "%Ti*" in the formula (1) is obtained from the following formula (2).

$$\%Ti^* = \%Ti - 48\times\{(\%N)/14+(\%S)/32\} \quad \text{Formula (2)}$$

%C, %V, %Nb, %Mo, %W, %Ti, %N and %S in the formula (1) and the formula (2) are the amounts of C, V, Nb, Mo, W, Ti, N and S in the steel sheet by mass%.

[0014] The steel sheet according to [1] may contain, as the chemical composition, by mass%, one or more selected from the group consisting of Nb: 0.001% to 0.100%, V: 0.005% to 1.000%, Mo: 0.001% to 1.000%, Cu: 0.02% to 1.00%, Ni: 0.02% to 1.00%, Cr: 0.02% to 2.00%, W: 0.02% to 1.000%, B: 0.0001% to 0.0020%, Ca: 0.0002% to 0.0100%, Mg: 0.0002% to 0.0100%, REM: 0.0002% to 0.0100%, and Bi: 0.0001 % to 0.0200%.

[0015] The steel sheet according to [1] or [2], in which a plating layer may be formed on a surface.

[0016] The steel sheet according to [3], in which the plating layer may be a hot-dip galvanized layer.

[0017] The steel sheet according to [4], in which the hot-dip galvanized layer may be a hot-dip galvannealed layer.

Effects of the Invention

[0018] According to the above-described aspect of the present invention, it is possible to provide a steel sheet having a high strength and being excellent in terms of elongation, stretch flangeability and bending workability. The steel sheet of the present invention is preferable as a material that is used in uses for automobiles, home appliances, mechanical structures, construction and the like, and, in particular, when the steel sheet is used as a material for components such as inner sheet members, structural members, suspension members, and the like of automobiles, not only is a contribution made to weight reduction in vehicle bodies and improvement in impact resistance but the steel sheet is also easily worked into component shapes.

Embodiments of the Invention

[0019] Hereinafter, a steel sheet according to an embodiment of the present invention (the steel sheet according to the present embodiment) will be described below in detail. However, the present invention is not limited only to the configuration disclosed in the present embodiment and can be modified in a variety of manners within the scope of the gist of the present invention.

[0020] First, the chemical composition of the steel sheet according to the present embodiment will be described.

[0021] Numerical value limiting ranges expressed below using "to" include the values at both ends as the lower limit and the upper limit in the ranges. However, numerical values expressed with 'less than' or 'more than' are not included in numerical value ranges. In the following description, "%" regarding the chemical composition of the steel sheet indicates "mass%" in all cases.

Chemical Composition of Steel Sheet

C: 0.050% To 0.250%

[0022] C is an element that bonds to Ti or the like to form a carbide, thereby increasing the tensile strength of steel. When the C content is less than 0.050%, it becomes difficult to obtain a tensile strength of 980 MPa or more. Therefore, the C content is set to 0.050% or more. The C content is preferably set to 0.070% or more.

[0023] On the other hand, when the C content is more than 0.250%, there is a concern about a deterioration of the weldability. Therefore, the C content is set to 0.250% or less. The C content is preferably 0.220% or less, more preferably 0.200% or less and still more preferably 0.180% or less.

Si: 0.005% To 2.000%

[0024] Si is an element having an action of increasing the tensile strength of steel by solid solution strengthening and the enhancement of hardenability. In addition, Si is an element that also has an action of suppressing the precipitation of cementite. When the Si content is less than 0.005%, it becomes unlikely for the above-described action to be exhibited. Therefore, the Si content is set to 0.005% or more. The Si content is preferably 0.010% or more.

[0025] On the other hand, when the Si content is more than 2.000%, the surface properties of the steel sheet significantly deteriorate due to surface oxidation in a hot rolling step. Therefore, the Si content is set to 2.000% or less. The Si content is preferably 1.500% or less and more preferably 1.300% or less.

Mn: 0.10% To 3.00%

[0026] Mn is an element having an action of increasing the tensile strength of steel by solid solution strengthening and the enhancement of hardenability. When the Mn content is less than 0.10%, ferritic transformation is excessively promoted, and a Ti-based carbide is coarsely precipitated together with the ferritic transformation at high temperatures. In this case, it becomes difficult to obtain a tensile strength of the steel sheet of 980 MPa or more. Therefore, the Mn content is set to 0.10% or more. The Mn content is preferably 0.30% or more and more preferably 0.50% or more.

[0027] On the other hand, when the Mn content is more than 3.00%, ferritic transformation and bainitic transformation are delayed, and a desired ferrite area fraction cannot be obtained. In this case, the elongation deteriorates, and the formation of MA degrades the stretch flangeability or the

bending workability. Therefore, the Mn content is set to 3.00% or less. The Mn content is preferably 2.50% or less, more preferably 2.00% or less and still more preferably 1.50% or less.

Sol. Al: 0.001% To 1.00%

[0028] Al is an element having an action of cleaning steel by deoxidation in a steelmaking stage. When the sol. Al content is less than 0.001%, it becomes difficult to exhibit the above-described action. Therefore, the sol. Al content is set to 0.001% or more. The sol. Al content is preferably 0.01% or more, more preferably 0.02% or more and still more preferably 0.03% or more.

[0029] On the other hand, even when the sol. Al content is set to more than 1.00%, the effect of the above-described action is saturated, and the refining cost increases. Therefore, the sol. Al content is set to 1.00% or less. The sol. Al content is preferably 0.80% or less and more preferably 0.60% or less. sol. Al refers to acid-soluble Al.

Ti: 0.150% To 0.400%

[0030] Ti is an element that bonds to C to form a Ti-based carbide and contributes to increase in the tensile strength of the steel sheet. In addition, Ti is an element having an action of refining the microstructure by forming a Ti nitride to suppress the coarsening of austenite during the reheating and hot rolling of a slab. When the Ti content is less than 0.150%, it becomes difficult to obtain a tensile strength of 980 MPa or more due to the lack of the precipitation hardening amount. Therefore, the Ti content is set to 0.150% or more. The Ti content is preferably 0.170% or more, more preferably 0.190% or more and still more preferably 0.210% or more.

[0031] On the other hand, when the Ti content becomes excessive, a coarse Ti-based carbide remains in austenite in an undissolved state, which degrades the elongation or the bending workability, and the amount of a Ti-based carbide having a Baker-Nutting orientation relationship contributing to the strength, which decreases the strength. Therefore, the Ti content is set to 0.400% or less. The Ti content is preferably 0.380% or less and more preferably 0.350% or less.

N: 0.0010% To 0.0100%

[0032] N is an element having an action of refining the microstructure by forming a Ti nitride to suppress the coarsening of austenite during the reheating and hot rolling of a slab. When the N content is less than 0.0010%, it becomes difficult to exhibit the above-described action. Therefore, the N content is set to 0.0010% or more. The N content is preferably 0.0015% or more and more preferably 0.0020% or more.

[0033] On the other hand, when the N content is more than 0.0100%, a coarse Ti nitride is formed, and the stretch flangeability of the steel sheet deteriorates. Therefore, the N content is set to 0.0100% or less. The N content is preferably 0.0060% or less and more preferably 0.0050% or less.

P: 0.100% or Less

[0034] P is an element that is contained in steel as an impurity and has an action of degrading the stretch flangeability or bending workability of the steel sheet. Therefore, the P content is set to 0.100% or less. The P content is preferably 0.060% or less, more preferably 0.040% or less and still more preferably 0.020% or less. P is mixed from a raw material as an impurity, and the lower limit thereof is not particularly limited, but the P content is preferably as small as possible from the viewpoint of ensuring the bending workability. However, when the P content is excessively decreased, the manufacturing cost increases. From the viewpoint of the manufacturing cost, the P content is preferably 0.001% or more and more preferably 0.005% or more.

S: 0.0100% or Less

[0035] S is an element that is contained in steel as an impurity and has an action of degrading the stretch flangeability or bending workability of the steel sheet. Therefore, the S content is set to 0.0100% or less. The S content is preferably 0.0080% or less, more preferably 0.0060% or less and still more preferably 0.0030% or less. S is mixed from the raw material as an impurity, and the lower limit thereof is not particularly limited, but the S content is preferably as small as possible from the viewpoint of ensuring the bending workability. However, when the S content is excessively decreased, the manufacturing cost increases. From the viewpoint of the manufacturing cost, the S content is preferably 0.0001% or more, more preferably 0.0005% or more and still more preferably 0.0010% or more.

[0036] The remainder of the chemical composition of the steel sheet according to the present embodiment includes Fe and impurities. In the present embodiment, the impurity means a substance that is mixed from ore as a raw material, a scrap, the manufacturing environment or the like and is allowed to an extent that the steel sheet according to the present embodiment is not adversely affected.

