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(54) **HOT-ROLLED STEEL PLATE FOR HIGH-STRENGTH LINE PIPE AND HAVING TENSILE STRENGTH OF AT LEAST 540 MPa**

(57) An object is to provide a hot-rolled steel sheet for a high strength linepipe excellent in terms of HIC resistance which is suitably used as a raw material of a high strength electric resistance welded linepipe of X70 or more in accordance with API standards.

A hot-rolled steel sheet for a high strength linepipe having a tensile strength of 540 MPa or more, the steel sheet having a chemical composition containing, by mass%, C: 0.02% or more and 0.06% or less, Si: 0.05% or more and 0.25% or less, Mn: 0.60% or more and 1.10%

or less, P: 0.008% or less, S: 0.0010% or less, Nb: 0.020% or more and 0.060% or less, Ti: 0.001% or more and 0.020% or less, Al: 0.01% or more and 0.08% or less, Ca: 0.0005% or more and 0.0050% or less, one or more selected from among Cu: 0.50% or less, Ni: 0.50% or less, Cr: 0.50% or less, Mo: 0.50% or less, and V: 0.10% or less, and the balance being Fe and inevitable impurities, in which the relationships $0.60 \leq CP \leq 0.90$ and $CM \leq 3.05$ are satisfied.

EP 2 927 338 A1

Description

Technical Field

5 **[0001]** The present invention relates to a hot-rolled steel sheet having hydrogen induced cracking resistance (hereinafter, called HIC resistance) and a strength of X70 or more in accordance with API (American Petroleum Institute) standards which can suitably be used as a material for an electric resistance welded steel pipe for a linepipe for transporting energy resources such as crude oil and a natural gas and to a method for manufacturing the steel sheet.

10 Background Art

[0002] UOE steel pipes have been mainly used for linepipes to date from the viewpoint of transport efficiency, because steel pipes having a large diameter and a large thickness can be manufactured using a UOE steel pipe. However, high strength electric resistance welded steel pipes, which are manufactured from hot-rolled steel sheets in a coil shape (hot-rolled steel strips) that are less expensive and have high productivity as a material, are being increasingly used for linepipes instead of UOE steel pipes nowadays. Electric resistance welded steel pipes have an advantage in that they are superior to UOE steel pipes in terms of deviation of a wall thickness and roundness in addition to cost advantage. On the other hand, since the pipe production method for electric resistance welded steel pipes involves cold roll forming, the method is characteristic of much more plastic strain being given to steel pipes than to a UOE steel pipe when pipe production is performed.

20 **[0003]** Nowadays, regarding exploitation of crude oil and a natural gas, there is a growing tendency for oil wells and gas wells to be developed in the polar areas or in deep regions due to an increase in the demand for energy and due to the progress of mining technology. Linepipes which are used at such places are required to have so-called sour resistance such as HIC resistance and sulfate stress corrosion cracking resistance (SSC resistance) in addition to strength, toughness, and weldability. In the case of linepipes, which are not given stress after having been laid, HIC resistance is particularly important.

25 **[0004]** HIC is a phenomenon in which hydrogen ions having been generated by a corrosion reaction become hydrogen atoms on the surface of a steel, and the hydrogen atoms enter into the steel, accumulate around inclusions such as MnS, carbides having a large grain diameter such as NbC, and a second hard phase so as to increase internal pressure and cause the steel material to eventually crack. In addition, in the case where a steel material is given plastic strain, many dislocations are formed around the inclusions, carbides, and the second hard phase mentioned above, and hydrogen atoms are more likely to accumulate, which results in HIC being more likely to occur.

[0005] To date, various solutions have been proposed in order to solve the problem of HIC described above.

35 **[0006]** Patent Literature 1 discloses a method for improving HIC resistance in which inclusions, which become the origins of HIC, are rendered harmless by controlling the total contents of chemical elements which combine respectively with S, O (oxygen), and N to form inclusions to be 0.01% or less or by controlling the maximum diameter of inclusions to be 5 μm or less, and in which the hardness of a center segregation part is controlled to be Hv 330 or less.

