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- **SHIBATA, Tomoaki**
Tokyo 100-0011 (JP)
- **KAMI, Chikara**
Tokyo 100-0011 (JP)

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(71) Applicant: **JFE Steel Corporation**
Tokyo, 100-0011 (JP)

(74) Representative: **Grünecker, Kinkeldey,
Stockmair & Schwanhäusser**
Leopoldstrasse 4
80802 München (DE)

(72) Inventors:

- **NAKATA, Hiroshi**
Tokyo 100-0011 (JP)

(54) **HOT ROLLED HIGH TENSILE STRENGTH STEEL SHEET AND METHOD FOR
MANUFACTURING SAME**

(57) The present invention provides a hot rolled high tensile strength steel sheet that exhibits excellent deformation characteristics after formed into pipes or tubes, without suffering local buckling when deformed by bending as steel pipes or tubes, and thus is suitable for making line pipes and oil well pipes or tubes. The steel sheet has a chemical composition containing, by mass%, C: 0.04-0.08 %, Si: 0.50 % or less, Mn: 0.8-2.2 %, P: 0.02 % or less, S: 0.006 % or less, Al: 0.1 % or less, N: 0.008

% or less, and Cr: 0.05-0.8 %, and further Nb: 0.01-0.08 %, V: 0.001-0.12 %, and Ti: 0.005-0.04 % in adjusted amounts, with the balance including Fe and incidental impurities. The steel sheet has a surface layer having a microstructure containing bainite as a main phase, martensite as a second phase in a volume fraction of 0.5-4 %, and at least one of ferrite phase, pearlite, and cementite as a third phase in a total volume fraction of 10 % or less.

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Description

TECHNICAL FIELD

[0001] The present invention relates to hot rolled high tensile strength steel sheets that are suitable for making welded steel pipes or tubes requiring high strength and high toughness, particularly, high-strength electric resistance welded steel pipes or tubes and high-strength spiral steel pipes or tubes, used as transport pipes (line pipes) or transport tubes for transporting crude oil, natural gas or the like, or as oil well pipes or tubes, and to a method for manufacturing the same. In particular, the present invention relates to hot rolled high tensile strength steel sheets exhibiting improved deformation characteristics after being molded into pipes or tubes (after pipe or tube formation).

[0002] As used herein, the term "hot rolled high tensile strength steel sheet" refers to a hot rolled steel sheet having high strength of API5L-X65 to -X80 grade.

BACKGROUND ART

[0003] In recent years, the rise in crude oil prices following the last oil crisis and increasing demand for diversified energy sources have accelerated the mining of petroleum and natural gas and the laying of pipelines in extremely cold climate areas. Additionally, with the latest trends in such pipelines, large diameter pipelines are operated at high pressure for enhancing the efficiency of transportation of natural gas and oils. For durability in high pressure operation of pipelines, it is necessary to use thick-walled steel pipes as transport pipes (line pipes), which encourages the use of steel pipes formed from thick steel plates, such as UOE steel pipes, and furthermore, steel pipes having high strength, such as API5L-X80 grade. On the other hand, there has also been a strong demand for a further reduction in pipeline construction costs and in material costs for steel pipes, which has driven the recent growth in the use, as transport pipes, of high-strength electric resistance welded steel pipes or high-strength spiral steel pipes that are formed from coil-shaped, hot rolled steel sheets (hot rolled steel strips), rather than the UOE steel pipes formed from thick steel plates.

[0004] These high-strength steel pipes or tubes are required to have both high strength and excellent low temperature toughness for preventing fracture of line pipes. To manufacture such steel pipes or tubes having both high strength and high toughness, the following measures have been taken to tailor the properties of steel sheets used as material for steel pipes or tubes: transformation toughening, which is achieved by performing accelerated cooling after hot rolling; strengthening, which is achieved by, for example, solid solution strengthening by means of precipitates of alloying elements, such as Nb, Ti, and V precipitates; and toughness improvement, which is achieved by, for example, microstructure refinement by means of controlled rolling and so on.

[0005] For example, JP 2001-207220 A (PTL 1) discloses a method for manufacturing a hot rolled steel sheet for high-strength electric resistance welded steel pipes, the method including: preparing a billet containing C, Si, Mn, and N in appropriate amounts, Si and Mn in such amounts that Mn/Si is equal to 5 to 8, and Nb in an amount of 0.01 % to 0.1 %; then subjecting the billet to rough rolling, in which the rolling reduction ratio is adjusted for each rolling temperature, and to subsequent final rolling, which is started when the temperature of a surface layer part of the billet is raised, after being cooled to a temperature of Ar₁ or lower, by recuperation or forced heating to a temperature in the range of (Ac₃ - 40 °C) to (Ac₃ + 40 °C), and in which a finisher delivery temperature is controlled to be equal to or higher than Ac₃ with a total rolling reduction ratio of 60 % or more at a temperature of 950 °C or lower, thereby obtaining a steel sheet; after completion of the finish rolling, cooling the steel sheet at 10 °C/s or higher to a temperature of 600 °C or lower; and coiling the steel sheet at temperatures in the range of 600 °C to 350 °C. PTL 1 discloses a technical solution that may produce a high-strength electric resistance welded steel pipe or tube having excellent low-temperature toughness by refining microstructures in a surface layer of the steel sheet without adding expensive alloying elements or applying heat treatment to the entire steel pipe or tube. The technique disclosed in PTL 1, however, falls short in its ability to cool a steel plate which has a large sheet thickness, and thus cannot ensure a desired cooling rate. Accordingly, a further improvement in its cooling ability is still needed.

[0006] On the other hand, as pipelines have recently been laid in more diversified environments, some pipelines show, after being laid, non-negligible bending deformation due to ground deformation, ocean currents and the like, resulting in design flaws in the construction of pipelines.

[0007] To address these issues, for example, JP 2006-144037 A (PTL 2) discloses a high-strength steel pipe for pipelines exhibiting excellent post-aging deformation characteristics, which is obtained by welding steel sheets, each containing C: 0.02 % to 0.09 %, Si: 0.001 % to 0.8 %, Mn: 0.5 % to 2.5 %, Ti: 0.005 % to 0.03 %, Nb: 0.005 % to 0.3 %, Al: 0.001 % to 0.1 %, N: 0.001 % to 0.008 %, and two or more of Ni: 0.1 % to 1.0 %, Cu: 0.1 % to 1.0 %, and Mo: 0.05 % to 0.6 % provided that the condition of (Ni + Cu) - Mo > 0.5 is satisfied, a mixed structure of ferrite having an area ratio of 50 % or less and an average grain size of 15 μm or less and the balance being martensite and/or bainite. According to PTL 2, this steel pipe is a high-strength steel pipe of strength grade of X-70 to X-100 that exhibits a uniform elongation of 5 % or more after being heated at 200 °C to 300 °C and has excellent post-aging deformation characteristics.

The technique disclosed in PTL 2 has a problem with weldability, however, because it is necessary to contain relatively large amounts of alloying elements, such as Ni, which is expensive, and Cu, which may cause liquid phase embrittlement during hot rolling.

[0008] Recently, the reel barge method has been widely used for the laying of submarine line pipes. The reel barge method involves: performing, in advance on shore, circumferential welding, testing, painting, and other processes necessary for making an elongated pipe; reeling the pipe onto an off-shore barge; and laying the pipe on a target ocean floor while reeling it in the water behind the barge. In the reel barge method, however, tension and compression stresses are exerted on some parts of the pipe when the pipe is bent back and forth for reeling and laying on the ocean floor. This causes local buckling of the pipe, at which the fracture of the pipe may begin.

