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(54) **COLD ROLLED STEEL SHEET AND METHOD FOR PRODUCING SAME**

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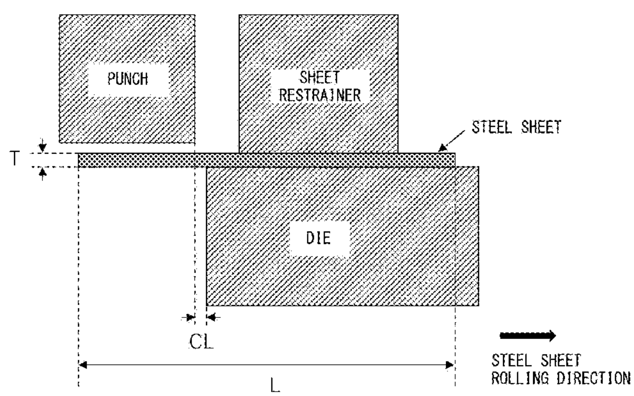
(57) **ABSTRACT**

A cold rolled steel sheet having a predetermined chemical composition, and a steel microstructure comprising, by area %, martensite: 90.0 to 99.5%, ferrite: 0 to 5%, retained austenite: 0.5 to 7.0%, and balance: bainite wherein a ratio of tempered martensite to the total martensite is 80 to 100%, a maximum value of curvature 1/R obtained by measuring the shape at a total width×length 300 mm region and expressed by the following formula (1) is 0.010 or less, and a tensile strength of 1470 MPa or more:

$$1/R = \mathrm{MAX}\{|\rho_1|, |\rho_2|\}. \quad (1)$$



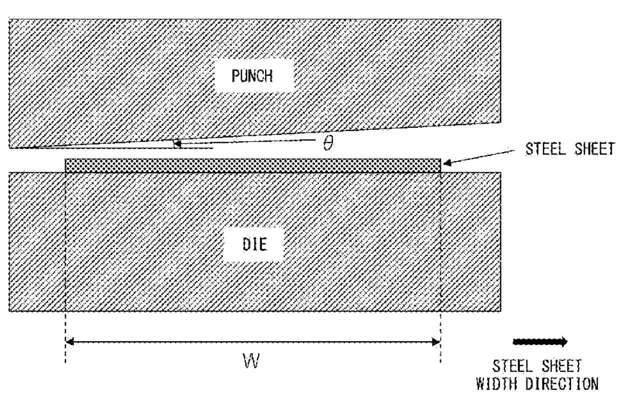
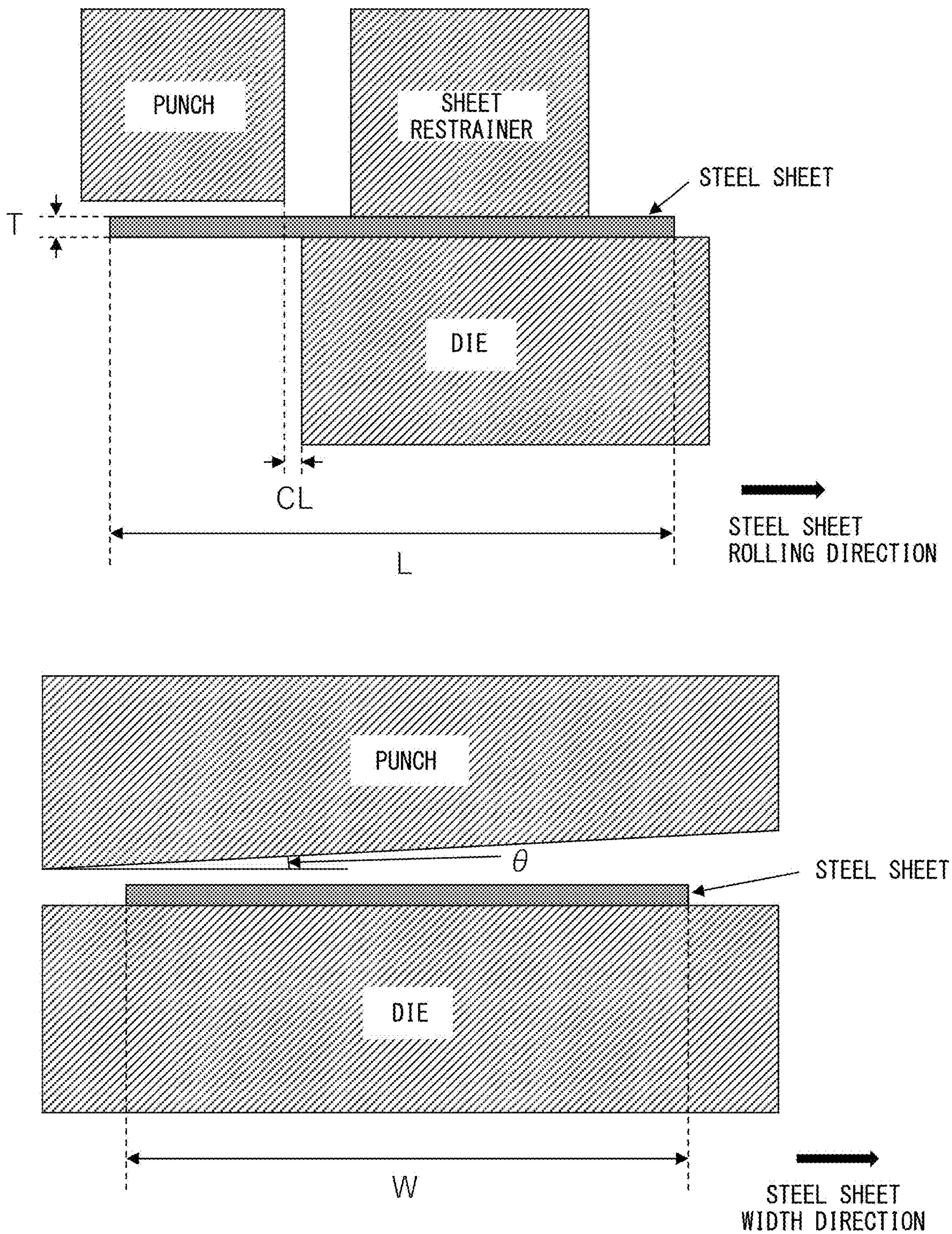


FIG. 1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COLD ROLLED STEEL SHEET AND METHOD FOR PRODUCING SAME

FIELD

[0001] The present disclosure relates to a cold rolled steel sheet and a method for producing the same.

BACKGROUND

[0002] In recent years, improvement of the fuel efficiency of automobiles has been sought from the viewpoint of regulations on hothouse effect gas emissions accompanying measures against global warming. To lighten the weight of car bodies and secure collision safety, use of high strength steel sheet is increasingly expanding. In particular, recently, the need for tensile strength 980 MPa or more ultrahigh strength steel sheet and ultrahigh strength steel sheet having further higher tensile strength has been rising. Further, high strength hot dip galvanized steel sheet having a hot dip galvanized layer at its surface is sought for portions of car bodies requiring anti-rust.

[0003] However, if applying ultrahigh strength steel sheet having such a high tensile strength as an automobile member, not only press-formability needless to say, but also a solution to the problem of hydrogen embrittlement cracking of the steel sheet is required.

[0004] "Hydrogen embrittlement cracking" is the phenomenon where a steel member to which high stress is being applied in the usage situation suddenly fractures due to the hydrogen penetrating the steel from the environment. This phenomenon is also called "delayed fracture" from the form of occurrence of the fracture. In general, it is known that hydrogen embrittlement cracking of steel sheet occurs more easier the more the tensile strength of the steel sheet rises. It is believed that this is because the stress remaining at the steel sheet after a part is shaped increases the higher the tensile strength of the steel sheet. The sensitivity to hydrogen embrittlement cracking (delayed fracture) is referred to as the "hydrogen embrittlement resistance".

[0005] Up to now, various attempts have been made to improve the hydrogen embrittlement resistance of steel sheet.

[0006] For example, PTL 1 discloses an ultrahigh strength cold rolled steel sheet having a tensile strength of 1300 MPa or more and excellent in hydrogen embrittlement resistance, wherein the ultrahigh strength cold rolled steel sheet has a predetermined chemical composition, and values of amount of dissolved B solB (mass %) in the steel and prior austenite grain size Dγ (μm) satisfying the relationship of formula (1): solB-Dγ 0.0010, and further has a steel microstructure comprising, by area ratio, polygonal ferrite in 10% or less, bainite in 30% or less, retained austenite in 6% or less, and tempered martensite in 60% or more, wherein a number density of Fe carbides in the tempered martensite is 1×10^6/mm^2 or more, an average dislocation density of the steel as a whole is 1.0×10^{15}/m^2 or more and 2.0×10^{16}/m^2 or less, and an effective crystal grain size is 7.0 μm or less.

[0007] PTL 2 discloses a cold-rolled steel sheet comprising a predetermined chemical composition, and a microstructure in which tempered martensite and bainite are contained in a total area ratio of 95% or more and 100% or less with respect to a whole volume of the microstructure, a number of inclusion groups having a total length in a rolling direction of more than 120 μm is at most 0.8/mm^2, the inclusion groups being formed by one or more inclusion particles, the one or more inclusion particles having a major axis length of 0.3 μm or more and extending and/or distributed in a dot-sequence manner along the rolling direction, and in the case of an inclusion group being formed by two or more inclusion particles, the two or more inclusion particles are spaced apart from one another by 30 μm or less, a number of carbides mainly composed of Fe that have an aspect ratio of 2.5 or less and a major axis length of 0.20 μm or more and 2 μm or less is at most 3500/mm^2, a number of carbides that are distributed in the tempered martensite and/or in the bainite and that have a diameter of 10 nm to 50 nm is at least 0.7×10^7/mm^2, and prior γ grains have a mean grain size of 18 μm or less; a sheet thickness of 0.5 mm to 2.6 mm; and a tensile strength of 1320 MPa or more. Further, PTL 2 describes that according to the above constitution, it is possible to obtain an ultrahigh strength cold rolled steel sheet excellent in hydrogen embrittlement resistance and having 1300 MPa or more tensile strength.

[0008] PTL 3 discloses an ultra-high-strength steel sheet excellent in resistance to delayed fracture at a cut end thereof, having a predetermined chemical composition, and a structure comprising, by area ratio based on a whole structure, martensite: 90% or more, and residual austenite: 0.5% or more, the ultra-high-strength steel sheet has 2% or more by area ratio of a region where a local Mn concentration is at least 1.1 times a Mn content in a whole steel sheet, and the ultra-high-strength steel sheet has a tensile strength of 1470 MPa or more.

[0009] However, in recent years, where the level of demands has become higher, further improvement in the hydrogen embrittlement resistance while maintaining a high tensile strength and total elongation has been sought. In particular, currently improvement is being sought in the hydrogen embrittlement resistance of sheared parts.

[0010] The inventors intensively tackled the improvement of the hydrogen embrittlement resistance of sheared parts and as a result obtained the following pointer. They discovered that the better the shape of the steel sheet, i.e., the flatter the steel sheet, the better the hydrogen embrittlement resistance of sheared parts. This is believed to be because if shearing steel sheet which is not flat, an angle would be given between the punch and steel sheet at the time of shearing and the damage to the sheared parts would become greater.