[0037] The steel sheet according to the present embodiment may contain the following optional elements instead of some of Fe. Since the steel sheet according to the present embodiment is capable of solving the problems even when the optional elements are not contained, the lower limit of the amount of the optional elements is 0%.

Nb: 0% To 0.100%

[0038] Nb is an optional element. Nb is an element having effects on the suppression of the coarsening of the crystal grain diameters of the steel sheet and an increase in the tensile strength of the steel sheet by the refinement of the ferrite grain diameters or precipitation hardening attributed to the precipitation of Nb as NbC. In order to obtain these effects, the Nb content is preferably set to 0.001 % or more. The Nb content is more preferably 0.005% or more and still more preferably 0.010% or more.

[0039] On the other hand, when the Nb content exceeds 0.100%, the above-described effects are saturated, and there is a concern about an increase in the rolling force during finish rolling. Therefore, in a case where Nb is contained, the Nb content is set to 0.100% or less. The Nb content is preferably 0.060% or less and more preferably 0.030% or less.

V: 0% To 1.000%

[0040] V is an optional element. V is an element having effects on an increase in the tensile strength of the steel sheet

by the formation of a solid solution in steel and increase in the tensile strength of the steel sheet by precipitation hardening attributed to the precipitation of V as a carbide, a nitride, a carbonitride or the like in steel. In order to obtain these effects, the V content is preferably set to 0.005% or more. The V content is more preferably 0.010% or more and still more preferably 0.050% or more.

[0041] On the other hand, when the V content exceeds 1.000%, a carbide is likely to become coarse and there is a case where the bending workability deteriorates. Therefore, in a case where V is contained, the V content is set to 1.000% or less. The V content is preferably 0.800% or less and more preferably 0.600% or less.

Mo: 0% to 1.000%

[0042] Mo is an optional element. Mo is an element having effects on the high-strengthening of the steel sheet by the enhancement of the hardenability of steel and the formation of a carbide or a carbonitride. In order to obtain these effects, the Mo content is preferably set to 0.001% or more. The Mo content is more preferably 0.005% or more, still more preferably 0.010% or more and far still more preferably 0.050% or more.

[0043] On the other hand, when the Mo content exceeds 1.000%, there is a case where the cracking sensitivity of a steel material such as a slab is enhanced. Therefore, in a case where Mo is contained, the Mo content is set to 1.000% or less. The Mo content is more preferably 0.800% or less and still more preferably 0.600% or less.

Cu: 0% To 1.00%

[0044] Cu is an optional element. Cu is an element having an effect on improvement in the toughness of steel and an effect on an increase in the tensile strength. In order to obtain these effects, the Cu content is preferably set to 0.02% or more.

[0045] On the other hand, when Cu is excessively contained, there is a case where the weldability of the steel sheet deteriorates. Therefore, in a case where Cu is contained, the Cu content is set to 1.00% or less. The Cu content is preferably 0.50% or less and more preferably 0.30% or less.

Ni: 0% To 1.00%

[0046] Ni is an optional element. Ni is an element having an effect on improvement in the toughness of steel and an effect on an increase in the tensile strength. In order to obtain these effects, the Ni content is preferably set to 0.02% or more.

[0047] On the other hand, when Ni is excessively contained, the alloying cost increases, and there is a case where the toughness of the steel sheet in a welded heat-affected zone deteriorates. Therefore, in a case where Ni is contained, the Ni content is set to 1.00% or less. The Ni content is preferably 0.50% or less and more preferably 0.30% or less.

Cr: 0% to 2.00%

[0048] Cr is an optional element. Cr is an element having an effect on an increase in the tensile strength by the enhancement of the hardenability of steel. In order to obtain this effect, the Cr content is preferably set to 0.02% or more. The Cr content is more preferably 0.05% or more and still more preferably 0.10% or more.

[0049] On the other hand, when the Cr content become excessive, the chemical convertibility deteriorates. Therefore, in a case where Cr is contained, the Cr content is set to 2.00% or less. The Cr content is preferably 1.50% or less, more preferably 1.00% or less and still more preferably 0.50% or less.

W: 0% To 1.000%

[0050] W is an optional element. W is an element having an effect on an increase in the tensile strength by the formation of a carbide or a carbonitride. In order to obtain this effect, the W content is preferably set to 0.020% or more.

[0051] On the other hand, even when more than a certain amount of W is contained, the effect of the above-described action is saturated, and thus the alloying cost increases. Therefore, in a case where W is contained, the W content is set to 1.000% or less. The W content is preferably 0.800% or less.

B: 0% To 0.0020%

[0052] B is an optional element. B is an element having an effect on an increase in the tensile strength of the steel sheet by grain boundary strengthening or solid solution strengthening. In order to obtain this effect, the B content is preferably set to 0.0001 % or more. The B content is more preferably 0.0002% or more.

[0053] On the other hand, even when more than 0.0020% of B is contained, not only is the above-described effect saturated, but the alloying cost also increases. Therefore, in a case where B is contained, the B content is set to 0.0020% or less. The B content is more preferably 0.0015% or less.

Ca: 0% To 0.0100%

[0054] Ca is an optional element. Ca is an element having an effect on the refinement of the microstructure of the steel sheet by the dispersion of a number of fine oxides in molten steel. In addition, Ca is an element having an effect on improvement in the stretch flangeability of the steel sheet by fixing S in molten steel as spherical CaS to suppress the formation of an elongated inclusion such as MnS. In order to obtain these effects, the Ca content is preferably set to 0.0002% or more. The Ca content is more preferably 0.0005% or more and still more preferably 0.0010% or more.

[0055] On the other hand, when the Ca content exceeds 0.0100%, the amount of CaO in steel increases, and there is a case where the toughness of the steel sheet deteriorates. Therefore, in a case where Ca is contained, the Ca content is set to 0.0100% or less. The Ca content is preferably 0.0050% or less and more preferably 0.0030% or less.

Mg: 0% To 0.0100%

[0056] Mg is an optional element. Similar to Ca, Mg is an element having effects on the suppression of the formation of coarse MnS by the formation of an oxide or a sulfide in molten steel and the refinement of the microstructure of the steel sheet by the dispersion of a number of fine oxides. In

order to obtain these effects, the Mg content is preferably set to 0.0002% or more. The Mg content is more preferably 0.0005% or more and still more preferably 0.0010% or more.

[0057] On the other hand, when the Mg content exceeds 0.0100%, an oxide in steel increases, and there is a case where the toughness of the steel sheet deteriorates. Therefore, in a case where Mg is contained, the Mg content is set to 0.0100% or less. The Mg content is preferably 0.0050% or less and more preferably 0.0030% or less.

REM: 0% To 0.0100%

[0058] REM is an optional element. Similar to Ca, REM is also an element having effects on the suppression of the formation of coarse MnS by the formation of an oxide or a sulfide in molten steel and the refinement of the microstructure of the steel sheet by the dispersion of a number of fine oxides. In the case of obtaining these effects, the REM content is preferably set to 0.0002% or more. The REM content is more preferably 0.0005% or more and still more preferably 0.0010% or more.

[0059] On the other hand, when the REM content exceeds 0.0100%, an oxide in steel increases, and there is a case where the toughness of the steel sheet deteriorates. Therefore, in a case where REM is contained, the REM content is set to 0.0100% or less. The REM content is preferably 0.0050% or less and more preferably 0.0030% or less.

[0060] Here, REM (rare earth metal) refers to a total of 17 elements including Sc, Y, and lanthanoids. In the present embodiment, the REM content refers to the total amount of these elements.

Bi: 0% to 0.0200%

[0061] Bi is an optional element. Bi is an element having an effect on improvement in the formability of the steel sheet by the refinement of the solidification structure. In order to obtain this effect, the Bi content is preferably set to 0.0001% or more. The Bi content is more preferably 0.0005% or more.

[0062] On the other hand, when the Bi content exceeds 0.0200%, the above-described effect is saturated, and the alloying cost increases. Therefore, in a case where Bi is contained, the Bi content is set to 0.0200% or less. The Bi content is preferably 0.0100% or less and more preferably 0.0070% or less.

Ex. C: 0.020% or Less

[0063] C is precipitated as a Ti-based carbide and contributes to the high-strengthening of the steel sheet. However, when the amount of C contained is larger than the amount of C to be precipitated as a Ti-based carbide, excess C forms pearlite, cementite, MA or the like and consequently degrades the stretch flangeability or the bending workability.