[0009] To address this issues, for example, JP H03-211255 A (PTL 3) discloses an electric resistance welded steel pipe or tube having an yield ratio of 85 % or less, a reduced area softened by welding, and excellent properties for reel barge laying, which is obtained by having a controlled composition containing C: 0.03 % to 0.20 %, Si: 0.05 % to 0.50 %, Mn: 0.50 % to 1.5 %, Al: 0.005 % to 0.060%, Nb + V + Ti equal to 0.04 % or less, a carbon equivalent Ceq of 0.20 % to 0.35 %, and a weld cracking parameter Pcm of 0.25 % or less. According to the technical solution disclosed in PTL 3, it is possible to prevent local buckling from occurring in the pipe when pipeline laying is conducted using the reel barge method.

[0010] In addition, JP 2006-122932 A (PTL 4) discloses a method for manufacturing an electric resistance welded steel pipe or tube, the method including: applying an average strain of 15 % or less in the sheet thickness direction to a steel strip before being molded into pipe or tube molding, the steel strip having a composition containing C: 0.1 % or less and Mn: 2.3 % or less, to thereby prevent local buckling during pipe laying.

CITATION LIST

Patent Literature

[0011]

PTL 1: JP 2001-207220 A

PTL 2: JP 2006-144037 A

PTL 3: JP H03-211255 A

PTL 4: JP 2006-122932 A

SUMMARY OF INVENTION

(Technical Problem)

[0012] In the technical solution disclosed in PTL 3, however, it is necessary to increase the content of C for reliably ensuring high strength of X65 grade and above, with the result that a required toughness cannot be obtained. On the other hand, the technical solution disclosed in PTL 4 needs to apply strain to the steel strip, which necessitates a large facility for introducing strain.

[0013] In addition, an anti-corrosion paint is usually applied to the surfaces of a line pipe. Additionally, to bake the paint, the line pipe is subjected to paint baking treatment in which the line pipe is heated at temperatures in the range of 200 °C to 300 °C. Accordingly, the steel pipes or tubes to which strain has been introduced during the pipe or tube formation may exhibit such deformation characteristics that cause the steel pipes or tubes to be hardened by strain aging, to show an increased yield strength, and to show a yield point elongation. Steel pipes or tubes having such deformation characteristics will suffer local buckling upon application of bending deformation, thereby causing fracture of the pipes or tubes.

[0014] An object of the present invention is thus to provide a hot rolled high tensile strength steel sheet that has high strength of API5L-X65 to -X80 grade, that has high toughness with a fracture appearance transition temperature vTrs of -80 °C or lower in the Charpy impact test, that has so excellent deformation characteristics as to exhibit a uniform elongation of 10 % or more in a surface layer of the steel sheet and in a middle portion in the sheet thickness direction of the steel sheet, that exhibits superior deformation characteristics after pipe or tube formation, to thereby solve the aforementioned problems in the conventional art.

[0015] As used herein, the phrase "excellent deformation characteristics after pipe or tube formation" means that the steel sheet has such deformation characteristics that

- the steel sheet exhibits, at its surface layer part, a uniform elongation of 10 % or more in a tensile test in accordance with the JIS Z 2241 standard using a JIS No. 5 test piece (GL: 50 mm),

- the steel sheet has so low paint bake hardenability that the steel sheet has a degree of paint bake hardening ΔYS of 40 MPa or less after being applied with a tensile strain of 2 % as prestrain and being subsequently heated at 250 °C for 60 min by paint bake hardening, and
- the steel sheet may prevent the resulting pipe or tube from exhibiting a reduced yield elongation after being subjected to pipe or tube formation and paint baking treatment so that the pipe or tube suffers less local buckling when deformed by bending.

(Solution to Problem)

[0016] To achieve the aforementioned object, the present inventors made intensive studies on various factors affecting the deformation characteristics of a pipe or tube, in particular, the occurrence of yield point elongation, after the pipe or tube being subjected to the paint baking treatment.

[0017] As a result, the inventors have found that a steel sheet may be adapted to contain Cr, Nb, Ti, and V as essential elements with the total content of Nb, Ti, and V adjusted in a suitable range; to thereby

- exhibit so high deformability that offers a uniform elongation of 10 % or more at a surface layer part of the steel sheet, which is achieved by having a microstructure at the surface layer part containing bainite as a main phase and martensite as a second phase in a small amount;
- have a degree of paint bake hardening ΔYS , which is given by $\{(\text{yield stress after paint baking treatment}) - (\text{deformation stress after application of prestrain})\}$, as low as 40 MPa or less after being applied with 2 % prestrain and subsequently heated at 250 °C for 60 min by heat treatment (paint baking treatment); and
- exhibit a reduced yield point elongation after the paint baking treatment.

[0018] Based on these findings and further considerations, the present invention has been accomplished. The primary features of the present invention are described below.

[1] A hot rolled high tensile strength steel sheet, comprising a chemical composition containing, by mass%,
 C: 0.04 % to 0.08 %,
 Si: 0.50 % or less,
 Mn: 0.8 % to 2.2 %,
 P: 0.02 % or less,
 S: 0.006 % or less,
 Al: 0.1 % or less,
 N: 0.008 % or less, and
 Cr: 0.05 % to 0.8 %

the chemical composition further containing Nb: 0.01 % to 0.08 %, V: 0.001 % to 0.12 %, and Ti: 0.005 % to 0.04 %, the contents of Nb, V, and Ti being adjusted so as to satisfy Formula (1) below, the chemical composition further containing the balance including Fe and incidental impurities, in which the steel sheet has a surface layer having a microstructure containing bainite as a main phase, martensite as a second phase in a volume fraction of 0.5 % to 4 %, and at least one of ferrite phase, pearlite, cementite as a third phase in a total volume fraction of 10 % or less:

$$0.05 \leq Nb + V + Ti \leq 0.20$$

Formula (1)

where Nb, V, and Ti each represent the content (mass%) of niobium, vanadium, and titanium in steel, respectively.

[2] The hot rolled high tensile strength steel sheet according to the aspect [1], in which the steel sheet has a middle portion in the sheet thickness direction, the middle portion having a microstructure containing bainite as a main phase, martensite as a second phase in a volume fraction of 0.5 % to 4 %, and at least one of ferrite phase, pearlite, and cementite as a third phase in a total volume fraction of 20 % or less, the middle portion exhibiting a uniform elongation of 10 % or more.

[3] The hot rolled high tensile strength steel sheet according to the aspect [1] or [2], in which the chemical composition further contains, by mass%, at least one of Mo: 0.3 % or less, Cu: 0.5 % or less, Ni: 0.5 % or less, and B: 0.001 % or less.

[4] The hot rolled high tensile strength steel sheet according to any one of the aspects [1] to [3], in which the chemical composition further contains, by mass%, at least one of Zr: 0.04 % or less and Ta: 0.07 % or less.

[5] The hot rolled high tensile strength steel sheet according to any one of the aspects [1] to [4], in which the chemical composition further contains, by mass%, at least one of Ca: 0.005 % or less and REM: 0.005 % or less.