[0011] In relation to this, as art for improving the shape of high strength steel sheet, there are for example the following literature.

[0012] PTL 4 discloses an ultrahigh strength cold rolled steel sheet having a predetermined chemical composition, a metallographic structure of solely martensite, a tensile strength of 980 MPa or more, and a flatness of the steel sheet of 10 mm or less and a method for producing the same.

[0013] PTL 5 discloses a method for producing a high strength cold rolled steel sheet excellent in shape of the steel sheet, having a predetermined chemical composition and a metallographic microstructure containing tempered martensite in 65 area % or more, wherein the method comprises an annealing step of heating a steel material satisfying the above chemical composition in an austenite single phase region for 15 to 600 seconds to anneal it, a primary cooling step, after annealing, of gradually cooling it down to a primary cooling stop temperature at a 650 to 800° C. temperature region by an average cooling rate of 10° C./s or less (not including 0° C./s), a secondary cooling step of cooling from the primary cooling stop temperature to a secondary cooling stop temperature in a temperature region of the temperature of an Ms point calculated from the following formula (1) or more and 500° C. or less by an average cooling rate of 20 to 100° C./s, a tertiary cooling step of rapidly cooling from the secondary cooling stop temperature to room temperature by an average cooling rate of more than 100° C./s, and an overaging treatment step of heating to a 150 to 300° C. temperature region and holding for 30 to 1500 seconds, in that order.

CITATIONS LIST

Patent Literature

[0014] [PTL 1] Japanese Unexamined Patent Publication No. 2016-50343

[0015] [PTL 2] WO 2016/152163

[0016] [PTL 3] Japanese Unexamined Patent Publication No. 2016-153524

[0017] [PTL 4] Japanese Unexamined Patent Publication No. 2011-202195

[0018] [PTL 5] Japanese Unexamined Patent Publication No. 2013-227657

SUMMARY

Technical Problem

[0019] However, the arts disclosed in the above PTLs 4 and 5 did not improve the shape of the steel sheet with the intent of improving the hydrogen embrittlement resistance of sheared parts, and therefore were insufficient in improving the hydrogen embrittlement resistance of sheared parts. In the above PTLs 4 and 5, the "maximum warping height" is used as an indicator for evaluating the quality of the steel sheet shape, but it was learned that even if the "maximum warping height" were in the range of the above patent literature, the hydrogen embrittlement resistance of sheared parts was not necessarily excellent.

[0020] Therefore, the present invention has as its object the provision of a cold rolled steel sheet having high tensile strength and total elongation while being improved in hydrogen embrittlement resistance.

Solution to Problem

[0021] The inventors discovered that to improve the hydrogen embrittlement resistance of sheared parts, it is necessary to improve not the "maximum warping height" of a steel sheet, but the amount of "curvature" expressing the degree of curving of a curved surface. Further, the inventors studied the method for producing the steel sheet necessary for improving the curvature of the steel sheet and as a result obtained the following findings:

[0022] (1) In the hot rolling step, the edge parts should be reheated after rough rolling. Due to this, fluctuations in strength of the hot rolled steel sheet in the steel sheet width direction will be suppressed. Further, after finish rolling, the steel sheet should be coiled at a suitable temperature range. As a result, after cold rolling, the shape of the steel sheet will be improved.

[0023] (2) In the cold rolling step, forward tension and backward tension at the rolling stands when passing through the rolling rolls should be controlled to suitable ranges in accordance with the yield strength of the hot rolled steel sheet before cold rolling and the rolling reductions at the rolling stands. Furthermore, the cumulative cold rolling reduction should be controlled to a suitable range. Due to this, after cold rolling, the shape of the steel sheet will be improved.

[0024] (3) In the cooling treatment after heating and holding in the heat treatment step after the cold rolling step, the average cooling rate at 300° C. or less should be limited to a predetermined range, a gas should be used as the cooling medium, and, in the cooling treatment, naturally cooling should be performed to promote heat dispersion. Furthermore, the average cooling rate from 300 to 700° C. and the cooling stop temperature also have to be controlled to suitable ranges. In addition, the steel sheet tension during cooling treatment should be controlled to a suitable range. Due to this, after heat treatment, the shape of the steel sheet will be improved.

[0025] If all of the requirements of the above (1) to (3) are satisfied, a steel sheet excellent in shape to a level not able to be achieved in the existing art is obtained.

[0026] The present invention was realized based on the above findings. Specifically, it is as follows:

[0027] (1) A cold rolled steel sheet having a chemical composition comprising, by mass %,

[0028] C: 0.16 to 0.40%,

[0029] Si: 0.05 to 2.00%,

[0030] Mn: 0.50 to 4.00%,

[0031] P: 0.050% or less,

[0032] S: 0.0100% or less,

[0033] Al: 0.001 to 1.00%,

[0034] N: 0.0100% or less,

[0035] O: 0.0050% or less,

[0036] Cr: 0 to 2.00%,

[0037] Mo: 0 to 1.00%,

[0038] Cu: 0 to 1.00%,

[0039] Ni: 0 to 1.00%,

[0040] B: 0 to 0.0100%,

[0041] Co: 0 to 1.00%,

[0042] W: 0 to 1.00%,

[0043] Sn: 0 to 1.00%,

[0044] Sb: 0 to 1.00%,

[0045] Nb: 0 to 0.100%,

[0046] Ti: 0 to 0.200%,

[0047] V: 0 to 0.50%,

[0048] Ca: 0 to 0.0100%,

[0049] Mg: 0 to 0.0100%,

[0050] Ce: 0 to 0.0100%,

[0051] Zr: 0 to 0.0100%,

[0052] La: 0 to 0.0100%,

[0053] Hf: 0 to 0.0100%,

[0054] Bi 0 to 0.0100%,

[0055] REM other than Ce and La: 0 to 0.0100%, and

[0056] balance: Fe and impurities, and

[0057] a steel microstructure in a range of ⅛ thickness to ⅜ thickness centered on ¼ thickness from the surface comprising, by area %,

[0058] martensite: 90.0 to 99.5%,

[0059] ferrite: 0 to 5%,

[0060] retained austenite: 0.5 to 7.0%, and

[0061] balance: bainite,

[0062] wherein a ratio of tempered martensite to the total martensite is 80 to 100%,

[0063] a maximum value of curvature 1/R obtained by measuring the shape at a total width×length 300 mm region and expressed by the following formula (1) is 0.010 or less, and

[0064] a tensile strength is 1470 MPa or more.

[Equation 1]

$$1/R = \mathrm{MAX}\{|\rho_1|, |\rho_2|\} \tag{1}$$

[0065] where,

[0066] 1/R: curvature

[0067] ρ1 and β2: main curvatures on curved surface

[0068] (2) The cold rolled steel sheet according to the above (1), wherein the chemical composition comprises, by mass %, one or more selected from the group consisting of:

[0069] Cr: 0.001 to 2.00%,

[0070] Mo: 0.001 to 1.00%,

[0071] Cu: 0.001 to 1.00%,

[0072] Ni: 0.001 to 1.00%,

[0073] B: 0.0001 to 0.0100%,

[0074] Co: 0.001 to 1.00%,

[0075] W: 0.001 to 1.00%,

[0076] Sn: 0.001 to 1.00%,

[0077] Sb: 0.001 to 1.00%,

[0078] Nb: 0.001 to 0.100%,

[0079] Ti: 0.001 to 0.200%,

[0080] V: 0.001 to 0.50%,

[0081] Ca: 0.0001 to 0.0100%,

[0082] Mg: 0.0001 to 0.0100%,

[0083] Ce: 0.0001 to 0.0100%,

[0084] Zr: 0.0001 to 0.0100%,

[0085] La: 0.0001 to 0.0100%,

[0086] Hf: 0.0001 to 0.0100%,

[0087] Bi 0.0001 to 0.0100%, and

[0088] REM other than Ce and La: 0.0001 to 0.0100%.

[0089] (3) The cold rolled steel sheet according to the above (1) or (2), wherein no fracture occurs at sheared surfaces in a hydrogen embrittlement test of shearing the cold rolled steel sheet, then heat treating it at 170° C. for 10 minutes, and then immersing it in a concentration 0.3 g/L ammonium thiocyanate aqueous solution for 48 hours.

[0090] (4) The cold rolled steel sheet according to any one of the above (1) to (3), wherein the cold rolled steel sheet has any of an electrogalvanized layer, hot dip galvanized layer, and hot dip galvannealed layer on the surface thereof.

[0091] (5) A method for producing the cold rolled steel sheet according to any of the above (1) to (3) comprising

[0092] (A) a hot rolling step comprising rough rolling and finish rolling a slab having a chemical composition according to the above (1) or (2), wherein the hot rolling step satisfies the conditions of the following (A1) to (A3):

[0093] (A1) a slab heating temperature is 1150° C. or more,

[0094] (A2) width edge parts is heated so that a temperature of the width edge parts of the steel sheet after rough rolling is 10 to 150° C. higher than a temperature of a width center part, and

[0095] (A3) a coiling temperature is 450 to 650° C.,

[0096] (B) a cold rolling step comprising cold rolling the obtained hot rolled steel sheet using a tandem mill consisting of N number (N≥3) of rolling stands, wherein a cumulative cold rolling reduction is 30% or more, and the cold rolling step satisfies the following formulas (2) and (3):

[Equation 2]

$$\sum_{k=1}^{N}\left\{(1+R_k)^{\left|\frac{\sigma_{k-1}}{Pb_k}-\frac{\sigma_k}{Pf_k}\right|}-1\right\} < 3.0 \tag{2}$$

[Equation 3]

$$\sigma_k = (1.667\cdot\sigma_0)\cdot\varepsilon_k^{0.1} \tag{3}$$

[0097] R_k: rolling reduction at k-th rolling stand

[0098] Pb_k: backward tension at k-th rolling stand

[0099] Pf_k: forward tension at k-th rolling stand

[0100] σ_{k-1}: flow stress of steel sheet after passing k−1-th rolling stand

[0101] σ_k: flow stress of steel sheet after passing k-th rolling stand

[0102] σ_0: yield strength of hot rolled steel sheet

[0103] ε_k: cumulative strain after passing k-th rolling stand

[0104] (C) a heat treatment step comprising heat treating the obtained cold rolled steel sheet, wherein the heat treatment step satisfies the conditions of the following (C1) to (C3):

[0105] (C1) holding the cold rolled steel sheet at Ac3 to 950° C. for 10 seconds to 500 seconds (heating and holding),

[0106] (C2) performing cooling treatment satisfying the following (i) to (v):

[0107] (i) cooling stop temperature T1 is 110 to 250° C.,

[0108] (ii) average cooling rate from 300 to 700° C. is 20 to 150° C./s,

[0109] (iii) average cooling rate from T1 to 300° C. is 1.0 to 20° C./s and a gas is used as a cooling medium,

[0110] (iv) naturally cooling of 0.5 second or more each time is performed at least one time from Ms to 700° C. and from T1 to less than Ms, and

[0111] (v) tension applied to the cold rolled steel sheet is 5 to 20 MPa, and

[0112] (C3) holding from 200 to 300° C. for 100 to 1000 seconds (low temperature holding).