[0064] Ex. C that is obtained by the following formula (1) corresponds to the amount of C contained more than the amount of C to be precipitated as a Ti-based carbide. In the steel sheet according to the present embodiment, this Ex. C is set to 0.020% or less. Ex. C is preferably 0.018 or less and more preferably 0.015% or less. The lower limit is not particularly limited.

$$\text{Ex. C} = (\%C) - 12\{(\%Ti^*)/48+(\%V)/51+(\%Nb)/93+(\%Mo)/96+(\%W)/184\} \quad \text{Formula (1)}$$

[0065] Here, "%Ti*" in the formula (1) is obtained from the following formula (2).

$$\%Ti^* = \%Ti - 48 \times \{(\%N)/14+(\%S)/32\} \quad \text{Formula (2)}$$

%C, %V, %Nb, %Mo, %W, %Ti, %N and %S in the formula (1) and the formula (2) are the amounts of C, V, Nb, Mo, W, Ti, N and S in the steel sheet by mass%, respectively.

[0066] Next, the microstructure of the steel sheet will be described. In the steel sheet according to the present embodiment, the microstructure at a 1/4 depth position of the sheet thickness from the surface contains 60% or more of ferrite, 0% to 5% of MA and a total of 0% to 5% of pearlite and cementite with a remainder including bainite. In addition, in the microstructure, the average crystal grain diameter is 10.0 μm or less, the average aspect ratio of crystal grains is 0.30 or more, and the standard deviation of the Mn concentration is 0.60 mass% or less. In addition, a Ti-based carbide having a Baker-Nutting orientation relationship in the ferrite is precipitated in a semi-coherent state.

[0067] Here, the reason for regulating the microstructure at the ¼ depth position of the sheet thickness in the sheet thickness direction from the surface of the steel sheet (a t/4 position from the surface in a case where the sheet thickness is represented by t) is that the microstructure at this position is a typical microstructure of the steel sheet.

[0068] (Area fraction of ferrite: 60% or more)

[0069] (Area fraction of MA: 0% to 5%)

[0070] (Total area fraction of pearlite and cementite: 0% to 5%)

Remainder: Bainite

[0071] Ferrite is required to obtain favorable elongation. When the area fraction is less than 60%, the elongation deteriorates. Therefore, the area fraction of ferrite is set to 60% or more. The area fraction of ferrite is preferably 70% or more, more preferably 80% or more and may be 100% (that is, a ferrite single phase).

[0072] There is a case where the microstructure contains, in addition to ferrite, a small amount of MA, which is allowed as long as the area fraction is 5% or less. The area fraction is preferably 4% or less, more preferably 3% or less and most preferably 2% or less. In addition, there is a case where pearlite and cementite are precipitated, which is allowed as long as the total area fraction is 5% or less. The total area fraction is preferably 4% or less, more preferably 3% or less and most preferably 2% or less. When the area fraction of MA is more than 5%, the bending workability and the hole expandability deteriorate. Alternatively, when the area fraction of pearlite and cementite is more than 5%, the hole expandability deteriorates.

[0073] In the microstructure, the remainder other than the above-described structures includes bainite. The hardness difference is small between bainite and ferrite that has been precipitation-hardened by a Ti-based carbide. Therefore, bainite has a small effect on the degradation of the hole expandability compared with MA (Martensite-Auste-

nite constituents), pearlite and cementite. Therefore, bainite is contained as the remainder in microstructure.

Average Crystal Grain Diameter: 10.0 μm or Less)

[0074] When the average crystal grain diameter is large, the bending workability deteriorates. Therefore, in the microstructure, the average crystal grain diameter is set to 10.0 μm or less. The average crystal grain diameter is preferably 8.0 μm or less. Since the average crystal grain diameter is preferably as small as possible, the lower limit is not particularly limited. However, it is technically difficult to refine crystal grains by ordinary hot rolling such that the average crystal grain diameter becomes less than 1.0 μm. Therefore, the average crystal grain diameter may be set to 1.0 μm or more.

[0075] "The average crystal grain diameter" in the present embodiment refers to the average value of crystal grain diameters for which a region that is surrounded by grain boundaries having a crystal orientation difference of 15° or more and has a circle equivalent diameter of 0.3 μm or more in a material having a bcc crystal structure, that is, ferrite, bainite, martensite, and pearlite is defined as a crystal grain, and the crystal grain diameters of residual austenite are not included in the average crystal grain diameter.

Average Aspect Ratio of Crystal Grain: 0.30 or More

[0076] In the present embodiment, the average aspect ratio of bcc crystal grains is 0.30 or more. The aspect ratio is a value obtained by dividing the length of the minor axis of a crystal grain by the length of the major axis and has a value of 0 to 1.00. As the average aspect ratio of crystal grains becomes smaller, the crystal grains become flatter, and, as the average aspect ratio becomes closer to 1.00, it is indicated that a crystal grain becomes more equiaxial. When the average aspect ratio of the crystal grains is less than 0.30, there are a number of flat crystal grains, the anisotropy of the material becomes large, and the stretch flangeability and the bending workability deteriorate. Therefore, the average aspect ratio of the crystal grains excluding residual austenite is set to 0.30 or more. As the crystal grains become more equiaxial, the anisotropy becomes smaller, and the workability becomes superior, and thus the average aspect ratio of the crystal grains excluding residual austenite is preferably as close to 1.00 as possible.

[0077] In the present embodiment, the average crystal grain diameter, the average aspect ratio of the crystal grains and the area fractions of the microstructure are obtained by the scanning electron microscopic (SEM) observation and the electron back scattering diffraction (EBSD) analysis of the microstructure at the ¼ depth position of the steel thickness from the surface of the steel sheet of a cross section of the steel sheet parallel to a rolling direction and the sheet thickness direction using an EBSD analyzer composed of a thermal field emission scanning electron microscope and an EBSD detector. In a region that is 200 μm long in the rolling direction and 100 μm long in the sheet thickness direction and has the ¼ depth position of the sheet thickness from the surface of the steel sheet at the center, crystal orientation information is acquired at 0.2 μm intervals while differentiating fcc and bcc. Crystal grain boundaries having a crystal orientation difference of 15° or more are specified using the software attached to the EBSD analyzer ("OIM Analysis (registered trademark)" manufactured by AME1EK, Inc.). Regarding the average crystal grain diameter of bcc, the average crystal grain diameter is obtained by defining a region that is surrounded by crystal grain boundaries having a crystal orientation difference of 15° or more and has a circle equivalent diameter of 0.3 μm or more as a crystal grain.

[0078] A crystal grain boundary having a crystal orientation difference of 15° or more is mainly a ferrite grain boundary or a block boundary of martensite and bainite. In a method for measuring ferrite grain diameters according to JIS G 0552: 2013, there is a case where a grain diameter is calculated even for a ferrite grain having a crystal orientation difference of less than 15°, and furthermore, a block of martensite or bainite is not calculated. Therefore, as the average crystal grain diameter in the present embodiment, a value obtained by EBSD analysis as described above is adopted. In the EBSD analysis, since the length of the major axis and the length of the minor axis of each crystal grain are also obtained at the same time, the average aspect ratio of bcc crystal grains is also obtained by adopting the present method.

[0079] The area fraction of ferrite is measured by the following method. Here, a region that is surrounded by grain boundaries having a crystal orientation difference of 5° or more and has a circle equivalent diameter of 0.3 μm or more is defined as a crystal grain. Among such crystal grains, for crystal grains for which a value that is obtained by an analysis with Grain Average Misorientation analysis equipped in OIM Analysis (GAM value) is 0.6° or less, the area fraction is calculated. The area fraction of ferrite is obtained by such a method. The reason for defining a boundary having a crystal orientation difference of 5° or more as a grain boundary at the time of obtaining the area fraction of ferrite is that there is a case where it is not possible to differentiate different microstructures formed as close variants from the same prior austenite grain.

[0080] The area fraction of pearlite and cementite is obtained by observing microstructures revealed by Nital etching with a SEM. The area fraction of MA is obtained by observing a microstructure revealed by LePera etching with an optical microscope. The area fraction may be obtained by an image analysis or may be obtained by a point counting method. For example, for pearlite and cementite, the area fractions may be obtained by the point counting method with lattice spacings of 5 μm after three or more visual fields (100 μm × 100 μm/visual field) in a region at the ¼ depth position of the sheet thickness from the surface of the steel sheet are observed at a magnification of 1000 times. In addition, the area fraction of MA may be obtained by the point counting method with lattice spacings of 5 μm after two or more visual fields (200 μm × 200 μm/visual field) in a region at the ¼ depth position of the sheet thickness from the surface of the steel sheet are observed at a magnification of 500 times.

Standard Deviation of Mn Concentration: 0.60 mass% or Less

[0081] The standard deviation of the Mn concentration at the ¼ depth position of the sheet thickness from the surface of the steel sheet according to the present embodiment is 0.60 mass% or less. In such a case, a local unevenness in the tensile strength attributed to Mn segregation is reduced, and it is possible to stably obtain favorable bending work-

ability. The value of the standard deviation of the Mn concentration is desirably as small as possible, but the substantial lower limit is 0.10 mass% due to restrictions in the manufacturing process.