[6] A method for manufacturing a hot rolled high tensile strength steel sheet, the method comprising: heating a steel material; then subjecting the steel material to hot rolling to obtain a hot rolled sheet; subjecting, immediately after the hot rolling, the hot rolled sheet to accelerated cooling; and then coiling the sheet at a coiling temperature, the steel material comprising a chemical composition containing, by mass%,

C: 0.04 % to 0.08 %,

Si: 0.50 % or less,

Mn: 0.8 % to 2.2 %,

P: 0.02 % or less,

S: 0.006 % or less,

Al: 0.1 % or less,

N: 0.008 % or less, and

Cr: 0.05 % to 0.8 %,

the chemical composition further containing Nb: 0.01 % to 0.08 %, V: 0.001 % to 0.12 %, and Ti: 0.005 % to 0.04 %, the contents of Nb, V, and Ti being adjusted so as to satisfy Formula (1) below, the chemical composition further containing the balance including Fe and incidental impurities,

in which the heating of the steel material is performed to heat the steel material to temperatures in a range of 1100 °C to 1250 °C,

in which a cumulative rolling reduction ratio in a temperature range of 930 °C or lower is set to be 50 % or more and a finisher delivery temperature is set to be 760 °C or higher during finish rolling in the hot rolling,

in which the accelerated cooling is adapted to start cooling, immediately after completion of the finish rolling, at an average cooling rate CR of 7 °C/s to 50 °C/s and to stop the cooling at a cooling stop temperature in a temperature range of 550 °C or higher to a temperature SCT + 30 °C, the SCT being defined by Formula (2) below,

in which the sheet is allowed to cool or gradually cooled during a period of time after the accelerated cooling is stopped and before the coiling is started, so that the sheet is retained at temperatures in a temperature range of (SCT - 20 °C) to (SCT + 30 °C) for 10 seconds to 60 seconds, and

in which the coiling temperature is set in a range of 430 °C or higher to (SCT - 50 °C)

$$0.05 \leq \text{Nb} + \text{V} + \text{Ti} \leq 0.20$$

Formula (1)

where Nb, V, and Ti each represent the content (mass%) of niobium, vanadium, and titanium in steel, respectively,

$$\text{SCT (}^{\circ}\text{C)} = 750 - 270\text{C} - 90\text{Mn} + 4\text{Si} (25 - \text{CR}) - 80\text{Mo} - 30 (\text{Cu} + \text{Ni})$$

Formula (2)

where C, Mn, Si, Mo, Cu, and Ni each represent the content (mass%) of carbon, manganese, silicon, molybdenum, copper, and nickel in steel, and

CR is an average cooling rate (°C/s) during the accelerated cooling.

[7] The method for manufacturing a hot rolled high tensile strength steel sheet according to the aspect [6], in which the chemical composition further contains at least one of Mo: 0.3 % or less, Cu: 0.5 % or less, Ni: 0.5 % or less, and B: 0.001 % or less.

[8] The method for manufacturing a hot rolled high tensile strength steel sheet according to the aspect [6] or [7], in which the chemical composition further contains, by mass%, at least one of Zr: 0.04 % or less and Ta: 0.07 % or less.

[9] The method for manufacturing a hot rolled high tensile strength steel sheet according to any one of the aspects [6] to [8], in which the chemical composition further contains, by mass%, at least one of Ca: 0.005 % or less and REM: 0.005 % or less.

(Advantageous Effect of Invention)

[0019] According to the present invention, it is possible to manufacture a hot rolled high tensile strength steel sheets at low cost that will not suffer local buckling when deformed by bending as the resulting steel pipes or tubes, that exhibit excellent deformation characteristics after pipe or tube formation, and that are suitable for making line pipes and oil well pipes or tubes. Therefore, the present invention has a significantly advantageous effect in industrial terms.

DESCRIPTION OF EMBODIMENTS

[0020] A hot rolled high tensile strength steel sheet according to the present invention is a hot rolled steel sheet, from which such steel pipes or tubes may be manufactured that have high strength of API5L-X65 to -X80 grade, that are suitable for making line pipes and oil well pipes or tubes, and that exhibit excellent deformation characteristics after being molded into pipes or tubes (after pipe or tube formation).

[0021] The reasons for limitations to the chemical composition of the high tensile strength steel sheet according to the present invention will now be described. Mass percentage (mass%) will be simply noted as % hereinafter, unless otherwise specified herein.

C: 0.04 % to 0.08 %

[0022] Carbon (C) is an element that acts to increase the strength of steel. In the present invention, C needs to be contained by 0.04 % or more in steel to ensure a desired strength thereof. However, a C content exceeding 0.08 % reduces the toughness of the base material and the toughness of a heat-affected zone. Accordingly, the content of C is limited in the range of 0.04 % to 0.08 %, and preferably in the range of 0.05 % to 0.07 %.

Si: 0.50 % or less

[0023] Silicon (Si) is an element that acts as a deoxidizer. Such an effect is observed when the content of Si is 0.01 % or more. In addition, Si forms an oxide containing Si during electric resistance welding, which leads to a degradation in the quality of welded parts and a reduction in the toughness of a heat-affected zone. From this perspective, the content of Si is desirably minimized, although up to 0.50 % of Si is acceptable. Therefore, the content of Si is limited to 0.50 % or less, and preferably to 0.40 % or less.

Mn: 0.8 % to 2.2 %

[0024] Manganese (Mn) is an element that improves the quench hardenability of the steel sheet, which contributes to an increase in the strength of the steel sheet. In addition, Mn forms MnS to fix S, thereby preventing the grain boundary segregation of S and suppressing the cracking of a slab. The content of Mn needs to be at least 0.8 % to attain such an effect. However, an excessive Mn content over 2.2 % tends to incur segregation during coagulation, with the result that Mn-concentrated portions remain in the steel sheet and separation occurs more frequently. Accordingly, the content of Mn is limited in the range of 0.8 % to 2.2 %, and preferably in the range of 0.9 % to 2.1 %.

P: 0.02 % or less

[0025] Phosphorus (P) is an element that acts to increase the strength of steel, but shows a marked tendency to segregate and reduces the toughness of steel. Thus, the content of P is desirably minimized in the present invention, although up to 0.02 % of P is acceptable. Therefore, the content of P is limited to 0.02 % or less, and preferably to 0.016 % or less.

S: 0.006 % or less

[0026] Sulfur (S) is an element that exists primarily as an inclusion (a sulfide) in steel and has an adverse effect on the ductility and toughness of steel. Thus, the content of S is desirably minimized in the present invention, although up to 0.006 % of S is acceptable. Therefore, the content of S is limited to 0.006 % or less, and preferably to 0.004 % or less.

Al: 0.1 % or less

[0027] Aluminum (Al) is an element that acts as a deoxidizer. To attain this effect, the content of Al is desirably 0.001 % or more. However, an Al content exceeding 0.1 % greatly compromises the cleanliness of welded portions during electric resistance welding. Therefore, the content of Al is limited to 0.1 % or less.

N: 0.008 % or less

[0028] Nitrogen (N) is an element that is incidentally contained in steel. However, if contained excessively in steel, N causes frequent cracking of a slab during casting. In addition, solute N induces aging and causes an increase in yield strength (paint bake hardening) during paint baking treatment. Accordingly, the content of N is desirably minimized.

Therefore, the content of N is limited to 0.008 % or less,

Cr: 0.05 % to 0.8 %

[0029] Chromium (Cr) is an element that acts to improve the quench hardenability of the steel sheet, to increase the strength thereof, and to suppress the occurrence of yield point elongation after paint bake treatment. To attain this effect, the content of Cr needs to be at least 0.05 %. However, an excessive Cr content over 0.8 % unnecessarily increases the strength of the steel sheet, leading to a reduction in the ductility and toughness. Accordingly, the content of Cr is limited in the range of 0.05 % to 0.8 %, and preferably in the range of 0.3 % to 0.5 %.

Nb: 0.01 % to 0.08 %

[0030] Niobium (Nb) is an element that acts to inhibit the grain boundary migration of austenite and suppress the coarsening and recrystallization of austenite grains. Nb also forms fine precipitates in the form of carbonitrides, to thereby act to increase the strength of the hot rolled steel sheet even at a small content of Nb, without compromising the weldability. Nb also acts to fix C and N, thereby reducing the degree of hardening during paint bake treatment. To attain this effect, the content of Nb needs to be at least 0.01 %. However, an excessive Nb content over 0.08 % unnecessarily increases the strength of the steel sheet, leading to a reduction in the ductility and toughness. Accordingly, the content of Nb is limited in the range of 0.01 % to 0.08 %, and preferably in the range of 0.02 % to 0.07 %.

V: 0.001 % to 0.12 %

[0031] Vanadium (V) is an element that forms fine precipitates in the form of carbonitrides, to thereby act to increase the strength of the steel sheet. V also acts to fix C and N, thereby suppressing the occurrence of yield point elongation after paint bake treatment and improving the deformation characteristics after pipe or tube formation. To attain this effect, the content of V needs to be at least 0.001 %. However, an excessive V content over 0.12 % unnecessarily increases the strength of the steel sheet, leading to a reduction in the ductility and toughness. Accordingly, the content of V is limited in the range of 0.001 % to 0.12 %, and preferably in the range of 0.001 % to 0.08 %.