Advantageous Effects of Invention

[0113] According to the present invention, it is possible to provide a cold rolled steel sheet having 1470 MPa or more tensile strength and a high total elongation while being improved in hydrogen embrittlement resistance.

BRIEF DESCRIPTION OF DRAWINGS

[0114] FIG. **1** is a schematic view of shearing relating to a hydrogen embrittlement test.

DESCRIPTION OF EMBODIMENTS

"Chemical Composition"

[0115] First, the reasons for limiting the chemical composition of the steel sheet according to an embodiment of the present invention such as explained above will be explained.

In this Description, the "%" defining the chemical composition are all "mass %" unless otherwise indicated. Further, in this Description, the "to" showing a range of numerical values, unless otherwise indicated, is used in the sense including the numerical values before and after it as the upper limit value and lower limit value.

[C: 0.16 to 0.40%]

[0116] C (carbon) is an element essential for securing the steel sheet strength. To sufficiently obtain such an effect, the C content is 0.16% or more. The C content may also be 0.18% or more, 0.20% or more, or 0.22% or more. On the other hand, if excessively containing C, the press-formability and other workability and weldability and further the hydrogen embrittlement resistance will sometimes fall. For this reason, the C content is 0.40% or less. The C content may also be 0.37% or less, 0.33% or less, or 0.30% or less.

[Si: 0.05 to 2.00%]

[0117] Si (silicon) is an element suppressing the formation of iron carbides and contributing to improvement of strength and shapeability. To sufficiently obtain these effects, the Si content is 0.05% or more. The Si content may also be 0.10% or more, 0.20% or more, or 0.40% or more. On the other hand, excessive addition sometimes causes the toughness or weldability and further the hydrogen embrittlement resistance to drop. Therefore, the Si content is 2.00% or less. The Si content may also be 1.60% or less, 1.30% or less, or 1.00% or less.

[Mn: 0.50 to 4.00%]

[0118] Mn (manganese) is a powerful austenite stabilizing element and an element effective for making a steel sheet high strength. To sufficiently obtain these effects, the Mn content is 0.50% or more. The Mn content may also be 0.80% or more, 1.00% or more, or 1.30% or more. On the other hand, excessive addition sometimes causes the press-formability and other workability or weldability and further the hydrogen embrittlement resistance to drop. Therefore, the Mn content is 4.0% or less. The Mn content may also be 3.0% or less, 2.5% or less, or 2.0% or less.

[P: 0.050% or Less]

[0119] P (phosphorus) is a solution strengthening element and an element effective for making a steel sheet high strength, but excessive addition causes the weldability and toughness to deteriorate. Therefore, the P content is limited to 0.050% or less. The P content is preferably 0.045% or less, 0.035% or less, or 0.020% or less. The P content may be 0% as well, but to excessively reduce the P content, the dephosphorization cost rises, therefore from the viewpoint of economy, the lower limit is preferably 0.001%.

[S: 0.0100% or Less]

[0120] S (sulfur) is an element contained as an impurity. It forms MnS in steel to cause the toughness and hole expandability to deteriorate. Therefore, the S content is limited to 0.0100% or less as a range where deterioration of the toughness or hole expandability is not remarkable. The S content is preferably 0.0050% or less, 0.0040% or less, or 0.0030% or less. The S content may also be 0%, but to excessively reduce the S content, the desulfurization cost rises, therefore from the viewpoint of economy, the lower limit is preferably 0.0001%.

[Al: 0.001 to 1.00%]

[0121] A1 (aluminum) is added in at least 0.001% for deoxidation of the steel. The A1 content may be 0.005% or more, 0.01% or more, or 0.02% or more. On the other hand, even if excessively adding A1, the effect becomes saturated and a rise in cost is particularly invited. Not only that, this causes the transformation temperature of the steel to rise and the load at the time of hot rolling to increase and as a result sometimes causes the mechanical properties of the steel sheet to decline. Therefore, the A1 content has 1.00% as its upper limit. The A1 content may also be 0.80% or less, 0.60% or less, or 0.30% or less.

[N: 0.0100% or Less]

[0122] N (nitrogen) is an element contained as an impurity. If its content is large, coarse nitrides are formed inside the steel and sometimes the bendability or hole expandability is made to deteriorate. Therefore, the N content is limited to 0.0100% or less. The N content is preferably 0.0080% or less, 0.0060% or less, or 0.0050% or less. The N content may also be 0%, but to excessively reduce the N content, the denitridation cost rises, therefore from the viewpoint of economy, the lower limit is preferably 0.0001%.

[O: 0.0050% or Less]

[0123] O (oxygen) is an element contained as an impurity. If the content is large, coarse oxides are formed in the steel and sometimes the bendability and hole expandability are made to deteriorate. Therefore, the O content is limited to 0.0100% or less. The O content is preferably 0.0080% or less, 0.0060% or less, or 0.0050% or less. The O content may also be 0%, but from the viewpoint of the production costs, the lower limit is preferably 0.0001%.

[0124] The basic chemical composition of the cold rolled steel sheet according to an embodiment of the present invention and the slab used for its production is as explained above. Furthermore, the cold rolled steel sheet and slab may contain the following optional elements in accordance with need. The lower limit of content in the case of not including optional element is 0%.

[Cr: 0 to 2.00%, Mo: 0 to 1.00%, Cu: 0 to 1.00%, Ni: 0 to 1.00%, B: 0 to 0.0100%, Co: 0 to 1.00%, W: 0 to 1.00%, Sn: 0 to 1.00%, Sb: 0 to 1.00%, Nb: 0 to 0.100%, Ti: 0 to 0.200%, and V: 0 to 0.50%]

[0125] Cr (chrome), Mo (molybdenum), Cu (copper), Ni (nickel), B (boron), Co (cobalt), W (tungsten), Sn (tin), and Sb (antimony) are all elements raising the quenchability of steel and effective for making the steel sheet high strength. Further, Nb (niobium), Ti (titanium), and V (vanadium) are alloy carbide forming elements and elements which precipitate as fine carbides in the steel sheet to thereby contribute to making the steel sheet high strength. For this reason, one or more of these elements may be added in accordance with need. However, if excessively adding these elements, the effect becomes saturated and an increase in costs is particularly invited. Therefore, the contents are Cr: 0 to 2.00%, Mo: 0 to 1.00%, Cu: 0 to 1.00%, Ni: 0 to 1.00%, B: 0 to 0.0100%, Co: 0 to 1.00%, W: 0 to 1.00%, Sn: 0 to 1.00%, Sb: 0 to

1.00%, Nb: 0 to 0.100%, Ti: 0 to 0.200%, and V: 0 to 0.50%. The elements may also be 0.001% or more, 0.005% or more, or 0.010% or more. In particular, the B content may be 0.0001% or more or 0.0005% or more.

[Ca: 0 to 0.0100%, Mg: 0 to 0.0100%, Ce: 0 to 0.0100%, Zr: 0 to 0.0100%, La: 0 to 0.0100%, Hf: 0 to 0.0100%, Bi: 0 to 0.0100%, and REM Other Than Ce and La: 0 to 0.0100%]

[0126] Ca (calcium), Mg (magnesium), Ce (cerium), Zr (zirconium), La (lanthanum), Hf (hafnium), and a REM (rare earth element) other than Ce and La are elements contributing to the fine dispersion of steel inclusions while Bi (bismuth) is an element lightening the microsegregation of Mn, Si, and other substitution type alloy elements in the steel. These contribute to the improvement of the workability of the steel sheets, therefore one or more of these elements may be added in accordance with need. However, excessive addition triggers deterioration of the ductility. Therefore, the content is 0.0100% as an upper limit. Further, the elements may be contained in 0.0001% or more, 0.0005% or more, or 0.0010% or more.

[0127] In the cold rolled steel sheet according to an embodiment of the present invention, the balance other than the above constituents is consisting of Fe and impurities. "Impurities" are constituents, etc., entering due to various factors in the production process, such as the ore, scraps, and other such raw materials, when industrially producing a cold rolled steel sheet.

"Steel Microstructure of Cold Rolled Steel Sheet"

[0128] Next, the steel microstructure of the cold rolled steel sheet according to an embodiment of the present invention will be explained.

[Martensite: 90.0 to 99.5%, Ferrite: 0 to 5%, Retained Austenite: 0.5 to 7.0%, Bal.: Bainite, and Ratio of Tempered Martensite to Total Martensite: 80 to 100%]

[0129] The steel microstructure in a range of ⅛ thickness to ⅜ thickness centered on ¼ thickness from the surface of the cold rolled steel sheet comprises, by area %, martensite: 90.0 to 99.5%, ferrite: 0 to 5%, retained austenite: 0.5 to 7.0%, and balance: bainite and a ratio of tempered martensite to the total martensite is 80 to 100%.

[0130] By being mainly comprised of martensite (as quenched martensite+tempered martensite), the desired tensile strength can be obtained. On the other hand, if in the martensite, the as quenched martensite is large in ratio and the tempered martensite is small, the hydrogen embrittlement resistance deteriorates. Accordingly, the area ratio of the martensite is 90.0 to 99.5% and the ratio of the tempered martensite to the total martensite is 80 to 100%. The lower limit of the area ratio of the martensite is preferably 93.0% or more, more preferably 95.0% or more. The upper limit of the area ratio of the martensite may also be 99.0% or less or 98.0% or less. The lower limit of the ratio of the tempered martensite to the total martensite is preferably 85% or more, more preferably 90% or more. The upper limit of the ratio of the tempered martensite to the total martensite may be 98% or less or 95% or less.

[0131] If the ferrite is more than 5%, obtaining the desired tensile strength becomes difficult. Further, in a mainly martensite microstructure, if the soft structure ferrite is present, the microstructure becomes increasingly uneven, therefore hydrogen embrittlement cracking is promoted. Accordingly, the area ratio of ferrite is 0 to 5%. The upper limit of the area ratio of ferrite is preferably 4% or less, more preferably 2% or less, ideally 0%.

[0132] If including retained austenite in the steel microstructure, the work hardening rate rises due to the TRIP (transformation-induced plasticity) effect, therefore the ductility is improved (i.e., the total elongation becomes higher). On the other hand, if excessively including retained austenite, the hydrogen embrittlement resistance deteriorates. Accordingly, the area ratio of retained austenite is 0.5 to 7.0%. The lower limit of the area ratio of retained austenite is preferably 1.0% or more and may also be 2.0% or more. The upper limit of the area ratio of the retained austenite is preferably 6.0% or less and may also be 5.0% or less or 4.0% or less.

[0133] The steel microstructure may also contain a balance microstructure in addition to the martensite, ferrite, and retained austenite. As the balance microstructure, for example, bainite can be illustrated. As the area ratio of the balance microstructure, 0 to 9.5% is illustrated.