[0082] The standard deviation of the Mn concentration can be obtained by collecting a sample such that a cross section parallel to the rolling direction and the sheet thickness direction of the steel sheet becomes an observed section, mirror-polishing the observed section and then measuring the ¼ depth position of the sheet thickness from the surface of the steel sheet with an electron probe microanalyzer (EPMA). As the measurement conditions, the acceleration voltage is set to 15 kV, the magnification is set to 5000 times, and a distribution image in a range that is 20 μm long in the rolling direction of the sample and 20 μm long in the sheet thickness direction of the sample is measured. More specifically, the measurement intervals are set to 0.1 μm, and the Mn concentrations at 40000 or more sites are measured. 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.

Ti-Based Carbide

[0083] In the steel sheet according to the present embodiment, a carbide containing Ti (Ti-based carbide) is precipitated in ferrite. Ti is an element having a high driving force for the precipitation of a carbide in ferrite, and the control of the content and a heat treatment make it easy to control the precipitation state of a carbide. In addition, the Ti-based carbide also has a high precipitation hardening capability. Here, the Ti-based carbide refers to a carbide having a NaCl-type crystal structure containing Ti. In a case where such a carbide contains Ti, even when a small amount of other carbide-forming alloying elements are contained, the above-described driving force is not significantly weakened, and thus the effect can be obtained. Within the range of the chemical composition that is regulated by the present embodiment, the Ti-based carbide may contain other carbide-forming alloying elements, for example, Mo, Nb, V, Cr and W. Furthermore, even when the Ti-based carbide is a carbonitride in which some of carbon atoms have been substituted with nitrogen atoms, the precipitation state does not change, and thus the effect can be obtained.

Precipitation of Ti-Based Carbides in Ferrite in Semi-Coherent State

[0084] In a case where the proportion of Ti-based carbides for which the interface with ferrite is a semi-coherent interface to the Ti-based carbides precipitated in ferrite, which have the Baker-Nutting orientation relationship, is 50% or more, the stretch flangeability of the steel sheet becomes stably favorable. The state where "the Ti-based carbides are precipitated in a semi-coherent state" mentioned in the present embodiment refers to such case. In a case where the Ti-based carbides are not precipitated in a semi-coherent state, the hole expandability deteriorates.

[0085] Whether or not the Ti-based carbides having the Baker-Nutting orientation relationship are in a semi-coherent state is determined as described below. That is, an annular dark-field scanning transmission electron microscopic image, for which the detection angle of an annular detector is set to 60 mrad or more and 200 mrad or less in the scanning transmission electron microscopy (magnification: 910,000 times to 5,100 ,000 times), is captured by injecting electron beams into a thin film sample for a transmission electron microscope produced from the ¼ depth position of the sheet thickness from the surface along a [001] orientation of ferrite. When a particle forming a plate-like form having a (100) plane of ferrite in the matrix as a habit plane and a particle forming a plate-like form having a (010) plane of ferrite as a habit plane are regarded as the Ti-based carbides having the Baker-Nutting orientation relationship, a case where the numbers of the crystal planes of a {010} plane of ferrite and a {01-1} plane of the Ti-based carbides that sandwich the habit plane of the (100) plane of the particle forming a plate-like form having a (100) plane of ferrite in the matrix as a habit plane and the habit plane of the (100) plane of the particle forming a plate-like form having a (010) plane of ferrite as a habit plane coincide with each other is determined as a coherent state, and a case where the numbers of the crystal planes do not coincide with each other is determined as the semi-coherent state. In a case where 20 or more Ti-based carbides are observed and 50% or more is in the semi-coherent state, the Ti-based carbides having the Baker-Nutting orientation relationship in steel from which the observed thin film sample for a transmission electron microscope has been collected are determined to be in the semi-coherent state.

[0086] Regarding the sizes of the Ti-based carbides, ordinarily, as the carbides become larger, the number density tends to become smaller. In the present invention, from the viewpoint of ensuring the number density of the Ti-based carbides that are precipitated in ferrite to have the Baker-Nutting orientation relationship, the thickness of the Ti-based carbide needs to be 1 nm or more and 5 nm or less.

[0087] The thickness of the Ti-based carbide is measured by the following method.

[0088] A thin film sample for a transmission electron microscope is produced from the ¼ depth position in the sheet thickness direction from the surface of the steel sheet and observed with a scanning transmission electron microscope (hereinafter, also referred to as "STEM"). In a Ti-based carbide forming sheet surfaces on the (100) plane and the (010) plane of ferrite observed in a STEM image captured by injecting electron beams along the [001] orientation of ferrite, the length of a small side between the sizes of the Ti-based carbide measured along the [100] and [010] orientations of ferrite is regarded as the thickness. In addition, at the time of evaluating the thickness of the Ti-based carbide, a scale is corrected such that the interatomic distance, which is as long as 10 unit lattices, becomes 2.866 nm in each of the [100] orientation and the [010] orientation of ferrite in a site where no precipitates are shown in the image.

Mechanical Properties

Tensile Strength: 980 MPa or More

[0089] The steel sheet according to the present embodiment has a high strength and is excellent in terms of the elongation, the stretch flangeability, and the bending workability by the control of the microstructure, the precipitation form of the Ti-based carbide and Mn segregation. However, when the tensile strength of the steel sheet is small, an effect on weight reduction in vehicle bodies, rigidness improve-

ment or the like is small. Therefore, the tensile strength (TS) of the steel sheet according to the present embodiment is set to 980 MPa or more. The tensile strength is preferably 1080 MPa or more. Although the upper limit is not particularly regulated; however, as the tensile strength increases, press forming becomes more difficult. Therefore, the tensile strength may be set to 1800 MPa or less.

[0090] From the viewpoint of the formability, the steel sheet according to the present embodiment aims at TS × λ, which serves as an index of the balance between the strength and the stretch flangeability, of 50000 MPa·% or more and aims at TS × El, which serves as an index of the balance between the strength and the elongation, of 14000 MPa·% or more. TS × El is more preferably 15000 MPa·% or more. TS x λ is more preferably 55000 MPa·% or more, still more preferably 60000 MPa % or more and far still more preferably 65000 MPa·% or more.

[0091] The tensile strength and elongation of the steel sheet are evaluated by the tensile strength and the total elongation at fracture (El) using a No. 5 test piece regulated in JIS Z 2241: 2011. The stretch flangeability of the steel sheet is evaluated with the limiting hole expansion ratio (λ) regulated in JIS Z 2256: 2010.

Manufacturing Method

[0092] The reason for limiting the conditions for manufacturing the steel sheet according to the present embodiment will be described.

[0093] The present inventors are confirming that the steel sheet according to the present embodiment can be obtained by a manufacturing method including a heating step, a hot rolling step, a cooling step and a coiling step as described below.

Heating Step

[0094] First, a slab or steel piece having the above-mentioned chemical composition is heated. The slab or steel piece may be a slab or steel piece obtained by continuous casting or casting and blooming or may be also a slab or steel piece obtained by additionally performing hot working or cold working on the above-described slab or steel piece.

Retention Time in Temperature Range of 700° C. to 850° C. During Heating: 900 Seconds or Longer

[0095] When the slab or steel piece that is to be subjected to hot rolling is heated, the slab or steel piece is caused to retain in a temperature range of 700° C. to 850° C. for 900 seconds or longer. In austenitic transformation occurring in the temperature range of 700° C. to 850° C., Mn is distributed to ferrite and austenite. Therefore, when the transformation time is extended by extending the retention time, it is possible to diffuse Mn in the ferrite region. This eliminates Mn microsegregation that is unevenly distributed in the slab and significantly reduces the standard deviation of the Mn concentration.

Heating Temperature: 1280° C. or Higher and SRT (°C) or Higher

[0096] The heating temperature of the slab or steel piece that is to be subjected to hot rolling is set to 1280° C. or higher and a temperature SRT (°C) represented by the following formula (3) or higher. When the heating temperature is lower than 1280° C., there is a case where the reduction in the standard deviation of the Mn concentration due to the diffusion of Mn during heating becomes insufficient. In addition, the heating temperature is lower than the SRT (°C), the solutionizing of a Ti carbonitride becomes insufficient, and, in any cases, the tensile strength or bending workability of the steel sheet deteriorates. Therefore, the temperature of the slab or steel piece that is to be subjected to hot rolling is set to 1280° C. or higher and the SRT (°C) or higher. Here, the fact that "the temperature of the slab or steel piece is 1280° C. or higher and the SRT (°C) or higher" means that the temperature of the slab or steel piece is higher than the higher temperature of 1280° C. and the SRT (°C) or the higher temperature of 1280° C. and the SRT (°C) is the same as the temperature of the slab or steel piece.