Ti: 0.005 % to 0.04 %

[0032] Titanium (Ti) is an element that forms fine precipitates in the form of carbonitrides, to thereby act to increase the strength of the steel sheet. Ti also acts to fix C and N, thereby suppressing the occurrence of yield point elongation after paint bake treatment and improving the deformation characteristics after pipe or tube formation. The content of Ti needs to be at least 0.005 % to attain such an effect. However, a Ti content exceeding 0.04 % compromises the weldability. Accordingly, the content of Ti is limited in the range of 0.005 % to 0.04 %.

[0033] The above-described composition also contains Nb, V, and Ti in amounts adjusted to fall within the aforementioned ranges and satisfy Formula (1) below:

$$0.05 \leq \text{Nb} + \text{V} + \text{Ti} \leq 0.20$$

Formula (1)

where Nb, V, and Ti each represent the content (mass%) of niobium, vanadium, and titanium, respectively.

[0034] If the total content of Nb, V, and Ti is less than 0.05 %, it is not possible to ensure as high strength as desired for the steel sheet, nor to suppress the occurrence of yield point elongation after paint bake treatment. On the other hand, an excessively large total content of Nb, V, and Ti over 0.20 % causes a more pronounced reduction in the ductility and toughness. Therefore, in the present invention, the content of Nb, V, and Ti is adjusted to satisfy the Formula (1).

[0035] The steel sheet contains the aforementioned components as the basic components and may optionally and selectively contain, in addition thereto, at least one of Mo: 0.3 % or less, Cu: 0.5 % or less, Ni: 0.5 % or less, and B: 0.001 % or less, and/or at least one of Zr: 0.04 % or less and Ta: 0.07 % or less, and/or at least one of Ca: 0.005 % or less and REM: 0.005 % or less.

At least one of Mo: 0.3 % or less, Cu: 0.5 % or less, Ni: 0.5 % or less, and B: 0.001 % or less

[0036] Molybdenum (Mo), copper (Cu), nickel (Ni), and boron (B) are elements each acting to increase the strength of the steel sheet. The steel sheet may optionally and selectively contain at least one of Mo, Cu, Ni, and B.

[0037] Mo acts to improve the quench hardenability of the steel sheet, to thereby increase the strength thereof. Mo

also forms fine precipitates in the form of carbonitrides, to thereby contribute to an increase in the strength of the steel sheet. In addition, Mo acts to suppress the occurrence of yield point elongation after paint bake treatment. To attain this effect, the content of Mo is desirably 0.05 % or more. However, a Mo content exceeding 0.3 % compromises the weldability. Accordingly, in a case where the steel sheet contains Mo, the content of Mo is preferably limited to 0.3 % or less.

[0038] In addition, Cu forms a solute or a precipitate to increase the strength of the steel sheet. To attain this effect, the content of Cu is desirably 0.05 % or more. However, a Cu content exceeding 0.5 % may degrade the surface quality of the steel sheet. Accordingly, in a case where the steel sheet contains Cu, the content of Cu is preferably limited to 0.5 % or less.

[0039] In addition, Ni forms a solute to increase the strength of the steel sheet and contributes to an increase in the toughness of the steel sheet. To attain this effect, the content of Ni is desirably 0.05 % or more. However, a Ni content exceeding 0.5 % leads to increased manufacturing costs. Therefore, in a case where the steel sheet contains Ni, the content of Ni is preferably limited to 0.5 % or less.

[0040] In addition, B markedly improves, even at a small content thereof, the quench hardenability of the steel sheet and contributes to an increase in the strength of the steel sheet. This effect becomes apparent when the content of B is 0.0003 % or more. However, containing B by more than 0.001 % saturates this effect. Therefore, in a case where the steel sheet contains B, the content of B is preferably limited to 0.001 % or less.

At least one of Zr: 0.04 % or less and Ta: 0.07 % or less

[0041] Zirconium (Zr) and tantalum (Ta) are elements each forming fine precipitates in the form of carbonitrides to thereby act to increase the strength of the steel sheet, and may be optionally and selectively contained in the steel sheet. To attain this effect, it is desirable to contain Zr by 0.005 % or more and Ta by 0.01 % or more. However, a Zr content exceeding 0.04 % and a Ta content exceeding 0.07 % compromise the weldability. Accordingly, in a case where the steel sheet contains Zr and Ta, it is preferred to limit the content of Zr to 0.04 % or less and the content of Ta to 0.07 % or less.

At least one of Ca: 0.005 % or less and REM: 0.005 % or less

[0042] Calcium (Ca) and rare earth metals (REM) are elements each contributing to the morphological control for spheroidizing elongated coarse sulfides, and may be optionally and selectively contained in the steel sheet. To attain this effect, it is desirable to contain Ca by 0.001 % or more and REM by 0.001 % or more. However, an excessive Ca content over 0.005 % and an excessive REM content over 0.005 % compromise the cleanliness of the steel sheet. Accordingly, if applicable, the content of Ca and/or REM is preferably limited to 0.005 % or less.

[0043] Note that the balance other than the above chemical components includes Fe and incidental impurities.

[0044] The hot rolled high tensile strength steel sheet according to the present invention has the aforementioned composition and a surface layer containing bainite as a main phase, martensite as a second phase in a volume fraction of 0.5 % to 4 %, and at least one of ferrite, pearlite, and cementite as a third phase in a total volume fraction of 10 % or less.

[0045] As used herein, the term "main phase" refers to a phase having a volume fraction of 50 % or more, and preferably 80 % or more. In addition, the term "surface layer" refers herein to a region extending to a depth of 2 mm in the sheet thickness direction below the surface of the steel sheet.

[0046] The microstructure of the surface layer of the steel sheet may be arranged to contain bainite as the main phase and martensite as the second phase in a volume fraction of 0.5 % to 4 %, with the result that the steel sheet has so excellent deformation characteristics as to offer a uniform elongation of preferably 10 % or more. Moreover, the degree of hardening may be still small even when the steel sheet undergoes paint bake treatment after being molded into a pipe or tube, and furthermore, a yield point elongation, which would otherwise occur subsequent to the paint bake treatment, may be suppressed, and no buckling occurs even when the pipe or tube undergoes bending. As a result, the resulting steel pipe or tube have excellent bending workability. Note that the term "bainite" is intended herein to include bainite and bainitic ferrite.

[0047] In addition, the martensite contained as the second phase may decrease the yield ratio, improve the deformation characteristics after pipe or tube formation, lower the degree of hardening during paint bake treatment, and suppress the occurrence of yield point elongation after pipe or tube formation. Moreover, as the third phase other than the bainite and the martensite, at least one of ferrite phase, pearlite, and cementite may be contained. It is more preferred that these phases have smaller volume fractions because these phases impair uniform elongation, although a total volume fraction of up to 10 % is acceptable.

[0048] Furthermore, the steel sheet has a middle portion in the sheet thickness direction that has a microstructure preferably containing bainite as a main phase, martensite as a second phase in a volume fraction of 0.5 % to 4 %, and at least one of ferrite phase, pearlite, and cementite as a third phase in a total volume fraction of 20 % or less.

[0049] The microstructure of the middle portion in the sheet thickness direction of the steel sheet, which contains bainite as the main phase and martensite as the second phase in a volume fraction of 0.5 % to 4 %, may provide the

steel sheet with both high strength and high toughness. Specifically, the microstructure thus obtained allows the steel sheet to achieve a uniform elongation of 10 % or more, while maintaining high strength. As used herein, the term "middle portion in the sheet thickness direction" refers to a portion other than the surface layer. Moreover, as the third phase other than the bainite and the martensite, at least one of ferrite phase, pearlite, and cementite may be contained. It is more preferred that these phases have smaller volume fractions because these phases reduce the strength and toughness of the steel sheet, and it is preferred to limit the total volume fraction of these phases to 20 % or less.