[Method of Measurement of Area Ratios of Structures]

[0134] The area ratios of the structures other than the retained austenite are evaluated by the SEM-EBSD method (electron beam backscatter diffraction method) and examination of an SEM secondary electron image. First, a sample is taken using as the examined surface the cross-section of sheet thickness parallel to the rolling direction of the steel sheet. The examined surface is machine polished to finish it to a mirror surface, then is electrolytically polished. Next, in one or more examined fields in a range of ⅛ thickness to ⅜ thickness centered on ¼ thickness from the surface of the steel sheet at the examined surface, an area of a total of 3000 μm^2 or more is analyzed for crystal structure and orientation by the SEM-EBSD method. For analysis of the data obtained by the EBSD method, "OIM Analysis 7.0" made by TSL is used. Further, the distance between evaluation points (steps) is 0.03 to 0.20 m. A crystal grain boundary map is obtained using as grain boundaries the boundaries where the difference in crystal orientation becomes 15 degrees or more. Next, the same sample is etched by Nital. After that, the same field as the field analyzed for crystal orientation by EBSD is captured using an FE-SEM as a secondary electron image. At this time, it is sufficient to attach a mark by a Vickers indent in advance. Finally, the crystal grain boundary map and secondary electron image are superposed. The individual crystal grains surrounded by grain boundaries of an orientation difference of 15 degrees or more are classified as structures based on the following criteria:

[0135] In the secondary electron image, crystal grains where neither substructures nor iron-based carbides are recognized and where the crystal structure is BCC are judged to be ferrite. In the secondary electron image, crystal grains where substructures are recognized and where iron-based carbides precipitate in single variants or crystal grains where iron-based carbides are not recognized are judged to be bainite. In the secondary electron image, crystal grains where cementite precipitates in a lamella form are judged to be pearlite. However, in the present invention, in principle, pearlite is not included. The balance is judged to be martensite and retained austenite. By subtracting from the area ratio of the balance the area ratio of retained austenite explained later, the area ratio of the martensite is found. In the balance, in the secondary electron image, crystal grains where substructures are recognized and where two or more iron-based carbides precipitate in multiple variants are judged to be tempered martensite.

[0136] The area ratio of the retained austenite is calculated by measurement using X-rays. That is, the part of the steel sheet from the surface down to a depth ¼ position in the sheet thickness direction is removed by mechanical polishing and chemical polishing. Further, after polishing, the sample is examined using MoKal rays as the characteristic X-rays. The structural fraction of the retained austenite is calculated from the integrated intensity ratios of the diffraction peaks of (**200**), (**211**) of the bcc phase and (**200**), (**220**), (**311**) of the fcc phase. This is deemed the area ratio of the retained austenite.

[Maximum Value of Curvature 1/R: 0.010 or Less]

[0137] In the cold rolled steel sheet according to an embodiment of the present invention, despite being high strength, for example, a 1470 MPa or more high strength, there is extremely high flatness. Due to this, for example, even when shearing the cold rolled steel sheet by a punch, the properties of the end faces of the sheared parts are extremely good. As a result, it is possible to achieve excellent hydrogen embrittlement resistance. In the present invention, the shape of the steel sheet having such a high flatness is prescribed using the maximum value of curvature 1/R corresponding to the reciprocal of the curvature radius R (mm). More specifically, the maximum value of curvature 1/R in the present invention is defined by the following formula (1) using two main curvatures ρ_1, ρ_2 on the curved surface. In an embodiment according to the present invention, the maximum value of curvature 1/R is controlled to 0.010 or less.

[Equation 4]

$$1/R = \mathrm{MAX}\{|\rho_1|, |\rho_2|\} \tag{1}$$

[0138] Here, the "curvature" in the present invention is the larger value of the absolute values of the main curvatures ρ1, ρ2 on a curved surface. The main curvatures ρ1, ρ2 are measured using a general shape measuring instrument and are evaluated from 3D geometric data with measurement noise suppressed. For example, as a typical shape measuring instrument, an ATOS 3D scanner made by GOM can be used for measurement. By measuring points on an area of a total width×300 mm length of the cold rolled steel sheet, a distribution of curvature in the cold rolled steel sheet is obtained. In the present invention, the "total width" means the length of the steel sheet in a direction vertical to the longitudinal direction of the cold rolled steel sheet (cold rolled coil). The cold rolled steel sheet according to the present invention has a maximum value of the distribution of curvature measured in this way of 0.010 or less. For example, if the cold rolled steel sheet becomes warped or wavy and the maximum value of the distribution of curvature exceeds 0.010, an angle is given between a punch and the cold rolled steel sheet at the time of shearing and the damage to the sheared parts is believed to become greater. As a result, the hydrogen embrittlement resistance of the sheared parts deteriorates. The maximum value of curvature 1/R may, for example, be 0.008 or less, 0.006 or less, 0.004 or less, or 0.002 or less. The lower limit value is not particularly limited, but the maximum value of curvature 1/R may also be, for example, 0.0005 or more, 0.0006 or more, 0.0007 or more, 0.0008 or more, 0.0009 or more, or 0.001 or more. According to an embodiment of the present invention, as explained above, despite being a 1470 MPa or more high strength, an extremely high flatness can be achieved. As specifically shown in the examples, even in the case of more than 1800 MPa extremely high tensile strength, it is possible to realize a flatness of the maximum value of curvature 1/R of 0.001. Therefore, a person skilled in the art would easily understand that, in the case of a lower tensile strength, for example, a tensile strength nearer to 1470 MPa, it would be possible to further reduce the maximum value of curvature 1/R and, for example, realize a flatness of the maximum value of curvature 1/R of 0.0005.

[0139] The measurement of the distribution of curvature is not limited to any specific conditions such as the timing of measurement, etc. For example, it may be performed on cold rolled steel sheet treated for flattening using a leveler, etc., after production or may be performed on cold rolled steel sheet right after production when no specific mechanical flattening treatment is performed. For example, in the case of a conventional cold rolled steel sheet having a 1470 MPa or more extremely high tensile strength, if just flattening the sheet by a leveler, etc., it is extremely difficult to control the maximum value of curvature 1/R explained above to 0.010 or less. In an embodiment of the present invention, a slab having a predetermined chemical composition is used, as explained in detail later, to produce the cold rolled steel sheet while suitably controlling the conditions of the hot rolling step, cold rolling step, and heat treatment step to thereby enable achievement of such a high flatness. Further, if the cold rolled steel sheet has a plated layer, since the plated layer does not particularly affect measurement of the distribution of curvature, the plated layer is not peeled off: the distribution of the curvature is measured for the cold rolled steel sheet provided with the plated layer.

[0140] Next, the mechanical properties, etc., of the cold rolled steel sheet according to an embodiment of the present invention will be explained.

[Tensile Strength (TS)]

[0141] According to the cold rolled steel sheet according to an embodiment of the present invention, it is possible to achieve excellent mechanical properties, for example, a 1470 MPa or more tensile strength (TS). The tensile strength is preferably 1490 MPa or more, more preferably 1500 MPa or more. The upper limit is not particularly limited, but, for example, the tensile strength may be 2000 MPa or less, 1900 MPa or less, or 1800 MPa or less.

[Total Elongation (El)]

[0142] According to the cold rolled steel sheet according to an embodiment of the present invention, it is possible to achieve a high total elongation (El) and more specifically possible to achieve a 6.0% or more total elongation. The total elongation is preferably 7.0% or more, more preferably 8.0% or more. The upper limit is not particularly limited, but, for example, the total elongation may be 20.0% or less or 15.0% or less. Here, the tensile strength and total elongation of the cold rolled steel sheet are measured by taking a JIS No. 5 tensile test piece from a direction perpendicular to the rolling direction of the steel sheet at room temperature (25° C.) in the atmosphere and performing a tensile test prescribed in JIS Z 2241: 2011.

[Hole Expansion Rate (λ)]

[0143] According to the cold rolled steel sheet according to an embodiment of the present invention, it is possible to achieve a high hole expandability, more specifically it is possible to achieve a 20% or more hole expansion rate (λ). The hole expansion rate is preferably 25% or more, more preferably 30% or more. The upper limit is not particularly limited, but for example the hole expansion rate may also be 80.0% or less or 70.0% or less. The hole expansion rate (λ) is measured by the "JFS T 1001: 1996 Hole Expansion Test Method" of the standard of the Japan Iron and Steel Federation.

[Evaluation by Hydrogen Embrittlement Test]

[0144] The cold rolled steel sheet according to an embodiment of the present invention is characterized by not cracking in a hydrogen embrittlement test conducted by the following method. The shearing operation is performed by the method shown in FIG. **1**. A T (thickness)×50 W (width)×50 L (length) (unit: mm) sample is taken from steel sheet so as to include a location giving the maximum value of curvature 1/R. The shear angle is 1 degree, and the clearance CL is 0.15×T. The sheet restraining pressure is at least 1 ton or more. The sample is cut by shearing, then the product side (sheet restrainer side) steel sheet is heat treated at 170° C. for 10 minutes. After that, this is immersed in a concentration 0.3 g/L ordinary temperature ammonium thiocyanate aqueous solution for 48 hours to introduce the generated hydrogen into the steel sheet. After that, the sheared surface is examined by a microscope and evaluated for the presence of cracks. The heat treatment at 170° C. for 10 minutes is modeled on the heat treatment for baking on a coating.

[Sheet Thickness]

[0145] The cold rolled steel sheet according to an embodiment of the present invention has, for example, a 0.5 to 3.0 mm sheet thickness. While not particularly limited, the sheet thickness may also be 0.6 mm or more, 0.8 mm or more, or 1.0 mm or more. Similarly, the sheet thickness may be 2.8 mm or less, 2.6 mm or less, or 2.3 mm or less.

[Sheet Width]

[0146] The cold rolled steel sheet according to an embodiment of the present invention has, for example, a 500 mm or more sheet width. While not particularly limited, the sheet width may also be 700 mm or more, 800 mm or more, or 900 mm or more. The upper limit of the sheet width is not particularly limited, but the sheet width may be 2000 mm or less, 1800 mm or less, 1600 mm or less, 1400 mm or less, 1300 mm or less, 1200 mm or less, or 1100 mm or less.

[Plated Layer]

[0147] The cold rolled steel sheet according to an embodiment of the present invention may have a plated layer on both surfaces or one surface, preferably on both surfaces. As the plated layer, an electrogalvanized layer, hot dip galvanized layer, or hot dip galvannealed layer may be typically illustrated. These galvanized layers may have any compositions known to persons skilled in the art. In addition to Zn, Al, Mg, and other additive elements may be included. Further, the amount of deposition of the plated layer is not particularly limited and may be a general amount of deposition.

<Method of Production>

[0148] Next, a method for producing the cold rolled steel sheet according to an embodiment of the present invention will be explained. The following explanation is intended to illustrate the characteristic method for producing the cold rolled steel sheet according to an embodiment of the present invention and is not intended to limit the cold rolled steel sheet to one produced by the method of production explained below.

"(A) Hot Rolling Step"

[0149] First, the hot rolling step will be explained.