[0097] On the other hand, when the heating temperature is higher than 1400° C., there is a case where a thick scale is formed to decrease the yield or significantly damage heating furnaces. Therefore, the heating temperature is preferably 1400° C. or lower.

$$SRT\ (°C) = 1630 + 90 \times \ln([C] \times [Ti]) \quad (3)$$

Here, [element symbol] in the formula (3) indicates the amount of each element by mass%.

Hot Rolling Step

[0098] In the hot rolling step, multi-pass hot rolling is performed on the slab or steel piece after the heating step using a plurality of rolling stands to produce a hot-rolled steel sheet. The hot rolling step is divided into rough rolling and finish rolling that is performed after the rough rolling.

[0099] The multi-pass hot rolling can be performed using a reverse mill or a tandem mill; however, at least several stages from the end are preferably performed using a tandem mill from the viewpoint of the industrial productivity.

Time From Beginning of Rough Rolling to Completion of Finish Rolling: 600 Seconds or Shorter

[0100] Since rolling promotes the precipitation of the Ti-based carbide and makes the precipitation begin, when the time taken until the completion of the finish rolling is too long, a large amount of a coarse Ti-based carbide is precipitated in austenite. In this case, a fine Ti-based carbide that contributes to high-strengthening and is precipitated in ferrite after the finish rolling reduces, the tensile strength of the steel sheet significantly decreases, and the bending workability deteriorates. Therefore, the time from the beginning of the rough rolling to the completion of the finish rolling is set to 600 seconds or shorter. The time is preferably 500 seconds or shorter, more preferably 400 seconds or shorter and most preferably 320 seconds or shorter.

[0101] Normally, in hot rolling steps, the rolling reduction and the rolling temperature are controlled depending on the specification of a roller, the sheet thickness and sheet width of a coil to be manufactured and a desired material, but the time from the beginning of rough rolling to the completion of finish rolling is not comprehensively controlled. The present inventors newly found that the time from the beginning

of the rough rolling to the completion of the finish rolling affects the precipitation state of the Ti-based carbide.

Total Rolling Reduction Within Temperature Range of 850° C. to 1100° C.: 90% or Larger

[0102] When hot rolling is performed in a manner that the total rolling reduction within a temperature range of 850° C. to 1100° C. becomes 90% or larger, mainly recrystallized austenite is refined, and the accumulation of the strain energy in the non-recrystallized austenite is promoted. As a result, the recrystallization of austenite is promoted, the diffusion of Mn atoms is promoted, and the standard deviation of the Mn concentration becomes small. Therefore, in the hot rolling, the total rolling reduction (cumulative rolling reduction) within the temperature range of 850° C. to 1100° C. is set to 90% or larger.

[0103] The total rolling reduction within the temperature range of 850° C. to 1100° C. can be represented by (t0 - t1)/t0 × 100 (%) where the inlet sheet thickness before the first pass in rolling within this temperature range is indicated by t0 and the outlet sheet thickness after the final pass in the rolling within this temperature range is indicated by t1.

Finish Rolling Completion Temperature FT (°C): TR (°C) or Higher and 1080° C. or Lower

[0104] When the FT (°C) is lower than TR (°C) represented by the following formula (4), significantly flat austenite is formed before cooling after the finish rolling, the microstructure is elongated in the rolling direction in the final product steel sheet, the average aspect ratio of crystal grains excluding residual austenite and having a bcc structure becomes smaller, and the plastic anisotropy becomes large. In this case, the elongation, stretch flangeability and/or bending workability of the steel sheet deteriorates. Therefore, the FT (°C) is set to the TR (°C) or higher.

[0105] On the other hand, when the FT (°C) exceeds 1080° C., the structure becomes coarse, and the bending workability of the steel sheet deteriorates. Therefore, the FT (°C) is set to 1080° C. or lower. The FT (°C) is preferably 1060° C. or lower.

[0106] The temperature during the finish rolling refers to the surface temperature of steel and can be measured with a radiation-type thermometer or the like.

$$TR\ (°C) = 805 + 385 \times [Ti] + 584 \times [Nb] \quad (4)$$

[0107] Here, [element symbol] in the formula (4) indicates the amount of each element by mass%, and zero is assigned in a case where the corresponding element is not contained.

Cooling Step

[0108] The method for manufacturing the steel sheet according to the present embodiment has, as the next step of the hot rolling step, a cooling step of cooling the hot-rolled steel sheet with water to a temperature range of 650° C. to 800° C. at an average cooling rate of 45° C./second or faster. In addition, in the method for manufacturing the steel sheet according to the present embodiment, the cooling step is begun within 3.0 seconds after the end of the hot rolling step (after the completion of the finish rolling).

Time From Completion of Finish Rolling to Beginning of Water Cooling: 3.0 Seconds or Shorter

[0109] When the time from the completion of the finish rolling to the beginning of water cooling is longer than 3.0 seconds, the tensile strength or the bending workability deteriorates due to the growth of the refined austenite crystal grains or the coarse precipitation of a carbonitride of Ti or the like. Therefore, in the method for manufacturing the steel sheet according to the present embodiment, the water cooling is begun within 3.0 seconds after the completion of the finish rolling. The time is preferably 2.0 seconds or shorter and more preferably 1.5 seconds or shorter.

Average Cooling Rate from Beginning of Water Cooling After Completion of Finish Rolling to Water Cooling Stop Temperature of 650° C. to 800° C.: 45° C./Second or Faster

[0110] When the average cooling rate to a water cooling stop temperature of 650° C. to 800° C. is slower than 45° C./second, a coarse Ti-based carbide is precipitated in non-transformed austenite or in transformed ferrite grains, and it becomes difficult to obtain a desired strength. Therefore, the average cooling rate is set to 45° C./second or faster. The average cooling rate is preferably 50° C./second or faster and more preferably 55° C./second or faster. The upper limit is not particularly limited, but is preferably 300° C./second or slower from the viewpoint of the facility cost. The average cooling rate is a value obtained by dividing the amount of temperature dropped from the beginning of the water cooling after the completion of the hot rolling to the stopping of the water cooling by the required time.

Retention Time Within Temperature Range of 650° C. to 800° C.: 5 to 50 Seconds

[0111] After cooled to 650° C. to 800° C. at an average cooling rate of 45° C./second or faster, the steel sheet is caused to retain in the corresponding temperature range. When the retention time at 650° C. to 800° C. is short, since it becomes difficult to obtain a desired ferrite area fraction, the retention time needs to be five seconds or longer. The retention time is preferably seven seconds or longer. On the other hand, when the retention time is long, pearlite is formed, and the hole expandability deteriorates. Therefore, the retention time within this temperature range is set to 50 seconds or shorter. The retention time is preferably 40 seconds or shorter.

[0112] In addition, while the steel sheet is caused to retain at 650° C. to 800°, ferritic transformation progresses, and a Ti-based carbide having a semi-coherent interface is precipitated in ferrite. As the results, a steel sheet being excellent in terms of the tensile strength and the hole expandability can be obtained. When the Ti-based carbide is precipitated at a temperature higher than 800°, the Ti-based carbide is coarsely precipitated, a desired number density cannot be obtained, and it becomes difficult to obtain a desired tensile strength. On the other hand, when the Ti-based carbide is precipitated at a temperature lower than 650° C., a Ti-based carbide having a coherent

interface is precipitated, and the hole expandability deteriorates.

Average Cooling Rate Within Temperature Range of 550° C. to 650° C.: 45° C./Second or Faster

[0113] After the retention, the steel sheet is cooled to a temperature of 550° C. or lower (coiling temperature in a manner that the average cooling rate within a temperature range of 550° C. to 650° C. becomes 45° C./second or faster. When the average cooling rate is slower than 45° C./second, a Ti-based carbide having a coherent interface is precipitated during the cooling, and the hole expandability deteriorates. The upper limit of the average cooling rate is not particularly limited, but is preferably 300° C./second or slower from the viewpoint of the facility cost.

Coiling Step

Coiling Temperature: 350° C. or Higher and Lower Than 550° C.

[0114] After the cooling step, the steel sheet is coiled at 350° C. or higher and lower than 550° C. When the coiling temperature is lower than 350° C., non-transformed austenite transforms into martensite, and the hole expandability or the bending workability deteriorates. On the other hand, when the coiling temperature becomes 550° C. or higher, a Ti-based carbide having a coherent interface is formed after the coiling, and the hole expandability deteriorates. The coiling temperature is preferably 400° C. or higher and lower than 500° C.