[0050] Next, a method for manufacturing a hot rolled steel sheet according to the present invention will be described below.

[0051] At first, a steel material having the aforementioned composition is used as a starting material.

[0052] No particular limitation is placed on the method for manufacturing the steel material, and molten steel may be prepared by any commonly used, well-known steelmaking process, such as by using a converter. The molten steel prepared by steelmaking may be cast into a steel material, such as a slab, by applying any commonly used, well-known casting method, such as continuous casting.

The resulting steel material is then reheated.

[0053] The reheating of the steel material is performed to heat the steel material to temperatures in the range of 1100 °C to 1250 °C. A reheating temperature below 1100 °C reduces the amount of increase in strength resulting from the formation of solute Nb and of precipitates after the rolling process, which fails to ensure as high strength as desired for the steel sheet. On the other hand, a reheating temperature above 1250 °C coarsens crystal grains, reduces the low temperature toughness, produces more scales, gives a poor surface texture, and deteriorates the yield. Therefore, it is preferred that the heating temperature of the steel material is limited in the range of 1100 °C to 1250 °C. Note that the steel material may be subjected to hot rolling directly without reheating if it is hot enough to be kept at temperatures in the aforementioned range until the hot rolling, or may be retained in a heating oven for a short period of time before hot rolling.

[0054] The heated steel material is then subjected to hot rolling including rough rolling and finish rolling.

[0055] The rough rolling is not particularly limited, as long as capable of shaping the steel material into a sheet bar having a predetermined dimension and shape. On the other hand, the finish rolling is adapted to have a cumulative rolling reduction ratio of 50 % or more in a temperature range of 930 °C or lower, and a finisher delivery temperature of 760 °C or higher. The cumulative rolling reduction ratio below 50 % in the temperature range of 930 °C or lower (non-recrystallization temperature range) can neither achieve refinement of crystal grains, nor ensure as high toughness as desired for the steel material. Note that the cumulative rolling reduction ratio in this temperature range is preferably set to be 85 % or less. On the other hand, a cumulative rolling reduction ratio above 85 % is too high, with the result that crystal grains assume a shape flattened excessively in the rolling direction and thus come off in the sheet thickness direction upon fracture of the material, thereby causing separation. Therefore, the cumulative rolling reduction ratio in the non-recrystallization temperature range is set to be 50 % or more and, preferably, 85 % or less.

[0056] Further, a finisher delivery temperature below 760 °C promotes austenite to ferrite transformation, particularly in the surface layer, with the result that the surface layer cannot have a microstructure containing a desired bainite phase as its main phase, and that the resulting steel sheet cannot have as high toughness as desired. Note that the finisher delivery temperature is preferably set to be 870 °C or lower. A finisher delivery temperature above 870 °C cannot achieve refinement of the microstructure and causes a reduction in the toughness of the resulting steel sheet. Therefore, the finisher delivery temperature is limited to 760 °C or higher and, preferably, 870 °C or lower.

[0057] Accelerated cooling is started immediately, preferably within 15 seconds and more preferably within 10 seconds, after completion of the finish rolling.

[0058] The accelerated cooling cools the steel sheet to a cooling stop temperature at an average cooling rate of 7 °C/s to 50 °C/s and stops the cooling process when the cooling stop temperature is reached. This may suppress generation of ferrite phase and pearlite and prevent coarsening of crystal grains. If the average cooling rate is below 7 °C/s, ferrite phase forms excessively, which makes it difficult to ensure as high strength and toughness as desired. The excessive generation of ferrite, which is generated at high temperature, makes it difficult to allow for the formation of fine bainite phase. On the other hand, if the average cooling rate is above 50 °C/s, martensite phase forms more easily, which makes it difficult to obtain a microstructure containing bainite phase as its main phase. Therefore, the average cooling rate for the accelerated cooling is limited in the range of 7 °C/s to 50 °C/s. Note that the average cooling rate is preferably set to be 20 °C/s or lower.

[0059] The cooling stop temperature for the accelerated cooling is set in the range of 550 °C or higher to (SCT + 30 °C).

[0060] On the other hand, if the cooling stop temperature is below 550 °C, martensite phase forms more easily as the main phase of the resulting microstructure, which makes it difficult to obtain a desired microstructure having bainite phase as its main phase. On the other hand, if the cooling stop temperature is above (SCT + 30 °C), ferrite and pearlite form in large quantity, which makes it difficult to reliably ensure desired characteristics.

[0061] As used herein, the SCT is:

- a temperature that is defined by Formula (2):

$$\text{SCT } (^{\circ}\text{C}) = 750 - 270\text{C} - 90\text{Mn} + 4\text{Si} (25 - \text{CR}) - 80\text{Mo} - 30 (\text{Cu} + \text{Ni})$$

Formula (2)

where

C, Mn, Si, Mo, Cu, and Ni each represent the content (mass%) of carbon, manganese, silicon, molybdenum, copper, and nickel in steel, respectively, and
CR is an average cooling rate ($^{\circ}\text{C/s}$) during the accelerated cooling,

- a value indicative of how easy to form bainite phase containing martensite, and
- a value depending on the amount of alloying elements contained and the degree of the accelerated cooling.

[0062] According to the present invention, the steel sheet is allowed to cool or gradually cooled during a period of time after the accelerated cooling is stopped and before coiling is started, so that the steel sheet is retained at temperatures in a temperature range of (SCT - 20 $^{\circ}\text{C}$) to (SCT + 30 $^{\circ}\text{C}$) for 10 seconds to 60 seconds. This causes heat recuperation in the surface of the steel sheet, provides more uniform temperature distributions in the sheet thickness direction, suppresses generation of ferrite, and facilitates generation of bainite phase containing martensite. If retained at temperatures in the aforementioned temperature range for less than 10 seconds, the steel sheet fails to gain sufficient heat recuperation, resulting in insufficient formation of martensite in the surface layer. On the other hand, if retained for more than 60 seconds, the steel sheet sees the growth of bainite grains, which leads to a reduction in its toughness and even in its productivity. Accordingly, in the present invention, the steel sheet is allowed to cool or gradually cooled during a period of time after the accelerated cooling is stopped and before coiling is started, so that it is retained at temperatures in a temperature range of (SCT-20 $^{\circ}\text{C}$) to (SCT + 30 $^{\circ}\text{C}$) for 10 seconds to 60 seconds.

[0063] Then, the steel sheet is rolled into a coil. The temperature for coiling is set in the range of 430 $^{\circ}\text{C}$ or higher to (SCT - 50 $^{\circ}\text{C}$). A coiling temperature below 430 $^{\circ}\text{C}$ inhibits diffusion of carbon, thereby preventing martensite phase from forming in bainite corresponding to the main phase. On the other hand, a coiling temperature above (SCT - 50 $^{\circ}\text{C}$) leads to generation of pearlite, which makes it impossible to obtain a desired microstructure.

EXAMPLE

[0064] The present invention will be described in detail below based on Example thereof.

[0065] Molten steel samples having the compositions shown in Table 1 were prepared by steelmaking using a converter and subjected to continuous casting to produce slabs (of 220 mm thick). These slabs were heated to 1200 $^{\circ}\text{C}$, subjected to hot rolling including rough rolling and finish rolling under the conditions shown in Table 2, subjected to, upon completion of the finish rolling, accelerated cooling and allowed to cool under the cooling conditions shown in Table 2, rolled into coils under the conditions shown in Table 2, and then allowed to cool to obtain hot rolled steel sheets (hot rolled steel strips) having a sheet thickness of 12 mm to 16 mm.

[0066] Test pieces were collected from the hot rolled steel sheets (hot rolled steel strips) thus obtained and subjected to microstructure observation, tensile tests, impact tests, and tensile tests after paint bake treatment, so as to assess their microstructures, tensile properties, toughness, and tensile properties after paint bake treatment. The test pieces were assessed as stated below.