[Slab Heating Temperature: 1150° C. or More]

[0150] In the hot rolling step, a slab having the same chemical composition as the chemical composition explained in relation to the cold rolled steel sheet is heated before hot rolling, then is rough rolled and finish rolled. The heating temperature of the slab has to be 1150° C. or more so as to sufficiently melt the borides, carbides, etc., 1200° C. or more is preferred. The steel slab used is preferably cast by the continuous casting method from the viewpoint of the production ability, but it may also be produced by ingot casting and thin slab casting.

[Rough Rolling]

[0151] The heated slab is rough rolled before the finish rolling. The rough rolling conditions are not particularly limited, but the operation is preferably performed at 1050° C. to give a total rolling reduction of 60% or more. If the total rolling reduction is less than 60%, the recrystallization during the hot rolling becomes insufficient, therefore sometimes this leads to an uneven microstructure of the hot rolled steel sheet. The total rolling reduction may, for example, be 90% or less.

[Heating Width Edge Parts so that Temperature of Width Edge Parts is 10 to 150° C. Higher than Temperature of Width Center Part]

[0152] The steel sheet finished being rough rolled is heated to reheat the width edge parts so that the temperature (Te) of the width edge parts is 10 to 150° C. higher than a temperature (Tc) of the width center part. By performing such reheating, it is possible to suppress fluctuations in strength of the hot rolled steel sheet in the width direction and produce the hot rolled steel sheet more uniform in strength in the width direction. For this reason, it is possible to perform uniform rolling over the entire width direction at the subsequent cold rolling step and possible to better improve the shape of the steel sheet after cold rolling. If not performing such reheating, the width edge parts become greater in subsequent cooling rate than the width center part, therefore the width edge parts harden more than the width center part. As a result, in the subsequent cold rolling step, a shape defect called a "center wave" where the width center part is stretched more than the width edge parts results. As a result, the curvature becomes worse at the final product.

On the other hand, if excessively heating the width edge parts, the width edge parts will excessively soften, therefore in the subsequent cold rolling step, a shape defect called an "edge wave" where the edge parts are stretched from the center part results. To avoid these shape defects, the edges are heated so that the temperature of the width edge parts is 10 to 150° C. higher than the temperature of the width center part. Preferably, they become higher by 20 to 100° C., more preferably 40 to 90° C. The width edge parts can be heated (reheated) by any suitable means known to persons skilled in the art. While not particularly limited, for example, the heating can be performed using an edge heater.

[Finish Rolling]

[0153] After reheating the edge parts, finish rolling is performed. The conditions for this are not particularly limited, but this is desirably performed in a range satisfying the conditions of a finish rolling entry side temperature of 950 to 1050° C., a finish rolling exit side temperature of 850 to 1000° C., and a total rolling reduction of 70 to 95%. If the finish rolling entry side temperature falls below 950° C., the finish rolling exit side temperature falls below 850° C., or the total rolling reduction exceeds 95%, the hot rolled steel sheet develops texture, therefore anisotropy sometimes appears at the final product sheet. On the other hand, if the finish rolling entry side temperature exceeds 1050° C., the finish rolling exit side temperature exceeds 1000° C., or the total rolling reduction falls below 70%, the crystal grain size of the hot rolled steel sheet coarsens and sometimes coarsening of the microstructure of the final product sheet is triggered.

[Coiling Temperature: 450 to 650° C.]

[0154] In the present method, after the finish rolling, the steel sheet can be coiled up at a 450 to 650° C. coiling temperature so as to improve the shape of the steel sheet after cold rolling. If the coiling temperature falls under 450° C., the hot rolled steel sheet becomes high strength, therefore the shape of the steel sheet after cold rolling deteriorates. On the other hand, if the coiling temperature exceeds 650° C., the cementite coarsens and undissolved cementite remains, therefore sometimes the workability is impaired.

[Pickling]

[0155] After the hot rolling, pickling is performed to remove the scale in accordance with need. The pickling method may be based on an ordinary method. Further, to correct the shape of the hot rolled coil and improve the pickling ability, before the pickling, skin pass rolling or shot blasting or other pretreatment may be performed.

"(B) Cold Rolling Step"

[0156] Next, the cold rolling step will be explained.

[Cold Rolling Using Tandem Mill Consisting of N Number (N≥3) of Rolling Stands]

[0157] In the present method, a cold rolling step comprising cold rolling the obtained hot rolled steel sheet using a tandem mill consisting of N number (N≥3) of rolling stands is performed, a cumulative cold rolling reduction is 30% or more, and the cold rolling step satisfies the following formulas (2) and (3):

[Equation 5]

$$\sum_{k=1}^{N}\left\{(1+R_k)^{\left|\frac{\sigma_{k-1}}{Pb_k}-\frac{\sigma_k}{Pf_k}\right|}-1\right\}<3.0 \tag{2}$$

[Equation 6]

$$\sigma_k=(1.667\cdot\sigma_0)\cdot\varepsilon_k^{0.1} \tag{3}$$

[0158] R_k: rolling reduction at k-th rolling stand

[0159] Pb_k: backward tension at k-th rolling stand

[0160] Pf_k: forward tension at k-th rolling stand

[0161] σ_{k-1}: flow stress of steel sheet after passing k−1-th rolling stand

[0162] σ_k: flow stress of steel sheet after passing k-th rolling stand

[0163] σ_0: yield strength of hot rolled steel sheet

[0164] ε_k: cumulative strain after passing k-th rolling stand

[0165] In the cold rolling step in the present invention, it is necessary to control the rolling reduction, the forward tension/flow stress, and the backward tension/flow stress at each of the rolling stands to satisfy the above formula (2). The forward tension and the backward tension at the rolling stands in a tandem mill are generally measured parameters. For example, as described in "Special Report No. 36: Theory and Practice of Sheet Rolling (Revised Edition), the Iron and Steel Institute of Japan, Production Technology Division, Rolling Theory Subcommittee ed., 2010, p. 264", it is possible to place a detection roll on a steel sheet during cold rolling and measure the tension from the load in the vertical direction. Further, flow stress of a steel sheet during cold rolling is given by formula (3). Here, σ_0 is the flow stress of the steel sheet before passing the first stand, i.e., the yield strength of the hot rolled steel sheet. σ_0 is obtained by obtaining a JIS No. 5 tensile test piece along the rolling direction from the width center part of the hot rolled steel sheet and performing a tensile test based on JIS Z 2241: 2011. Formula (2) means that if applying a large rolling reduction in the state with a large difference between the forward tension/flow stress and the backward tension/flow stress, the value becomes larger. To reduce formula (2), it is necessary to reduce the difference between the forward tension/flow stress and the backward tension/flow stress. By reducing the difference between the forward tension/flow stress and the backward tension/flow stress so as to satisfy formula (2), it is possible to reliably suppress the phenomenon of the steel sheet sliding with respect to the rolling rolls, the occurrence of so-called "slip", etc., and to realize stabler cold rolling. As a result, it is possible to improve the shape of the steel sheet after cold rolling.

[0166] If the left side of formula (2) becomes 3.0 or more, the shape of the steel sheet after cold rolling remarkably worsens and the curvature at the final product no longer satisfies formula (1). The smaller the left side of formula (2), the better. For example, less than 2.5 or less than 2.0 is preferable and less than 1.0 is further preferable. The lower limit is not particularly prescribed, but, for example, the left side of formula (2) may be 0.1 or more or 0.2 or more. Formula (2) is one preferable indicator for balancing well the tension and yield strength of the hot rolled steel sheet before and after the rolling stands so as to realize stable cold rolling free of slip and other rolling problems. Therefore, to realize such stable cold rolling, it is also possible to utilize another control method instead of the control method according to formula (2).

[0167] In the cold rolling step, in addition to satisfying formula (2), the cumulative cold rolling reduction being 30% or more is important in obtaining a good steel sheet shape with a high flatness. If the cumulative cold rolling reduction is less than 30%, the shape of the steel sheet after cold rolling is not sufficiently improved and as a result the curvature in the final product no longer satisfies formula (1). The cumulative cold rolling reduction may also be 40% or more or 50% or more. The upper limit is not particularly prescribed, but excessive rolling reduction causes the rolling load to become excessive and the load of the cold rolling mill increases, therefore, for example, the cumulative cold rolling reduction may be 75% or less or 70% or less.

"(C) Heat Treatment Step"

[0168] Next, the heat treatment step will be explained.

[Heating and Holding: Holding at Ac3 to 950° C. for 10 Seconds to 500 Seconds]

[0169] The obtained cold rolled steel sheet is supplied to a predetermined heat treatment in the heat treatment step. First, to sufficiently promote austenite transformation, the steel sheet is heated at Ac3° C. or more for 10 seconds or more. If the heating temperature is less than Ac3° C. or the holding time is less than 10 seconds, austenite transformation does not sufficiently proceed, therefore the desired steel microstructure comprised mainly of martensite is not obtained and sufficient strength is not obtained. On the other hand, if the heating temperature is more than 950° C. or the holding time is more than 500 seconds, the crystal grain size coarsens and an increase of the fuel costs and damage to the facilities is invited. Ac3 (° C.) is calculated by the following formula. The mass % of the elements are entered for the symbols of elements in the following formula. For elements which are not contained, 0 mass % is entered.

$$\text{Ac3}(°\text{ C.}) = 912-230.5\times\text{C}+31.6\times\text{Si}-20.4\times\text{Mn}-39.8\times\text{Cu}-18.1\times\text{Ni}-14.8\times\text{Cr}+16.8\times\text{Mo}+100.0\times\text{Al}$$

[Cooling Stop Temperature T1: 110 to 250° C.]

[0170] After heating, the steel sheet is cooled down to a range of 110 to 250° C. If T1 is below 110° C., the retained austenite falls below 0.5% by area ratio and the total elongation falls. On the other hand, if more than 250° C., the ratio of tempered martensite to the martensite becomes smaller than 80% and as a result the hydrogen embrittlement resistance falls. The cooling stop temperature may be 120° C. or more and/or may be 220° C. or less.

[Average Cooling Rate from 300 to 700° C.: 20 to 150° C./s]

[0171] By controlling the average cooling rate from 300 to 700° C. (average cooling rate 1) to a range of 20 to 150° C./s, it is possible to suppress an increase in the temperature spread inside the steel sheet, therefore it becomes possible to improve the curvature of the steel sheet. If the average cooling rate over this range is less than 20° C./s, the martensite fraction becomes lower and the desired tensile strength can no longer be obtained. On the other hand, if more than 150° C./s, the temperature spread inside the steel sheet increases and therefore the curvature of the steel sheet worsens. The "average cooling rate" in the present invention is a rate including the later explained natural cooling.

[Average Cooling Rate from T1 to 300° C.: 1.0 to 20° C./s and Cooling Medium: Gas]

[0172] By making the T1 to 300° C. average cooling rate (average cooling rate 2) 1.0 to 20° C./s and using a gas (for example, nitrogen gas) as a cooling medium for cooling relatively moderately, it is possible to suppress an increase in temperature spread inside steel sheet, therefore it becomes possible to decrease the curvature of the steel sheet. If the average cooling rate over that range is less than 1.0° C./s, the martensite fraction becomes lower and the desired tensile strength can no longer be obtained. On the other hand, if more than 20° C./s, the temperature spread inside the steel sheet increases and the steel sheet becomes worse in curvature. Further, for the cooling medium, from the viewpoint of reliably suppressing an increase in temperature spread inside the steel sheet, it is necessary to use a gas.