[0115] In the present embodiment, a plated steel sheet having a plating layer may be produced by performing plating on the surface of the steel sheet after the coiling step. Even in a case where plating is performed, there is no problem in performing the plating as long as the conditions for the method for manufacturing the steel sheet according to the present embodiment are satisfied. The plating may be any of electroplating and hot-dip plating, and the plating type is also not particularly limited, but is ordinarily zinc-based plating including zinc plating and zinc alloy plating. As examples of the plated steel sheet, an electrolytic zinc-plated steel sheet, an electrolytic zinc-nickel alloy-coated steel sheet, a hot-dip galvanized steel sheet, a galvannealed steel sheet, a hot-dip zinc-aluminum alloy-coated steel sheet and the like are exemplary examples. The plating adhesion amount may be an ordinary amount. Before the plating, Ni or the like may be applied to the surface as pre-plating.

[0116] At the time of manufacturing the steel sheet according to the present embodiment, well-known temper rolling may be performed as appropriate for the purpose of shape correction.

[0117] The sheet thickness of the steel sheet according to the present embodiment is not particularly limited, but is preferably 8.0 mm or less since, in a case where the sheet thickness is too thick, microstructures formed in the surface layer and the inside of the steel sheet significantly differ. The sheet thickness is more preferably 6.0 mm or less. On the other hand, when the sheet thickness is too thin, since threading during hot rolling becomes difficult, ordinarily, the sheet thickness is preferably 1.0 mm or more. The sheet thickness is more preferably 1.2 mm or more.

EXAMPLES

[0118] Next, the effect of one aspect of the present invention will be more specifically described using examples, but conditions in the examples are simply examples of the conditions adopted to confirm the feasibility and effect of the present invention, and the present invention is not limited to these examples of the conditions. The present invention is capable of adopting a variety of conditions within the scope of the gist of the present invention as long as the object of the present invention is achieved.

[0119] Steel materials having a chemical composition (unit mass%, the remainder was Fe and impurities) shown in Table 1A and Table 1B and having a sheet thickness of 250 mm were hot-rolled under conditions shown in Table 2A and Table 2B, thereby producing hot-rolled steel sheets having a sheet thickness of 2.5 to 3.5 mm. On some of the obtained hot-rolled steel sheets, a hot-dip galvanizing treatment with an annealing temperature of 700° C. and, furthermore, an alloying treatment were performed to produce hot-dip galvanized steel sheets (GI) or galvannealed steel sheets (GA).

TABLE 1A

	(Mass%: remainder is Fe and impurities)										
Steel	C	Si	Mn	P	S	sol. Al	Ti	N	Nb	V	Mo
A	0.082	0.620	1.32	0.015	0.0020	0.06	0.310	0.0024			
B	0.062	0.052	1.35	0.010	0.0012	0.05	0.225	0.0033			
C	0.120	1.561	1.32	0.013	0.0019	0.08	0.185	0.0045			
D	0.084	0.053	1.29	0.011	0.0009	0.09	0.316	0.0039			
E	0.081	0.064	1.32	0.009	0.0026	0.05	0.297	0.0032	0.025		
F	0.088	0.111	1.42	0.010	0.0017	0.07	0.248	0.0043		0.106	
G	0.087	0.042	1.40	0.009	0.0012	0.05	0.278	0.0032			0.110
H	0.084	0.063	1.31	0.014	0.0002	0.06	0.311	0.0034			
I	0.082	0.025	1.30	0.010	0.0027	0.09	0.313	0.0037			
J	0.072	0.079	1.25	0.016	0.0020	0.03	0.302	0.0044			
K	0.076	0.368	1.35	0.010	0.0027	0.04	0.279	0.0037			
L	0.075	0.032	1.36	0.016	0.0018	0.06	0.279	0.0029			
M	0.075	0.025	1.40	0.010	0.0024	0.04	0.285	0.0030			

TABLE 1A-continued

Steel	(Mass%: remainder is Fe and impurities) C	Si	Mn	P	S	sol. Al	Ti	N	Nb	V	Mo
N	0.073	0.039	1.32	0.010	0.0019	0.08	0.291	0.0038			
O	0.075	0.025	2.56	0.012	0.0015	0.05	0.262	0.0031	0.021		
P	0.071	0.102	0.68	0.008	0.0021	0.03	0.283	0.0034			
Q	0.041	0.209	1.38	0.014	0.0017	0.07	0.256	0.0030			
R	0.052	0.498	1.26	0.016	0.0006	0.08	0.138	0.0041			
S	0.125	0.046	1.35	0.011	0.0026	0.07	0.450	0.0031			
I	0.208	0.517	1.30	0.015	0.0027	0.05	0.252	0.0039			
U	0.083	0.498	3.25	0.014	0.0030	0.06	0.301	0.0034			
V	0.091	0.045	1.32	0.011	0.0015	0.09	0.292	0.0025	0.028		
W	0.125	0.510	0.52	0.012	0.0021	0.05	0.225	0.0025	0.020	0.235	0.104
X	0.082	0.025	1.30	0.010	0.0027	0.09	0.320	0.0037			
Y	0.078	0.201	1.58	0.015	0.0032	0.36	0.251	0.0021			
Z	0.088	0.950	1.72	0.008	0.0036	0.07	0.275	0.0036			

TABLE 1B

Steel	(Mass%: remainder is Fe and impurity) Cu	Ni	Cr	W	B	Ca	Mg	REM	Bi	ex. C (T)	SRT (° C)	TR (°C)
A										0.007	1300	924
B										0.009	1245	892
C										0.078	1287	876
D										0.009	1303	927
E										0.007	1295	934
F										0.005	1286	900
G										0.007	1295	912
H	0.06	0.04								0.009	1302	925
I			0.20							0.008	1300	926
J						0.0022				0.001	1285	921
K					0.0015					0.010	1283	912
L							0.0023			0.008	1282	912
M								0.0021		0.007	1284	915
N									0.0018	0.004	1283	917
O										0.010	1276	918
P										0.004	1278	914
Q										-0.020	1220	904
R										0.021	1186	858
S										0.016	1371	978
T										0.149	1365	902
U										0.012	1298	921
V										0.017	1303	934
W										0.001	1309	903
X				0.050						0.003	1302	928
Y	0.10	0.06				0.0020			0.0015	0.018	1276	902
Z				0.101				0.0025		0.017	1295	911

TABLE 2A

Test No.	Steel	Retention time at 700° C. to 850° C. during heating (seconds)	Heating tempera-ture (°C)	Time from beginning of rough rolling to completion of finish rolling (seconds)	Total rolling reduction in temperature range of 850° C. to 1100°	Finish rolling completion temperature FT (° C)	Time from finish rolling to beginning of water cooling (seconds)
1	A	1137	1383	431	91	951	0.8
2	A	1242	1375	330	95	957	2.4
3	A	1132	1373	359	93	952	1.6
4	A	1227	1380	320	95	954	1.0
5	A	1145	1375	557	94	965	2.3
6	A	834	1385	431	95	943	1.1
7	A	1485	1228	446	95	927	0.9
8	A	1518	1380	682	95	949	1.6
9	A	1562	1373	469	83	932	1.1
10	A	1469	1380	314	94	847	0.8
11	A	1084	1380	328	93	958	4.1
12	A	1202	1376	321	93	942	0.9

TABLE 2A-continued

Test No.	Steel	Retention time at 700° C. to 850° C. during heating (seconds)	Heating tempera-ture (°C)	Time from beginning of rough rolling to completion of finish rolling (seconds)	Total rolling reduction in temperature range of 850° C. to 1100°	Finish rolling completion temperature FT (° C)	Time from finish rolling to beginning of water cooling (seconds)
13	A	1010	1365	305	93	940	1.2
14	A	989	1383	337	94	941	1.2
15	A	993	1365	342	94	951	1.3
16	B	1120	1348	418	95	902	1.3
17	C	1463	1350	322	94	905	1.1
18	D	1272	1380	353	95	977	1.3
19	E	1532	1350	308	94	982	1.4
20	F	1070	1350	418	92	918	0.9
21	G	1285	1350	402	93	922	1.3
22	H	1142	1350	390	93	953	1.4
23	I	1052	1350	261	94	939	1.2
24	J	1317	1350	355	96	953	1.2
25	K	1194	1350	317	94	931	1.3
26	L	1500	1350	263	95	936	1.4
27	M	1336	1350	344	93	933	1.3
28	N	1563	1350	378	95	944	1.6
29	O	1133	1350	281	93	937	1.5
30	P	1484	1350	408	95	946	1.2
31	Q	1310	1350	362	94	920	1.4
32	R	1148	1350	391	93	887	1.1
33	S	1102	1380	375	93	989	1.6
34	T	978	1380	276	93	923	1.3
35	U	1210	1350	301	93	956	1.8
36	V	1023	1350	305	93	964	1.5
37	W	1065	1380	318	93	952	1.8
37	X	1253	1380	400	93	942	1.2
38	Y	1546	1350	293	94	963	0.7
39	Z	1032	1350	284	92	951	0.5