(1) Microstructure observation

[0067] Test pieces were collected from the obtained hot rolled steel sheets for microstructure observation. Each test piece was polished and etched at its cross section in the rolling direction and observed and imaged under a microscope (at magnification $\times 1000$) or a scanning electron microscope (at magnification $\times 1000$), in five or more fields of view at a surface layer (at a depth of 1 mm below the surface of the steel sheet) and at a middle position in the sheet thickness direction, respectively. The resulting micrographs were used to analyze the type of microstructure and measure the microstructure proportion using an image analyzer. The obtained results are shown in Table 3.

(2) Tensile test

[0068] JIS No. 5 tensile test pieces (GL: 50 mm) were collected, from a surface layer (region extending to a depth of 2 mm in the sheet thickness direction below the surface) of, and from a middle position in the sheet thickness direction of each of the obtained hot rolled steel sheets, in such a way that the tensile direction is set parallel to the rolling direction. Then, tensile tests were conducted on the test pieces thus obtained in accordance with the JIS Z 2241 standard to analyze their tensile properties (including yield strength, tensile strength, total elongation, and uniform elongation). Note that each tensile test piece from a surface layer (region extending to a depth of 2 mm in the sheet thickness direction below the surface) of each of the hot rolled steel sheets was collected in such a way that a middle position in its thickness direction is set at a depth of 1 mm below the surface of the steel sheet. The thickness of each tensile test piece was set to be 1.6 mm. Note that each tensile test piece from a middle position in the sheet thickness direction of each of the hot rolled steel sheets was prepared by removing by cutting the surface layer (region extending to a depth of 2 mm in the sheet thickness direction) of the steel sheet in such a way that a middle position in its thickness direction coincides with a middle position in the sheet thickness direction. The obtained results are shown in Table 4.

(3) Impact test

[0069] A V-notched test piece (of 10 mm wide) was collected from a middle portion in the sheet thickness direction of each of the obtained hot rolled steel sheets in such a way that its longitudinal direction is set perpendicular to the rolling direction. Then, the Charpy impact tests were conducted on the resulting test pieces in accordance with the JIS Z 2242 standard to measure their fracture appearance transition temperature $vTrs$ (°C) and to assess their toughness. The obtained results are shown in Table 4.

(4) Tensile test after paint bake treatment

[0070] JIS No. 5 tensile test pieces (GL: 50 mm) were collected, from a surface layer (region extending to a depth of 2 mm in the sheet thickness direction below the surface) of, and from a middle position in the sheet thickness direction of each of the obtained hot rolled steel sheets, in such a way that the tensile direction is set parallel to the rolling direction. Then, each of the tensile test pieces was applied with 2 % prestrain at room temperature and then subjected to the heat treatment which is comparable to the paint bake treatment (by which the test piece is heated at 250 °C for 60 min). Then, tensile tests were conducted on the resulting test pieces, as were described in the item (2) above, to measure their yield strength (deformation stress) and yield point elongation and to determine the degree of paint bake hardening of the test pieces. The obtained results are shown in Table 4.

Table 1

Steel ID	Chemical Composition (mass%)															Remarks
	C	Si	Mn	P	S	Al	N	Cr	Nb	V	Ti	Nb+V+Ti	Mo,Cu,Ni,B	Zr,Ta	Ca,REM	
A	0.07	0.26	1.43	0.010	0.003	0.03	0.002	0.38	0.04	0.02	0.01	0.07	Mo: 0.12	-	-	Inventive Example
B	0.07	0.22	1.79	0.009	0.003	0.03	0.002	0.31	0.05	0.003	0.02	0.073	-	-	-	Inventive Example
C	0.04	0.22	1.60	0.004	0.003	0.03	0.003	0.42	0.04	0.004	0.01	0.054	-	-	Ca: 0.002	Inventive Example
D	0.05	0.20	1.56	0.009	0.003	0.03	0.003	0.24	0.04	0.001	0.01	0.051	Mo: 0.11	-	Ca: 0.002	Inventive Example
E	0.08	0.23	1.64	0.013	0.001	0.04	0.003	0.38	0.04	0.003	0.02	0.063	-	-	-	Inventive Example
F	0.05	0.27	2.05	0.007	0.003	0.03	0.003	0.47	0.04	0.04	0.02	0.10	-	-	-	Inventive Example
G	0.07	0.18	1.42	0.016	0.004	0.03	0.002	0.56	0.08	0.003	0.01	0.093	-	-	Ca: 0.002	Inventive Example
H	0.07	0.26	1.62	0.013	0.002	0.03	0.003	0.11	0.05	0.02	0.01	0.08	Cu: 0.25, Ni: 0.19	-	-	Inventive Example
I	0.05	0.16	1.41	0.012	0.002	0.03	0.003	0.49	0.05	0.07	0.01	0.13	B: 0.0004	-	-	Inventive Example
J	0.05	0.18	1.59	0.010	0.003	0.03	0.003	0.46	0.04	0.001	0.005	0.046	-	Zr: 0.025	-	Inventive Example
K	0.05	0.22	1.65	0.009	0.002	0.03	0.004	0.35	0.05	0.07	0.02	0.14	-	Ta: 0.01	REM: 0.003	Inventive Example
L	0.11	0.24	1.48	0.015	0.001	0.04	0.004	0.27	0.03	0.001	0.02	0.051	-	-	-	Comparative Example
M	0.07	0.15	1.84	0.012	0.003	0.03	0.002	0.04	0.05	0.06	0.02	0.13	-	-	-	Comparative Example
N	0.07	0.16	1.24	0.013	0.003	0.03	0.003	0.31	0.02	-	0.08	0.10	-	-	-	Comparative Example
O	0.06	0.26	1.39	0.009	0.003	0.03	0.003	0.98	0.02	0.02	0.01	0.05	Cu: 0.29, Ni: 0.14	-	-	Comparative Example
P	0.02	0.16	1.61	0.008	0.002	0.03	0.003	0.10	0.10	0.05	0.01	0.16	-	-	-	Comparative Example

Table 2

Steel Sheet No.	Steel ID	Hot Rolling				Accelerated Cooling			Allowed to Cool	Coiling		Remarks
		Heating Temp. (°C)	Finish Rolling		Ave. Cooling Rate CR (°C/s)	Cooling Stop Temp. (°C)	SCT** + 30 °C	Retention Time*** (s)		Coiling Temp. (°C)	SCT** - 50 °C	
			Cumulative Rolling Reduction Ratio* (%)	Finisher Delivery Temp. (°C)								
1	A	1200	57		790	18	605	630	18	547	550	Inventive Example
2	B	1200	57		810	16	599	608	<u>3</u>	<u>410</u>	528	Comparative Example
3	C	1200	<u>24</u>		790	13	628	636	12	<u>574</u>	556	Comparative Example
4	B	1200	58		800	12	587	611	16	527	531	Inventive Example
5	C	1200	62		810	7	630	641	19	560	561	Inventive Example
6	D	1200	57		790	20	<u>525</u>	621	10	467	541	Comparative Example
7	D	1200	52		770	18	615	623	10	542	543	Inventive Example
8	E	1200	57		820	22	600	614	14	533	534	Inventive Example
9	F	1200	57		770	30	555	577	29	486	497	Inventive Example
10	G	1200	62		820	16	588	640	17	537	560	Inventive Example
11	H	1200	57		800	17	599	610	12	525	530	Inventive Example
12	I	1200	57		810	13	619	647	17	460	567	Inventive Example

(continued)