[Performing Natural Cooling of 0.5 Second or More at Least One Time from Ms to 700° C. and from T1 to Less than Ms]

[0173] The cooling is temporarily stopped in the ranges of Ms to 700° C. and T1 to less than Ms and natural cooling is performed for 0.5 second or more. Due to this treatment, heat conduction inside the steel sheet is promoted and unevenness of temperature inside the steel sheet is decreased to thereby reduce the curvature of the steel sheet. Ms (° C.) is calculated by the following formula. The mass % of the elements are entered for the symbols of elements in the following formula. For elements which are not contained, 0 mass % is entered.

$$\text{Ms}(°\text{ C.}) = 561-474\times\text{C}-33\times\text{Mn}-17\times\text{Cr}-21\times\text{Mo}-7.5\times\text{Si}+10\times\text{Co}$$

[Tension Applied to Cold Rolled Steel Sheet: 5 to 20 MPa]

[0174] During the above cooling step, the tension applied to the cold rolled steel sheet has to be limited to 6 to 20 MPa. By controlling the tension to such a range, it is possible to improve the flatness of the cold rolled steel sheet and possible to decrease the curvature of the finally obtained cold rolled steel sheet. On the other hand, if the tension is outside the above range, the curvature of the cold rolled steel sheet becomes worse. This tension may also be 8 MPa or more. Similarly, this tension may also be 16 MPa or less.

[Low Temperature Holding: Holding at 200 to 300° C. for 100 to 1000 Seconds]

[0175] After cooling down to the cooling stop temperature T1, the steel sheet is held at 200 to 300° C. for 100 to 1000 seconds. Due to this, it is possible to place carbon at the nontransformed austenite to obtain retained austenite. If the temperature is less than 200° C. or the holding time is less than 100 seconds, the desired amount of retained austenite is not obtained. On the other hand, if the temperature is more than 300° C. or the holding time is more than 1000 seconds, the desired steel microstructure is not obtained and as a result the desired tensile strength and total elongation are not obtained.

[0176] The cold rolled steel sheet obtained by the method for producing the cold rolled steel sheet according to an embodiment of the present invention may be post-treated by a plating step for forming a plated layer on one surface or both surfaces of the cold rolled steel sheet, etc. The plating step or other post step can be performed by an ordinary method.

EXAMPLES

[0177] Below, examples of the cold rolled steel sheet according to an embodiment of the present invention will be explained. The conditions of the examples are just illustrations employed for confirming the feasibility and effects of the present invention. The present invention is not limited to these illustrations. The present invention can employ various conditions so long as not deviating from the gist of the present invention and achieving the object of the present invention.

[0178] First, steel having each of the chemical compositions shown in Table 1 was cast to prepare a slab. The balance besides the constituents shown in Table 1 was comprised of Fe and impurities. Each of these slabs was hot rolled, including rough rolling and finish rolling, under the conditions shown in Table 2 to produce hot rolled steel sheet. The width edge parts after the rough rolling were heated (reheated) using an edge heater. Next, the hot rolled steel sheet was pickled to remove the surface scale and was cold rolled under the conditions shown in Table 2 using a tandem mill comprised of five rolling stands. After the cold rolling, the sheet thickness was 1.6 mm in each case. The sheet width was 1000 mm. Finally, the obtained cold rolled steel sheet was heat treated under the conditions shown in Table 2. The cooling at the cooling stop temperature T1 to 300° C. was performed using nitrogen gas as the cooling medium (water in Comparative Example 24) to give a predetermined average cooling rate (average cooling rate 2 in Table 2).

[0179] In the thus obtained steel sheet, a JIS No. 5 tensile test piece was taken from a direction perpendicular to the rolling direction of the steel sheet at room temperature (25° C.) in the atmosphere. A tensile test was conducted based on JIS Z 2241: 2011 to measure the tensile strength (TS) and total elongation (El). Further, a test was conducted by the "JFS T 1001: 1996 Hole Expansion Test Method" of the standard of the Japan Iron and Steel Federation to measure the hole expansion rate (λ).

[0180] The maximum value of curvature 1/R was determined in the following way: First, a just produced cold rolled steel sheet not subjected to any specific mechanical flattening treatment was measured using an ATOS 3D scanner made by GOM for points of a total width×300 mm length area to thereby obtain the distribution of curvature in the cold rolled steel sheets. Next, the larger of the absolute values of the main curvatures ρ1, ρ2 in the distribution of curvature measured in this way was determined as the maximum value of curvature 1/R.

[0181] The hydrogen embrittlement resistance was evaluated by a hydrogen embrittlement test utilizing the shear operation shown in FIG. **1**. Specifically, first, a T (thickness)×50 W (width)×50 L (length) (unit: mm) sample was taken from steel sheet so as to include a location giving the maximum value of curvature 1/R. The shear angle was 1 degree, the clearance CL was 0.15×T, and the sheet restraining pressure was 1 ton or more. The sample was cut by shearing, then the product side (sheet restrainer side) steel sheet was heat treated at 170° C. for 10 minutes. After that, this was immersed in concentration 0.3 g/L or concentration 3 g/L ordinary temperature ammonium thiocyanate aqueous solutions for 48 hours to introduce hydrogen into the steel sheet. After that, the sheared surface was examined by a microscope and evaluated for the presence of cracks. A sample with cracks observed at 0.3 g/L was evaluated as "Poor" (failing), a sample with cracks not observed at 0.3 g/L, but with cracks observed at 3 g/L was evaluated as "Good" (passing), and a sample with cracks not observed at both 0.3 g/L and 3 g/L was evaluated as "Very Good" (passing).

[0182] A case where the TS was 1470 MPa or more and the El was 6.0% or more and, further, the hydrogen embrittlement resistance was passing was evaluated as cold rolled steel sheet having a high tensile strength and total elongation while being improved in hydrogen embrittlement resistance. The results are shown in Table 3.

TABLE 1

Steel	Chemical composition (mass %), balance: iron and impurities											
type	C	Si	Mn	P	S	Al	N	O	Cr	Mo	Cu	Ni
A	0.23	0.47	1.36	0.008	0.0016	0.11	0.0028	0.0025	0.06	0.12	0.18	0.09
B	0.18	1.45	2.58	0.012	0.0008	0.02	0.0038	0.0023	0.47			
C	0.23	1.01	0.55	0.010	0.0013	0.01	0.0030	0.0015	0.46	0.31		
D	0.18	0.08	3.77	0.011	0.0005	0.02	0.0021	0.0006				
F	0.21	0.80	2.01	0.012	0.0010	0.03	0.0034	0.0023				
F	0.24	0.10	1.92	0.001	0.0016	0.01	0.0034	0.0015		0.05	0.33	
G	0.18	1.01	3.19	0.007	0.0012	0.06	0.0032	0.0028				
H	0.21	1.90	2.65	0.005	0.0016	0.11	0.0021	0.0008				
I	0.38	0.62	1.26	0.006	0.0007	0.06	0.0028	0.0023				
J	0.22	0.35	1.50	0.007	0.0014	0.06	0.0022	0.0023		0.04		
K	0.22	0.52	1.93	0.021	0.0018	0.54	0.0023	0.0010				
L	0.21	0.95	1.77	0.017	0.0015	0.04	0.0039	0.0015				
M	0.23	0.56	1.40	0.010	0.0012	0.03	0.0030	0.0010				
N	0.22	0.50	1.56	0.013	0.0019	0.04	0.0033	0.0017	0.05	0.06		
O	0.23	0.42	1.53	0.009	0.0015	0.03	0.0040	0.0015			0.20	0.12
P	0.22	0.53	1.68	0.010	0.0008	0.03	0.0031	0.0009				
Q	0.23	0.64	1.45	0.011	0.0013	0.05	0.0025	0.0020				
R	0.22	0.82	2.04	0.008	0.0009	0.02	0.0036	0.0011	0.23	0.15	0.12	0.05
S	0.20	0.12	3.02	0.010	0.0011	0.03	0.0026	0.0015				

TABLE 1-continued

T	0.25	0.01	1.82	0.007	0.0018	0.05	0.0033	0.0020
U	0.23	0.89	0.44	0.010	0.0024	0.03	0.0028	0.0021
V	0.13	0.70	2.24	0.012	0.0006	0.03	0.0025	0.0024
W	0.42	0.50	1.31	0.009	0.0004	0.06	0.0021	0.0019
X	0.18	0.32	4.23	0.016	0.0016	0.03	0.0031	0.0017
Y	0.20	2.21	1.77	0.004	0.0005	0.03	0.0033	0.0018

Steel	Chemical composition (mass %), balance: iron and impurities									Ac3	Ms
type	B	Co	W	Sn	Sb	Nb	Ti	V	Others	° C.	° C.
A	0.0020						0.022			849	400
B	0.0006						0.018			859	372
C	0.0016						0.027			879	412
D										798	351
F	0.0019	0.22					0.025			851	391
F	0.0007					0.031				809	382
G										843	363
H										881	360
I	0.0015						0.034			824	335
J	0.0018		0.26					0.18		848	404
K	0.0013			0.20	0.11		0.009			892	389
L	0.0034									862	396
M	0.0013						0.017		Ca: 0.0037, Mg: 0.0040	851	402
N	0.0014						0.019		Ce: 0.0051	850	399
O	0.0012						0.019		Hf: 0.0047, Zr: 0.0041	834	398
P	0.0016					0.011	0.020		Bi: 0.0031, La: 0.0051	847	397
Q	0.0010						0.016		REM: 0.0038	855	399
R	0.0015						0.020			841	376
S	0.0023						0.015			811	366
T	0.0016						0.015			823	382
U	0.0017						0.021			881	431
V	0.0014						0.020			861	420
W	0.0015						0.008			810	315
X										797	334
Y	0.0010						0.019			903	391

Underlines indicate outside scope of present invention.