TABLE 2B

Test No.	Cooling rate from beginning of water cooling after completion of finish rolling to water cooling stop temperature of 650° C. to 850° C. (°C/s)	Retention time at 650° C. to 800° C. (seconds)	Average cooling rate from 550° C. to 650° C. (°C/s)	Coiling temperature (°C)	SRT (°C)	TR (°C)
1	87	7	88	402	1300	924
2	80	18	89	450	1300	924
3	54	12	68	443	1300	924
4	75	11	69	456	1300	924
5	71	12	62	489	1300	924
6	77	12	57	415	1300	924
7	60	12	62	451	1300	924
8	56	12	56	431	1300	924
9	60	16	66	426	1300	924
10	58	16	64	476	1300	924
11	62	12	51	431	1300	924
12	12	15	80	425	1300	924
13	68	3	71	425	1300	924
14	59	14	0.1	625	1300	924
15	65	14	1	456	1300	924
16	50	12	69	482	1245	892
17	72	16	94	465	1287	876
18	57	11	66	395	1303	927
19	77	15	76	415	1295	934
20	80	13	80	426	1286	900
21	87	14	87	457	1295	912
22	88	12	77	432	1302	925
23	71	11	71	419	1300	926
24	76	18	66	427	1285	921
25	79	14	85	461	1283	912
26	81	12	68	428	1282	912
27	68	16	69	409	1284	915
28	83	15	102	428	1283	917
29	52	35	59	437	1276	918

TABLE 2B-continued

Test No.	Cooling rate from beginning of water cooling after completion of finish rolling to water cooling stop temperature of 650° C. to 850° C. (°C/s)	Retention time at 650° C. to 800° C. (seconds)	Average cooling rate from 550° C. to 650° C. (°C/s)	Coiling temperature (°C)	SRT (°C)	TR (°C)
30	59	11	79	451	1278	914
31	82	11	97	468	1220	904
32	60	13	81	456	1186	858
33	72	13	62	451	1371	978
34	74	40	66	465	1365	902
35	55	45	59	468	1298	921
36	68	14	84	410	1303	934
37	80	13	89	459	1309	903
37	85	15	92	432	1302	928
38	65	14	54	410	1276	902
39	70	16	58	489	1295	911

[0120] Regarding the obtained steel sheets (the hot-rolled steel sheets and the plated steel sheets), the microstructures at the ¼ depth positions of the sheet thicknesses from the surfaces of the steel sheets were observed, and the area fractions of individual structures, the average crystal grain diameters and average aspect ratios of the crystal grains having a bcc structure and the standard deviations of the Mn concentrations were obtained.

[0121] The area fractions of the microstructure at the ¼ depth position of the sheet thickness from the surface of the steel sheet, the average crystal grain diameter and average aspect ratio of the crystal grains having a bcc structure were obtained by the scanning electron microscopic (SEM) observation and electron back scattering diffraction (EBSD) analysis of the microstructure at the ¼ depth position of the sheet thickness from the surface of the steel sheet of a cross section of the steel sheet parallel to a rolling direction and the sheet thickness direction using an EBSD analyzer composed of a thermal field emission scanning electron microscope and an EBSD detector.

[0122] At that time, in a region that was 200 μm long in the rolling direction and 100 μm long in the sheet thickness direction and had the ¼ depth position of the sheet thickness from the surface of the steel sheet at the center, crystal orientation information was acquired at 0.2 μm intervals while differentiating fcc and bcc. Crystal grain boundaries having a crystal orientation difference of 15° or more were specified using the software attached to the EBSD analyzer ("OIM Analysis (registered trademark)" manufactured by AMETEK, Inc.). Regarding the average crystal grain diameter of bcc, the average crystal grain diameter was obtained by defining a region that was surrounded by crystal grain boundaries having a crystal orientation difference of 15° or more, was identified as bcc and had a circle equivalent diameter of 0.3 μm or more as a crystal grain.

[0123] The area fraction of ferrite was measured by the following method.

[0124] A region that was surrounded by crystal grain boundaries having a crystal orientation difference of 5° or more, was identified as bcc and had a circle equivalent diameter of 0.3 μm or more was defined as a crystal grain. Among such crystal grains, for crystal grains for which a value that was obtained by an analysis with Grain Average Misorientation analysis equipped in OIM Analysis (GAM value) was 0.6° or less, the area fraction was calculated.

[0125] The area fraction of pearlite and cementite was obtained by the point counting method with lattice spacings of 5 μm after the microstructure revealed by Nital etching in a region at the ¼ depth position of the sheet thickness from the surface of the steel sheet was observed at three visual fields using a SEM at a magnification of 1000 times. In addition, the area fraction of MA was obtained by the point counting method with lattice spacings of 5 μm after the structure revealed by LePera etching in the region at the ¼ depth position of the sheet thickness from the surface of the steel sheet was observed at two visual fields using an optical microscope at a magnification of 500 times.

[0126] While not shown in the table, the remainders of the microstructures were bainite.

[0127] The standard deviation of the Mn concentration was obtained by mirror-polishing a cross section of the steel sheet parallel to the rolling direction and the sheet thickness direction and then measuring the ¼ depth position of the sheet thickness from the surface of the steel sheet with an electron probe microanalyzer (EPMA). As the measurement conditions, the acceleration voltage was set to 15 kV, the magnification was set to 5000 times, and a distribution image in a range that was 20 μm long in the sample rolling direction and 20 μm long in the sample sheet thickness direction was measured. More specifically, the measurement intervals were set to 0.1 μm, and the Mn concentrations at 40000 or more sites were measured. Next, the standard deviation was calculated based on the Mn concentrations obtained from all of the measurement points, thereby obtaining the standard deviation of the Mn concentration.

[0128] In order to evaluate the mechanical properties of the obtained steel sheets, the tensile strengths TS (MPa) and the total elongations at fracture El (%) were measured according to JIS Z 2241: 2011. In addition, the limiting hole expansion ratios (λ) were measured according to JIS Z 2256: 2010.

[0129] The bending workability was evaluated by a 90° V bend test in which the bend radius was set to twice the sheet thickness.

[0130] Table 3A and Table 3B show the microstructures and the test results of the mechanical properties.

[0131] The tensile strength was evaluated as a high strength in a case where the tensile strength was 980 MPa or more.

[0132] The elongation was evaluated as excellent in a case where the product of the tensile strength and the total elongation at fracture (TS x El) was 14000 MPa·% or more. In addition, in a case where TS × λ was 50000 MPa·% or more, the stretch flangeability was evaluated as excellent. The bending workability was evaluated as excellent bending workability (OK) when cracking did not occur in all test pieces during the bend test performed three times and evaluated as insufficient bending workability (NG) when cracking occurred in one or more test pieces.

TABLE 3A

		Microstructure						
Test No.	Steel	Ferrite area fraction (%)	MA area fraction (%)	Pearlite and cementite area fraction (%)	Average crystal grain diameter (μm)	Average aspect ratio	Standard deviation of Mn concentration (mass %)	Coherent/semi-coherent
1	A	62	2	0	6.2	0.61	0.52	Semi-coherent
2	A	95	0	0	5.8	0.60	0.42	Semi-coherent
3	A	77	0	0	6.5	0.59	0.45	Semi-coherent
4	A	74	0	0	6.1	0.61	0.43	Semi-coherent
5	A	71	0	0	6.7	0.58	0.43	Semi-coherent
6	A	77	1	0	5.2	0.56	0.71	Semi-coherent
7	A	83	0	0	6.2	0.41	0.65	Semi-coherent
8	A	74	0	0	6.2	0.58	0.27	Semi-coherent
9	A	76	0	0	6.0	0.51	0.64	Semi-coherent
10	A	90	0	0	7.3	0.12	0.31	Semi-coherent
11	A	78	0	0	10.5	0.66	0.45	Semi-coherent
12	A	89	0	0	10.3	0.56	0.45	Semi-coherent
13	A	5	5	0	8.5	0.54	0.46	Semi-coherent
14	A	99	0	1	8.1	0.58	0.40	Coherent
15	A	84	0	0	8.6	0.58	0.42	Coherent
16	B	84	0	0	6.1	0.56	0.34	Semi-coherent
17	C	69	1	6	5.4	0.56	0.28	Semi-coherent
18	D	78	0	0	6.1	0.68	0.29	Semi-coherent
19	E	89	0	0	5.6	0.65	0.22	Semi-coherent
20	F	80	0	0	5.3	0.62	0.45	Semi-coherent
21	G	81	0	0	6.3	0.58	0.42	Semi-coherent
22	H	79	0	0	5.8	0.60	0.41	Semi-coherent
23	I	78	0	0	6.8	0.56	0.38	Semi-coherent
24	J	100	0	0	6.3	0.57	0.33	Semi-coherent
25	K	85	0	0	6.0	0.59	0.42	Semi-coherent
26	L	81	0	0	7.0	0.62	0.26	Semi-coherent
27	M	91	0	0	5.8	0.62	0.30	Semi-coherent
28	N	90	0	0	5.6	0.59	0.31	Semi-coherent
29	O	78	0	0	6.1	0.61	0.39	Semi-coherent
30	P	98	0	0	5.6	0.56	0.29	Semi-coherent
31	Q	79	0	0	4.5	0.63	0.48	Semi-coherent
32	R	90	0	0	4.2	0.62	0.42	Semi-coherent
33	S	79	0	0	7.4	0.60	0.35	Semi-coherent
34	T	66	6	9	5.4	0.63	0.46	Semi-coherent
35	U	32	4	0	5.9	0.60	0.55	Semi-coherent
36	V	85	4	0	5.8	0.54	0.47	Semi-coherent
37	W	80	1	0	6.4	0.56	0.50	Semi-coherent
37	X	90	0	0	5.4	0.52	0.35	Semi-coherent
38	Y	78	0	1	6.2	0.63	0.31	Semi-coherent
39	Z	91	0	1	6.8	0.55	0.44	Semi-coherent