Steel Sheet No.	Steel ID	Hot Rolling			Accelerated Cooling			Allowed to Cool	Coiling		Remarks
		Heating Temp. (°C)	Finish Rolling		Ave. Cooling Rate CR (°C/s)	Cooling Stop Temp. (°C)	SCT** + 30 °C		Coiling Temp. (°C)	SCT** - 50 °C	
13	J	1200	57	Cumulative Rolling Reduction Ratio* (%)	20	602	627	12	542	547	Inventive Example
14	K	1200	52	Finisher Delivery Temp. (°C)	18	595	624	13	538	544	Inventive Example
15	L	1200	52	810	14	580	628	11	530	548	Comparative Example
16	M	1200	58	820	18	588	600	17	527	520	Comparative Example
17	N	1200	50	790	14	610	657	16	580	577	Comparative Example
18	O	1200	52	800	15	621	636	14	563	556	Comparative Example
19	P	1200	57	800	18	601	634	18	538	554	Comparative Example

*) Rolling reduction ratio in temperature range of 930 °C or lower (non-recrystallization temperature range)

**) SCT (°C) = 750 - 270C - 90Mn + 4Si (25 - CR) - 80Mo - 30(Cu + Ni) Formula (2)

***) Retention time in temperature range of (SCT - 20 °C) to (SCT + 30 °C)

Table 3

Steel Sheet No.	Steel ID	Microstructure										Remarks
		Surface Layer				Middle Position in Sheet Thickness Direction						
		Main Phase		M Phase Fraction (vol%)	Others in Total (vol%)	Main Phase		M Phase Fraction (vol%)	Others in Total (vol%)			
		Type*	Fraction (vol%)			Type*	Fraction (vol%)					
1	A	BF	98	1.2	θ: 0.8	BF	94	2.0	P: 4.0	Inventive Example		
2	B	BF	99	<u>0.2</u>	θ: 0.8	BF	94	0.8	P: 5.2	Comparative Example		
3	C	BF	86	1.3	θ + P: <u>12.7</u>	BF	77	2.0	F + P + θ: 21.0	Comparative Example		
4	B	B	96	1.1	θ + P: 2.9	B	92	2.0	F + P + θ: 6.0	Inventive Example		
5	C	BF	90	0.9	θ + P: 9.1	BF	85	2.0	F + P + θ: 13.0	Inventive Example		
6	D	B	100	-	-	BF	95	1.1	P: 3.9	Comparative Example		
7	D	BF	98	0.7	θ + P: 1.3	BF	92	1.4	F: 6.6	Inventive Example		
8	E	B	98	1.5	θ: 0.5	B	95	2.0	P + θ: 3.0	Inventive Example		
9	F	B	97	2.0	θ + P: 1.0	B	97	3.0	-	Inventive Example		
10	G	BF	98	1.0	θ + P: 1.0	BF	95	3.0	P + θ: 2.0	Inventive Example		
11	H	BF	99	0.7	θ: 0.3	BF	95	2.0	F + P + θ: 3.0	Inventive Example		
12	I	BF	98	0.9	θ + P: 1.1	BF	92	1.2	F + P + θ: 6.8	Inventive Example		
13	J	B	99	0.7	θ + P: 0.3	BF	97	2.0	P: 1.0	Inventive Example		
14	K	BF	99	0.6	θ + P: 0.4	BF	95	2.0	P: 3.0	Inventive Example		
15	L	BF	100	-	-	B	63	4.0	F + P: 33.0	Comparative Example		
16	M	BF	100	-	-	BF	99	0.6	θ: 0.4	Comparative Example		
17	N	BF	99	0.5	θ: 0.5	BF	95	2.0	F + P + θ: 3.0	Comparative Example		

(continued)

Steel Sheet No.	Steel ID	Microstructure							Remarks	
		Surface Layer				Middle Position in Sheet Thickness Direction				
		Main Phase		M Phase Fraction (vol%)	Main Phase		M Phase Fraction (vol%)	Others in Total (vol%)		
		Type*	Fraction (vol%)		Type*	Fraction (vol%)				
18	<u>Q</u>	B	96	1.4	BF	89	7.0	F + P: 4.0	Comparative Example	
19	<u>P</u>	BF	98	-	BF	95	0.8	P + θ : 4.2	Comparative Example	
*) B: bainite, BF: bainitic ferrite, F: ferrite, P: pearlite, M: martensite, θ : cementite										

Table 4

Steel Sheet No.	Tensile Properties						Paint Bake Hardenability						Toughness		Remarks
	Surface Layer			Middle Position in Sheet Thickness Direction			Surface Layer			Middle Position in Sheet Thickness Direction			vTrs		
	YS (MPa)	TS (MPa)	U-EI (%)	YS (MPa)	TS (MPa)	U-EI (%)	Degree of Hardening (MPa)	Yield Elongation	Degree of Hardening (MPa)	Yield Elongation	Degree of Hardening (MPa)	Yield Elongation	(°C)		
1	599	701	10.6	552	651	11.3	32	Not Occurred	22	Not Occurred	Not Occurred	-85	Inventive Example		
2	610	665	7.6	585	647	8.6	47	Not Occurred	43	Not Occurred	Not Occurred	-85	Comparative Example		
3	572	683	11.8	556	637	10.8	20	Not Occurred	6	Not Occurred	Not Occurred	-55	Comparative Example		
4	621	706	10.7	526	649	11.8	27	Not Occurred	15	Not Occurred	Not Occurred	-95	Inventive Example		
5	528	632	11.4	505	611	12.2	36	Not Occurred	29	Not Occurred	Not Occurred	-80	Inventive Example		
6	569	632	7.8	483	580	9.8	68	Occurred	53	Occurred	Occurred	-105	Comparative Example		
7	556	655	10.2	520	617	11.4	4	Not Occurred	10	Not Occurred	Not Occurred	-90	Inventive Example		
8	536	652	12.1	504	616	11.8	19	Not Occurred	15	Not Occurred	Not Occurred	-80	Inventive Example		
9	564	691	10.4	541	639	12.0	30	Not Occurred	17	Not Occurred	Not Occurred	-95	Inventive Example		
10	610	702	11.3	579	668	11.4	26	Not Occurred	20	Not Occurred	Not Occurred	-90	Inventive Example		
11	571	662	11.4	536	638	11.2	28	Not Occurred	19	Not Occurred	Not Occurred	-95	Inventive Example		
12	584	683	10.8	571	644	11.4	35	Not Occurred	30	Not Occurred	Not Occurred	-105	Inventive Example		
13	513	624	11.0	581	580	11.6	24	Not Occurred	22	Not Occurred	Not Occurred	-110	Inventive Example		

(continued)

Steel Sheet No.	Tensile Properties						Paint Bake Hardenability						Toughness		Remarks
	Surface Layer			Middle Position in Sheet Thickness Direction			Surface Layer			Middle Position in Sheet Thickness Direction			vTrs		
	YS (MPa)	TS (MPa)	U-EI (%)	YS (MPa)	TS (MPa)	U-EI (%)	Degree of Hardening (MPa)	Yield Elongation	Degree of Hardening (MPa)	Yield Elongation	Degree of Hardening (MPa)	Yield Elongation	(°C)		
14	618	715	10.9	566	695	10.6	15	Not Occurred	9	Not Occurred			-105	Inventive Example	
15	628	696	8.8	535	673	11.0	50	Occurred	28	Occurred			-30	Comparative Example	
16	615	673	7.0	585	631	8.0	95	Occurred	88	Occurred			-105	Comparative Example	
17	602	654	7.9	590	646	8.2	58	Occurred	20	Occurred			-33	Comparative Example	
18	613	722	10.2	576	709	10.9	12	Not Occurred	0	Not Occurred			-50	Comparative Example	
19	635	690	8.0	606	674	8.1	69	Occurred	72	Occurred			-42	Comparative Example	

[0071] It was found from the results shown in Tables 1 to 4 that each of the inventive examples

- had a microstructure containing bainite phase as its main phase,
- exhibited high strength of X65 grade giving a yield strength YS of 450 MPa or more, and high toughness giving vTrs of -80 °C or lower,
- exhibited so excellent deformation characteristics that showed a uniform elongation of 10 % or more at a surface layer and at a middle portion in the sheet thickness direction,
- showed no yield point elongation even after being subjected to paint bake treatment, and
- exhibited low paint bake hardenability such that the degree of paint bake hardening was 40 MPa or less.