TABLE 2

		Hot rolling step							Cold rolling step	
			Rough rolling		Finish rolling					
No.	Steel type	Slab heating temp. ° C.	Total rolling reduction %	Te − Tc ° C.	Entry side temp. ° C.	Exit side temp. ° C.	Total rolling reduction %	Coiling temp. ° C.	Cumulative cold rolling reduction	Formula (2)
1	A	1230	85	85	990	910	91	570	53	0.9
2	A	1250	85	70	980	900	90	580	53	6.0
3	A	1250	85	5	990	900	91	550	53	1.1
4	A	1240	85	60	1000	920	90	560	20	1.5
5	A	1240	85	50	990	890	91	550	53	0.6
6	A	1220	85	55	980	900	91	530	53	0.5
7	A	1230	85	80	1010	930	90	560	53	1.5
8	A	1250	85	65	980	910	91	540	53	0.4
9	A	1240	85	50	970	880	90	600	53	1.4
10	A	1240	85	90	960	890	90	520	53	1.4
11	A	1230	88	80	1000	920	87	530	53	0.9
12	A	1260	85	220	970	870	91	550	53	0.5
13	A	1220	85	60	1000	930	91	560	53	0.6
14	A	1230	85	90	980	900	91	550	53	1.3
15	A	1250	85	45	990	910	91	560	53	0.9
16	A	1240	85	40	1000	890	91	390	53	1.6
17	A	1240	85	60	970	890	91	520	53	0.9
18	A	1240	85	60	970	890	91	520	53	1.5
19	A	1250	85	55	1010	930	91	570	53	1.7
20	A	1250	85	50	980	920	91	540	53	1.1
21	A	1250	85	70	990	900	91	590	53	2.3

TABLE 2-continued

22	A	1260	85	70	970	880	91	480	53	1.0
23	A	1250	85	55	990	890	91	540	53	0.8
24	A	1250	85	85	1020	920	91	530	53	0.7
25	B	1250	85	85	1000	900	91	560	53	1.4
26	C	1260	85	90	980	910	91	530	53	0.8
27	D	1260	85	80	990	920	91	560	53	1.0
28	E	1260	85	60	980	920	91	550	53	1.1
29	F	1240	85	75	980	890	91	480	53	0.6
30	G	1240	85	70	990	900	90	590	53	1.7
31	H	1230	85	40	990	930	90	620	53	0.8
32	I	1250	85	60	980	910	91	570	53	1.1
33	J	1250	85	45	1000	920	91	580	53	1.1
34	K	1240	79	75	980	930	94	550	53	1.9
35	L	1230	85	65	990	890	91	570	40	0.9
36	M	1250	85	80	980	900	91	560	53	1.0
37	N	1250	85	50	990	910	91	570	53	1.3
38	O	1250	85	65	960	900	91	570	53	0.4
39	P	1250	85	55	980	910	91	540	53	0.9
40	Q	1230	85	70	970	920	91	530	53	1.6
41	R	1240	85	65	990	900	91	560	53	1.0
42	R	1240	85	65	990	900	91	560	53	1.0
43	S	1250	85	40	990	920	91	610	53	0.8
44	S	1250	85	40	990	920	91	610	53	0.8
45	T	1250	85	50	1000	940	91	500	53	0.4
46	U	1240	85	75	960	890	91	510	53	0.4
47	V	1240	85	85	990	900	91	550	53	1.7
48	W	1250	85	90	980	910	91	530	53	1.8
49	X	1230	85	90	990	920	91	600	40	1.5
50	Y	1250	85	90	980	900	91	540	40	1.2

	Heat treatment step									
	Heating and holding		Cooling treatment						Low temp. holding	
No.	Max. heating temp. ° C.	Holding time s	Cooling stop temp. T1 ° C.	Average cooling rate 1 ° C./s	Average cooling rate 2 ° C./s	Naturally cooling (≥Ms)	Naturally cooling (<Ms)	Tension MPa	Holding temp. ° C.	Holding time s
1	870	110	160	59	12	Yes	Yes	11	260	330
2	870	110	200	60	9	Yes	Yes	10	260	330
3	880	110	190	62	10	Yes	Yes	10	260	330
4	880	110	180	54	10	Yes	Yes	11	240	330
5	880	110	80	90	12	Yes	Yes	13	250	330
6	870	110	190	16	11	Yes	Yes	11	250	330
7	880	110	150	44	30	Yes	Yes	11	240	330
8	880	110	210	50	11	Yes	Yes	3	250	330
9	870	110	150	55	12	Yes	Yes	12	350	330
10	880	110	150	61	12	Yes	Yes	10	160	330
11	820	110	160	53	10	Yes	Yes	9	250	330
12	880	110	170	57	10	Yes	Yes	9	230	330
13	880	110	290	51	7	Yes	Yes	10	290	330
14	860	110	130	170	10	Yes	Yes	10	240	330
15	870	110	200	55	0.7	Yes	Yes	11	250	330
16	900	110	180	57	10	Yes	Yes	10	260	330
17	880	110	180	71	9	No	Yes	11	270	330
18	880	110	190	56	15	Yes	No	10	270	330
19	870	110	190	52	13	Yes	Yes	30	230	330
20	860	110	180	22	16	Yes	Yes	9	260	330
21	880	110	180	64	9	Yes	Yes	11	230	330
22	870	110	180	50	14	Yes	Yes	10	250	330
23	880	110	160	56	12	Yes	Yes	10	240	50
24	870	110	50	55	200	Yes	No	13	250	330
25	880	110	170	60	12	Yes	Yes	10	220	330
26	900	110	200	68	10	Yes	Yes	11	250	330
27	830	110	200	47	11	Yes	Yes	11	250	330
28	880	110	180	48	11	Yes	Yes	10	240	330
29	850	110	190	46	10	Yes	Yes	11	270	330
30	860	110	150	55	8	Yes	Yes	9	260	330
31	900	110	220	61	7	Yes	Yes	10	300	330
32	870	110	120	50	10	Yes	Yes	16	280	330
33	870	110	200	58	10	Yes	Yes	10	220	330
34	910	110	170	55	11	Yes	Yes	12	250	330
35	880	110	160	51	12	Yes	Yes	11	240	330
36	890	110	180	52	9	Yes	Yes	10	250	330
37	890	110	170	46	10	Yes	Yes	10	250	330

TABLE 2-continued

38	870	110	180	53	10	Yes	Yes	10	240	330
39	890	110	180	45	10	Yes	Yes	12	250	330
40	880	110	180	50	12	Yes	Yes	9	240	330
41	860	110	150	41	10	Yes	Yes	10	260	190
42	860	110	150	41	10	Yes	Yes	10	260	190
43	850	110	150	35	8	Yes	Yes	10	250	200
44	850	110	150	35	8	Yes	Yes	10	250	200
45	860	110	180	60	9	Yes	Yes	10	240	330
46	900	110	180	59	10	Yes	Yes	8	250	330
47	900	110	190	51	13	Yes	Yes	10	230	330
48	840	110	150	55	10	Yes	Yes	12	250	330
49	860	110	170	54	11	Yes	Yes	10	250	330
50	920	110	160	59	10	Yes	Yes	10	290	330

Underlines indicate outside scope of present invention.

TABLE 3

			Microstructure										
			Martensite					Mechanical properties			Curvature 1/R max.	Hydrogen	
No.	Steel type	Surface	Area %	Quenching ratio Area %	Ferrite Area %	Retained γ Area %	Bainite Area %	TS MPa	El %	λ %	value 1/mm	embrittlement resistance	Remarks
1	A	CR	96.4	95	0	3.6	0	1490	9.1	53	0.001	Very good	Inv. ex.
2	A	CR	96.1	95	0	3.9	0	1512	8.3	45	0.014	Poor	Comp. ex.
3	A	CR	95.9	95	0	4.1	0	1501	9.0	52	0.012	Poor	Comp. ex.
4	A	CR	96.0	95	0	4.0	0	1498	8.6	47	0.015	Poor	Comp. ex.
5	A	CR	99.7	95	0	0.3	0	1534	5.2	50	0.001	Very good	Comp. ex.
6	A	CR	71.8	80	16	5.2	7	1416	10.7	28	0.003	Good	Comp. ex.
7	A	CR	97.5	95	0	2.5	0	1529	8.4	55	0.013	Poor	Comp. ex.
8	A	CR	96.3	95	0	3.7	0	1507	8.6	51	0.015	Poor	Comp. ex.
9	A	CR	99.7	100	0	0.3	0	1427	5.0	68	0.001	Very good	Comp. ex.
10	A	CR	99.7	85	0	0.3	0	1568	5.8	36	0.001	Good	Comp. ex.
11	A	CR	74.0	80	21	5.0	0	1393	9.5	34	0.002	Good	Comp. ex.
12	A	CR	96.2	95	0	3.8	0	1523	9.0	49	0.013	Poor	Comp. ex.
13	A	CR	91.3	70	0	4.7	4	1473	9.7	26	0.002	Poor	Comp. ex.
14	A	CR	97.6	95	0	2.4	0	1516	7.9	61	0.016	Poor	Comp. ex.
15	A	CR	85.5	90	0	5.5	9	1447	8.8	40	0.001	Good	Comp. ex.
16	A	CR	95.2	95	0	4.8	0	1543	8.0	54	0.012	Poor	Comp. ex.
17	A	CR	95.8	95	0	4.2	0	1481	8.5	49	0.012	Poor	Comp. ex.
18	A	CR	96.3	95	0	3.7	0	1487	8.3	53	0.012	Poor	Comp. ex.
19	A	CR	95.7	95	0	4.3	0	1529	8.2	46	0.013	Poor	Comp. ex.
20	A	CR	90.5	95	4	3.5	2	1475	9.4	32	0.002	Very good	Inv. ex.
21	A	CR	96.5	95	0	3.5	0	1536	8.3	39	0.006	Good	Inv. ex.
22	A	EG	96.0	95	0	4.0	0	1508	9.0	48	0.001	Very good	Inv. ex.
23	A	CR	99.7	85	0	0.3	0	1570	5.7	50	0.002	Good	Comp. ex.
24	A	CR	99.7	100	0	0.3	0	1544	5.6	55	0.020	Poor	Comp. ex.
25	B	CR	94.3	90	0	5.7	0	1495	10.0	39	0.002	Good	Inv. ex.
26	C	CR	96.6	95	0	3.4	0	1473	8.8	64	0.001	Very good	Inv. ex.
27	D	CR	95.8	90	0	4.2	0	1521	8.5	35	0.002	Good	Inv. ex.
28	E	CR	95.8	95	0	4.2	0	1505	8.4	50	0.002	Very good	Inv. ex.
29	F	CR	98.9	95	0	1.1	0	1510	6.8	63	0.001	Very good	Inv. ex.
30	G	CR	95.0	90	0	5.0	0	1508	10.2	38	0.002	Good	Inv. ex.
31	H	CR	91.2	90	0	6.8	2	1519	11.6	35	0.002	Good	Inv. ex.
32	I	CR	95.8	95	0	4.2	0	1806	6.8	30	0.001	Good	Inv. ex.
33	J	CR	96.7	95	0	3.3	0	1478	8.0	50	0.002	Very good	Inv. ex.
34	K	CR	96.0	95	0	4.0	0	1492	8.3	54	0.001	Very good	Inv. ex.
35	L	CR	96.5	95	0	3.5	0	1550	8.5	45	0.001	Very good	Inv. ex.
36	M	CR	95.7	95	0	4.3	0	1494	8.1	60	0.001	Very good	Inv. ex.
37	N	CR	96.1	95	0	3.9	0	1497	8.8	58	0.001	Very good	Inv. ex.
38	O	CR	95.6	95	0	4.4	0	1507	8.5	51	0.001	Very good	Inv. ex.
39	P	CR	95.7	95	0	4.3	0	1503	8.3	55	0.001	Very good	Inv. ex.
40	Q	CR	95.7	95	0	4.3	0	1494	8.6	57	0.001	Very good	Inv. ex.
41	R	GA	94.9	95	0	5.1	0	1499	8.3	41	0.001	Very good	Inv. ex.
42	R	GI	94.9	95	0	5.1	0	1491	8.1	40	0.001	Very good	Inv. ex.
43	S	GA	98.8	90	0	1.2	0	1500	7.0	36	0.001	Good	Inv. ex.
44	S	GI	98.8	90	0	1.2	0	1506	7.0	33	0.001	Good	Inv. ex.
45	T	CR	99.7	95	0	0.3	0	1510	5.1	66	0.001	Very good	Comp. ex.
46	U	CR	59.5	60	26	2.5	12	1303	11.0	24	0.002	Very good	Comp. ex.
47	V	CR	98.0	95	0	2.0	0	1256	8.9	78	0.001	Very good	Comp. ex.
48	W	CR	94.4	95	0	5.6	0	1978	7.2	22	0.002	Poor	Comp. ex.