TABLE 3B

	Characteristics							
Test No.	TS (MPa)	El (%)	λ (%)	TS × El (MPa·%)	TS x λ (MPa·%)	Bending workability	Plating	Note
1	1210	11.9	46	14399	55660	OK	-	Invention Example
2	1120	15.7	78	17584	87360	OK	-	Invention Example
3	1194	13.2	55	15761	65670	OK	GI	Invention Example
4	1182	13.5	53	15957	62646	OK	GA	Invention Example
5	1052	14.2	55	14938	57860	OK	-	Invention Example
6	1192	13.1	55	15615	65560	NG	-	Comparative Example
7	845	18.0	71	15210	59995	NG	-	Comparative Example
8	954	16.1	69	15359	65826	NG	-	Comparative Example
9	1180	13.2	67	15576	79060	NG	-	Comparative

TABLE 3B-continued

Test No.	Characteristics TS (MPa)	El (%)	λ (%)	TS × El (MPa·%)	TS x λ (MPa·%)	Bending workability	Plating	Note
								Example
10	1085	15.1	35	16384	37975	NG	-	Comparative Example
11	985	15.5	60	15268	59100	NG	-	Comparative Example
12	932	17.5	75	16310	69900	OK	-	Comparative Example
13	958	10.5	65	10059	62270	OK	-	Comparative Example
14	1185	14.2	28	16827	33180	OK	-	Comparative Example
15	1199	14.4	36	17266	43164	OK	-	Comparative Example
16	1008	16.3	73	16430	73584	OK	-	Invention Example
17	1025	14.2	35	14555	35875	OK	-	Comparative Example
18	1308	12.8	51	16742	66708	OK	-	Invention Example
19	1170	14.9	68	17464	79531	OK	-	Invention Example
20	1138	14.5	60	16503	68286	OK	-	Invention Example
21	1158	14.5	61	16791	70638	OK	-	Invention Example
22	1214	13.9	56	16879	68000	OK	-	Invention Example
23	1195	14.2	57	16963	68090	OK	-	Invention Example
24	1204	15.1	82	18178	98717	OK	-	Invention Example
25	1211	14.2	61	17200	73886	OK	-	Invention Example
26	1096	15.3	63	16767	69040	OK	-	Invention Example
27	1166	15.2	70	17717	81592	OK	-	Invention Example
28	1082	15.9	74	17192	80088	OK	-	Invention Example
29	1298	12.2	51	15839	66214	OK	-	Invention Example
30	1033	17.1	88	17671	90938	OK	-	Invention Example
31	865	18.2	75	15743	64875	OK	-	Comparative Example
32	825	19.2	92	15840	75900	OK	-	Comparative Example
33	942	15.0	54	14130	50868	NG	-	Comparative Example
34	1002	15.2	23	15230	23046	NG	-	Comparative Example
35	1160	11.5	45	13340	52200	OK	-	Comparative Example
36	1189	14.5	44	17241	52316	OK	-	Invention Example
37	1265	13.1	55	16572	69575	OK	-	Invention Example
37	1212	14.9	58	18059	70296	OK	-	Invention Example
38	1181	13.1	54	15471	63774	OK	-	Invention Example
39	1189	13.9	52	16527	61828	OK	-	Invention Example

[0133] As shown in Table 3A and Table 3B, in the invention examples where the requirements of the present invention were satisfied, all of TS, TS × El and the bending workability were excellent. On the other hand, in the comparative example where at least one of the requirements of the present invention was not satisfied, at least one of TS, TS × El and the bending workability was poor.

Industrial Applicability

[0134] According to the present invention, it is possible to provide a steel sheet having a high strength and being excellent in terms of elongation, stretch flangeability and bending workability. The steel sheet of the present invention is preferable as a material that is used in uses for automobiles,

home appliances, mechanical structures, construction and the like, and, in particular, when the steel sheet is used as a material for components such as inner sheet members, structural members, suspension members, and the like of automobiles, not only is a contribution made to weight reduction in vehicle bodies and improvement in impact resistance but the steel sheet is also easily worked into component shapes. Therefore, the steel sheet of the present invention makes an extreme industrial contribution.

1-5. (canceled)

6. A steel sheet comprising, as a chemical composition, by mass%:

C: 0.050% to 0.250%;
Si: 0.005% to 2.000%;
Mn: 0.10% to 3.00%;
P: 0.100% or less;
S: 0.0100% or less;
sol. Al: 0.001% to 1.00%;
Ti: 0.150% to 0.400%;
N: 0.0010% to 0.0100%;
Nb: 0% to 0.100%;
V: 0% to 1.000%;
Mo: 0% to 1.000%;
Cu: 0% to 1.00%;
Ni: 0% to 1.00%;
Cr: 0% to 2.00%;
W: 0% to 1.000%;
B: 0% to 0.0020%;
Ca: 0% to 0.0100%;
Mg: 0% to 0.0100%;
REM: 0% to 0.0100%; and
Bi: 0% to 0.0200%
with a remainder of Fe and impurities,
wherein Ex. C obtained by the following formula (1) is 0.020% or less,
a microstructure at a ¼ depth position of a sheet thickness from a surface contains 60% or more of ferrite, 0% to 5% of MA and a total of 0% to 5% of pearlite and cementite with a remainder of bainite in terms of area fractions,
in the microstructure,
an average crystal grain diameter is 10.0 μm or less,
an average aspect ratio of crystal grains is 0.30 or more,
a standard deviation of a Mn concentration is 0.60 mass% or less,
a Ti-based carbide having a Baker-Nutting orientation relationship in the ferrite is precipitated in a semi-coherent state, and
a tensile strength is 980 MPa or more,

$$\text{Ex. C} = (\%C) - 12\{(\%Ti^*)/48 + (\%V)/51 + (\%Nb)/93 + (\%Mo)/96 + (\%W)/184\} \quad \text{Formula (1)}$$

here, "%Ti*" in the formula (1) is obtained from the following formula (2),

$$\%Ti^* = \%Ti - 48 \times \{(\%N)/14 + (\%S)/32\} \quad \text{Formula (2)}$$

%C, %V, %Nb, %Mo, %W, %Ti, %N and %S in the formula (1) and the formula (2) are the amounts of C, V, Nb, Mo, W, Ti, N and S in the steel sheet by mass%.

7. The steel sheet according to claim **6**, comprising, as the chemical composition, by mass%, one or more selected from:

Nb: 0.001% to 0.100%;
V: 0.005% to 1.000%;
Mo: 0.001% to 1.000%;
Cu: 0.02% to 1.00%;
Ni: 0.02% to 1.00%;
Cr: 0.02% to 2.00%;
W: 0.02% to 1.000%;
B: 0.0001% to 0.0020%;
Ca: 0.0002% to 0.0100%;
Mg: 0.0002% to 0.0100%;
REM: 0.0002% to 0.0100%; and
Bi: 0.0001% to 0.0200%.

8. The steel sheet according to claim **6**,
wherein a plating layer is formed on a surface.

9. The steel sheet according to claim **7**,
wherein a plating layer is formed on a surface.

10. The steel sheet according to claim **8**,
wherein the plating layer is a hot-dip galvanized layer.

11. The steel sheet according to claim **9**,
wherein the plating layer is a hot-dip galvanized layer.

12. The steel sheet according to claim **10**,
wherein the hot-dip galvanized layer is a hot-dip galvannealed layer.

13. The steel sheet according to claim **11**,
wherein the hot-dip galvanized layer is a hot-dip galvannealed layer.

* * * * *