[0072] On the other hand, the comparative examples falling out of the present invention showed any of the following properties: insufficient strength; lower toughness; inferior elongation properties; and the occurrence of yield point elongation, and thus failed to ensure desired properties for high strength hot rolled steel sheets for line pipes.

[0073] In addition, the hot rolled steel sheets of the inventive examples were subjected to cold forming with rollers to obtain electric resistance welded steel pipes or tubes, which in turn were subjected to diameter-reducing rolling to produce steel pipes or tubes having an outer diameter of 406 mmφ. Note that during the diameter-reducing rolling, a tensile strain (pipe or tube formation-induced strain) of 3.5 % or higher was axially applied to the pipes or tubes. The obtained electric resistance welded steel pipes or tubes were further heated at 250 °C for 60 minutes by heat treatment. Then, arc-shaped tensile test pieces were collected from the resulting steel pipes or tubes such that the tensile direction coincides with the axial direction of the pipes or tubes. Then, tensile tests were conducted on the tensile test pieces in accordance with the API 5L standard, the results of which showed that the tensile test pieces were electric resistance welded steel pipes or tubes having so excellent deformation characteristics that causes no yield point elongation and even exhibits a uniform elongation of 4 % or more. These steel pipes or tubes are less susceptible to buckling even after being subjected to bending.

Claims

1. A hot rolled high tensile strength steel sheet, comprising a chemical composition containing, by mass%,
C: 0.04 % to 0.08 %,
Si: 0.50 % or less,
Mn: 0.8 % to 2.2 %,
P: 0.02 % or less,
S: 0.006 % or less,
Al: 0.1 % or less,
N: 0.008 % or less, and
Cr: 0.05 % to 0.8 %
the chemical composition further containing Nb: 0.01 % to 0.08 %, V: 0.001 % to 0.12 %, and Ti: 0.005 % to 0.04 %, the contents of Nb, V, and Ti being adjusted so as to satisfy Formula (1) below, the chemical composition further containing the balance including Fe and incidental impurities,
wherein the steel sheet has a surface layer having a microstructure containing bainite as a main phase, martensite as a second phase in a volume fraction of 0.5 % to 4 %, and at least one of ferrite phase, pearlite, cementite as a third phase in a total volume fraction of 10 % or less:

$$0.05 \leq \text{Nb} + \text{V} + \text{Ti} \leq 0.20$$

Formula (1)

where Nb, V, and Ti each represent the content (mass%) of niobium, vanadium, and titanium in steel, respectively.

2. The hot rolled high tensile strength steel sheet according to claim 1, wherein the steel sheet has a middle portion in the sheet thickness direction, the middle portion having a microstructure containing bainite as a main phase, martensite as a second phase in a volume fraction of 0.5 % to 4 %, and at least one of ferrite phase, pearlite, and cementite as a third phase in a total volume fraction of 20 % or less, the middle portion exhibiting a uniform elongation of 10 % or more.
3. The hot rolled high tensile strength steel sheet according to claim 1 or 2, wherein the chemical composition further contains, by mass%, at least one of Mo: 0.3 % or less, Cu: 0.5 % or less, Ni: 0.5 % or less, and B: 0.001 % or less.

4. The hot rolled high tensile strength steel sheet according to any one of claims 1 to 3, wherein the chemical composition further contains, by mass%, at least one of Zr: 0.04 % or less and Ta: 0.07 % or less.
5. The hot rolled high tensile strength steel sheet according to any one of claims 1 to 4, wherein the chemical composition further contains, by mass%, at least one of Ca: 0.005 % or less and REM: 0.005 % or less.
6. A method for manufacturing a hot rolled high tensile strength steel sheet, the method comprising: heating a steel material; then subjecting the steel material to hot rolling to obtain a hot rolled sheet; subjecting, immediately after the hot rolling, the hot rolled sheet to accelerated cooling; and then coiling the sheet at a coiling temperature, the steel material comprising a chemical composition containing, by mass%,
C: 0.04 % to 0.08 %,
Si: 0.50 % or less,
Mn: 0.8 % to 2.2 %,
P: 0.02 % or less,
S: 0.006 % or less,
Al: 0.1 % or less,
N: 0.008 % or less, and
Cr: 0.05 % to 0.8 %,
the chemical composition further containing Nb: 0.01 % to 0.08 %, V: 0.001 % to 0.12 %, and Ti: 0.005 % to 0.04 %, the contents of Nb, V, and Ti being adjusted so as to satisfy Formula (1) below, the chemical composition further containing the balance including Fe and incidental impurities,
wherein the heating of the steel material is performed to heat the steel material to temperatures in a range of 1100 °C to 1250 °C,
wherein a cumulative rolling reduction ratio in a temperature range of 930 °C or lower is set to be 50 % or more and a finisher delivery temperature is set to be 760 °C or higher during finish rolling in the hot rolling,
wherein the accelerated cooling is adapted to start cooling, immediately after completion of the finish rolling, at an average cooling rate CR of 7 °C/s to 50 °C/s and to stop the cooling at a cooling stop temperature in a temperature range of 550 °C or higher to a temperature SCT + 30 °C, the SCT being defined by Formula (2) below,
wherein the sheet is allowed to cool or gradually cooled during a period of time after the accelerated cooling is stopped and before the coiling is started, so that the sheet is retained at temperatures in a temperature range of (SCT - 20 °C) to (SCT + 30 °C) for 10 seconds to 60 seconds, and
wherein the coiling temperature is set in a range of 430 °C or higher to (SCT - 50 °C)

$$0.05 \leq Nb + V + Ti \leq 0.20$$

Formula (1)

where Nb, V, and Ti each represent the content (mass%) of niobium, vanadium, and titanium in steel, respectively,

$$SCT (°C) = 750 - 270C - 90Mn + 4Si (25 - CR) - 80Mo - 30 (Cu + Ni)$$

Formula (2)

where

C, Mn, Si, Mo, Cu, and Ni each represent the content (mass%) of carbon, manganese, silicon, molybdenum, copper, and nickel in steel, and
CR is an average cooling rate (°C/s) during the accelerated cooling.

7. The method for manufacturing a hot rolled high tensile strength steel sheet according to claim 6, wherein the chemical composition further contains at least one of Mo: 0.3 % or less, Cu: 0.5 % or less, Ni: 0.5 % or less, and B: 0.001 % or less.
8. The method for manufacturing a hot rolled high tensile strength steel sheet according to claim 6 or 7, wherein the chemical composition further contains, by mass%, at least one of Zr: 0.04 % or less and Ta: 0.07 % or less.
9. The method for manufacturing a hot rolled high tensile strength steel sheet according to any one of claims 6 to 8,

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wherein the chemical composition further contains, by mass%, at least one of Ca: 0.005 % or less and REM: 0.005 % or less.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/008211

A. CLASSIFICATION OF SUBJECT MATTER C22C38/00(2006.01)i, B21B3/00(2006.01)i, C21D8/02(2006.01)i, C22C38/38(2006.01)i, C22C38/58(2006.01)i		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) C22C38/00, B21B3/00, C21D8/02, C22C38/38, C22C38/58		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2013 Kokai Jitsuyo Shinan Koho 1971-2013 Toroku Jitsuyo Shinan Koho 1994-2013		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.		
* Special categories of cited documents:	"I" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family	
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"O" document referring to an oral disclosure, use, exhibition or other means		
"P" document published prior to the international filing date but later than the priority date claimed		
Date of the actual completion of the international search 05 March, 2013 (05.03.13)	Date of mailing of the international search report 12 March, 2013 (12.03.13)	
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer	
Facsimile No.	Telephone No.	

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/008211

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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REFERENCES CITED IN THE DESCRIPTION

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