TABLE 3-continued

No.	Steel type	Surface	Microstructure: Martensite Area %	Microstructure: Martensite Quenching ratio Area %	Microstructure: Ferrite Area %	Microstructure: Retained γ Area %	Microstructure: Bainite Area %	Mechanical properties: TS MPa	Mechanical properties: El %	Mechanical properties: λ %	Curvature 1/R max. value 1/mm	Hydrogen embrittlement resistance	Remarks
49	X	CR	96.7	60	0	3.3	0	1533	7.5	25	0.001	Poor	Comp. ex.
50	Y	CR	93.9	80	0	6.1	0	1497	8.6	21	0.002	Poor	Comp. ex.

Underlines indicate outside scope of present invention.

[0183] Referring to Table 3, in Comparative Example 2, in the cold rolling step, the formula (2) was not satisfied, therefore the maximum value of curvature 1/R became higher and the hydrogen embrittlement resistance fell. In each of Comparative Examples 3 and 12, in the hot rolling step, the difference in temperature of the width edge parts and the temperature of the width center part of the steel sheet after rough rolling was not suitable, therefore the maximum value of curvature 1/R became higher and the hydrogen embrittlement resistance fell. In Comparative Example 4, in the cold rolling step, the cumulative cold rolling reduction was low, therefore the maximum value of curvature 1/R became higher and the hydrogen embrittlement resistance fell. In Comparative Example 5, in the heat treatment step, the cooling stop temperature T1 was low, therefore retained austenite was not sufficiently formed and the El fell. In Comparative Example 6, in the heat treatment step, the average cooling rate from 300 to 700° C. (average cooling rate 1) was slow, therefore martensite was not sufficiently formed and the TS fell. In Comparative Example 7, in the heat treatment step, the average cooling rate from T1 to 300° C. (average cooling rate 2) was fast, therefore the maximum value of curvature 1/R became higher and the hydrogen embrittlement resistance fell. In each of Comparative Examples 8 and 19, in the heat treatment step, the tension applied to the cold rolled steel sheet was not sufficient, therefore the maximum value of curvature 1/R became higher and the hydrogen embrittlement resistance fell. In each of Comparative Examples 9, 10, and 23, in the heat treatment step, the temperature or time of the low temperature holding operation was not suitable, therefore the desired steel microstructure was not obtained and the TS and/or El fell. In Comparative Example 11, in the heat treatment step, the heating and holding temperature was low, therefore martensite was not sufficiently formed and the TS fell.

[0184] In Comparative Example 13, in the heat treatment step, the T1 was high, therefore the ratio of the tempered martensite in the martensite became smaller and the hydrogen embrittlement resistance fell. In Comparative Example 14, in the heat treatment step, the average cooling rate 1 was fast, therefore the temperature spread in the steel sheet increased and, as a result, the maximum value of curvature 1/R became higher and the hydrogen embrittlement resistance fell. In Comparative Example 15, in the heat treatment step, the average cooling rate 2 was slow, therefore martensite was not sufficiently formed and the TS fell. In Comparative Example 16, in the hot rolling step, the coiling temperature was low, therefore it is believed that the hot rolled steel sheet became high strength. As a result, the shape of the steel sheet after cold rolling deteriorated and the hydrogen embrittlement resistance fell. In each of Comparative Examples 17 and 18, in the heat treatment step, the steel was not suitably naturally cooled from Ms to 700° C. or from T1 to less than Ms, therefore it is believed the inside of the steel sheet became uneven in temperature. As a result, the maximum value of curvature 1/R became higher and the hydrogen embrittlement resistance fell. In Comparative Example 24, in the heat treatment step, the cooling from T1 to 300° C. was performed using water as the cooling medium, therefore the average cooling rate 2 became faster. Further, the steel sheet was not suitably naturally cooled from T1 to less than Ms. As a result, the temperature spread inside the steel sheet increased, the maximum value of curvature 1/R became higher, and the hydrogen embrittlement resistance fell. In Comparative Example 45, the Si content was low, therefore retained austenite was not sufficiently formed and the El fell. In Comparative Example 46, the Mn content was low, therefore martensite was not sufficiently formed and the TS fell. In Comparative Example 47, the C content was low, therefore the TS fell. In Comparative Examples 48 to 50, the C, Mn, or Si content was high, therefore the hydrogen embrittlement resistance fell.

[0185] In contrast to this, in each of the Invention Examples 1, 20 to 22, and 25 to 44, the steel had the predetermined chemical composition and microstructure and, further, the maximum value of curvature 1/R was controlled to 0.010 or less, therefore cold rolled steel sheet having a high tensile strength and total elongation while being improved in hydrogen embrittlement resistance could be obtained.

1. A cold rolled steel sheet having a chemical composition comprising, by mass %,

C: 0.16 to 0.40%,
Si: 0.05 to 2.00%,
Mn: 0.50 to 4.00%,
P: 0.050% or less,
S: 0.0100% or less,
Al: 0.001 to 1.00%,
N: 0.0100% or less,
O: 0.0050% or less,
Cr: 0 to 2.00%,
Mo: 0 to 1.00%,
Cu: 0 to 1.00%,
Ni: 0 to 1.00%,
B: 0 to 0.0100%,
Co: 0 to 1.00%,
W: 0 to 1.00%,
Sn: 0 to 1.00%,
Sb: 0 to 1.00%,
Nb: 0 to 0.100%,

Ti: 0 to 0.200%,
V: 0 to 0.50%,
Ca: 0 to 0.0100%,
Mg: 0 to 0.0100%,
Ce: 0 to 0.0100%,
Zr: 0 to 0.0100%,
La: 0 to 0.0100%,
Hf: 0 to 0.0100%,
Bi: 0 to 0.0100%,
REM other than Ce and La: 0 to 0.0100%, and
balance: Fe and impurities, and
a steel microstructure in a range of ⅛ thickness to ⅜ thickness centered on ¼ thickness from the surface comprising, by area %,
martensite: 90.0 to 99.5%,
ferrite: 0 to 5%,
retained austenite: 0.5 to 7.0%, and
balance: bainite,
wherein a ratio of tempered martensite to the total martensite is 80 to 100%,
a maximum value of curvature 1/R obtained by measuring the shape at a total width×length 300 mm region and expressed by the following formula (1) is 0.010 or less, and
a tensile strength is 1470 MPa or more,

[Equation 1]

$$1/R = \mathrm{MAX}\{|\rho_1|, |\rho_2|\} \tag{1}$$

where,
1/R: curvature
ρ1 and ρ2: main curvatures on curved surface.

2. The cold rolled steel sheet according to claim **1**, wherein the chemical composition comprises, by mass %, one or more of:
Cr: 0.001 to 2.00%,
Mo: 0.001 to 1.00%,
Cu: 0.001 to 1.00%,
Ni: 0.001 to 1.00%,
B: 0.0001 to 0.0100%,
Co: 0.001 to 1.00%,
W: 0.001 to 1.00%,
Sn: 0.001 to 1.00%,
Sb: 0.001 to 1.00%,
Nb: 0.001 to 0.100%,
Ti: 0.001 to 0.200%,
V: 0.001 to 0.50%,
Ca: 0.0001 to 0.0100%,
Mg: 0.0001 to 0.0100%,
Ce: 0.0001 to 0.0100%,
Zr: 0.0001 to 0.0100%,
La: 0.0001 to 0.0100%,
Hf: 0.0001 to 0.0100%,
Bi: 0.0001 to 0.0100%, and
REM other than Ce and La: 0.0001 to 0.0100%.

3. The cold rolled steel sheet according to claim **1**, wherein no fracture occurs at sheared surfaces in a hydrogen embrittlement test of shearing the cold rolled steel sheet, then heat treating it at 170° C. for 10 minutes, and then immersing it in a concentration 0.3 g/L ammonium thiocyanate aqueous solution for 48 hours.

4. The cold rolled steel sheet according to claim **1**, wherein the cold rolled steel sheet has any of an electrogalvanized layer, hot dip galvanized layer, and hot dip galvannealed layer on the surface thereof.

5. A method for producing the cold rolled steel sheet according to claim **1**, comprising
(A) a hot rolling step comprising rough rolling and finish rolling a slab having a chemical composition according to claim **1**, wherein the hot rolling step satisfies the conditions of the following (A1) to (A3):
(A1) a slab heating temperature is 1150° C. or more,
(A2) width edge parts is heated so that a temperature of the width edge parts of the steel sheet after rough rolling is 10 to 150° C. higher than a temperature of a width center part, and
(A3) a coiling temperature is 450 to 650° C.,
(B) a cold rolling step comprising cold rolling the obtained hot rolled steel sheet using a tandem mill consisting of N number (N≥3) of rolling stands, wherein a cumulative cold rolling reduction is 30% or more, and the cold rolling step satisfies the following formulas (2) and (3):

[Equation 2]

$$\sum_{k=1}^{N}\left\{(1+R_k)^{\left|\frac{\sigma_{k-1}}{Pb_k}-\frac{\sigma_k}{Pf_k}\right|}-1\right\}<3.0 \tag{2}$$

[Equation 3]

$$\sigma_k = (1.667\cdot\sigma_0)\cdot\varepsilon_k^{0.1} \tag{3}$$

R_k: rolling reduction at k-th rolling stand
Pb_k: backward tension at k-th rolling stand
Pf_k: forward tension at k-th rolling stand
σ_{k-1}: flow stress of steel sheet after passing k−1-th rolling stand
σ_k: flow stress of steel sheet after passing k-th rolling stand
σ_0: yield strength of hot rolled steel sheet
ε_k: cumulative strain after passing k-th rolling stand
(C) a heat treatment step comprising heat treating the obtained cold rolled steel sheet, wherein the heat treatment step satisfies the conditions of the following (C1) to (C3):
(C1) holding the cold rolled steel sheet at Ac3 to 950° C. for 10 seconds to 500 seconds (heating and holding),
(C2) performing cooling treatment satisfying the following (i) to (v):
(i) cooling stop temperature T1 is 110 to 250° C.,
(ii) average cooling rate from 300 to 700° C. is 20 to 150° C./s,
(iii) average cooling rate from T1 to 300° C. is 1.0 to 20° C./s and a gas is used as a cooling medium,
(iv) naturally cooling of 0.5 second or more each time is performed at least one time from Ms to 700° C. and from T1 to less than Ms, and
(v) tension applied to the cold rolled steel sheet is 5 to 20 MPa, and
(C3) holding from 200 to 300° C. for 100 to 1000 seconds (low temperature holding).

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