40 **[0007]** Patent Literature 2 discloses a method for decreasing the area ratio of HIC by decreasing the size of TiN grains, which become the origin of HIC. Specifically, the size of Al-Ca-based sulfides in molten steel is decreased by controlling a weight ratio $\text{CaO}/\text{Al}_2\text{O}_3$ to be 1.2 to 1.5 by adjusting the added contents of Al and Ca, and the grain diameter of Al-Ti-Ca-based complex inclusions which are formed using the sulfides as nuclei is controlled to be 30 μm or less.

45 **[0008]** In addition, Patent Literature 3 discloses a method in which the formation of carbonitrides of Nb and Ti, which become the origins of HIC, is less likely to occur by controlling Nb concentration to be 0.060% or less and Ti concentration to be 0.025% or less in a region located at a distance in the thickness direction of 5% of the thickness from the central part in the thickness direction.

[0009] Patent Literature 4 discloses a method for manufacturing a high strength linepipe excellent in terms of HIC resistance in which HIC resistance is improved by decreasing the degree of center segregation as a result of decreasing Mn content added in steel and in which Cr and Mo, which are comparatively less likely to undergo center segregation, are utilized.

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Citation List

Patent Literature

55 **[0010]**

PTL 1: Japanese Unexamined Patent Application Publication No. 2006-63351

PTL 2: Japanese Patent No. 4363403 (International Publication No. WO2005/075694)

PTL 3: Japanese Unexamined Patent Application Publication No. 2011-63840

PTL 4: Japanese Patent No. 2647302 (Japanese Unexamined Patent Application Publication No. 5-271766)

Summary of Invention

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Technical Problem

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[0011] Although it is possible to render the origins of HIC harmless to some extent using the methods disclosed in Patent Literature 1 to Patent Literature 3, there is an increase in sensitivity for HIC in the case of a high strength steel sheet of X70 or more in accordance with API standards in particular, and therefore a sufficient effect is not realized only by controlling the amount and size of inclusions.

[0012] In addition, in the case where the method disclosed in Patent Literature 4, in which Cr and Mo are utilized, is used, if Cr and Mo are excessively added, there is an increased tendency for the formation of a martensite phase to occur in a center segregation part, and therefore there is a problem of a deterioration in HIC resistance.

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[0013] The present invention has been completed in view of the situation described above, and an object of the present invention is to provide a hot-rolled steel sheet for a high strength linepipe excellent in terms of HIC resistance which can suitably be used as a raw material of a high strength electric resistance welded linepipe of X70 or more in accordance with API standards.

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[0014] Here, "excellent in terms of HIC resistance" refers to a case where a crack length ratio (CLR) is 15% or less after a steel sheet has been immersed in a NACE solution (NACE TM-0284 solution A: 5%NaCl + 0.5%CH₃OOH, 1 atmosphere, saturated with H₂S, and pH = 3.0 to 4.0) for 96 hours. Solution to Problem

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[0015] The present invention has been completed on the idea that, in the case of a hot-rolled steel sheet for a high strength linepipe having a TS of 540 MPa or more where there is an increase in sensitivity for HIC, a crack length ratio CLR is controlled to be small even in the presence of some amount of inclusions which become the origins of the occurrence of HIC, by improving propagation resistance of HIC as a result of decreasing the grain diameter of a microstructure in a center segregation part through an improvement in the hardenability of the center segregation part by controlling the chemical composition of steel. That is to say, the subject matter of the present invention is as follows.

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[1] A hot-rolled steel sheet for a high strength linepipe having a tensile strength of 540 MPa or more and excellent HIC resistance, the steel sheet having a chemical composition containing, by mass%, C: 0.02% or more and 0.06% or less, Si: 0.05% or more and 0.25% or less, Mn: 0.60% or more and 1.10% or less, P: 0.008% or less, S: 0.0010% or less, Nb: 0.020% or more and 0.060% or less, Ti: 0.001% or more and 0.020% or less, Al: 0.01% or more and 0.08% or less, Ca: 0.0005% or more and 0.0050% or less, one or more selected from among Cu: 0.50% or less, Ni: 0.50% or less, Cr: 0.50% or less, Mo: 0.05% or less, and V: 0.10% or less, and the balance being Fe and inevitable impurities, in which the relational expression (1) below is satisfied.

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$$0.60 \leq CP \leq 0.90 \quad \dots\dots (1),$$

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where CP is calculated from $CP = 4.46 \times C + 2.37 \times Mn/6 + (1.18 \times Cr + 1.95 \times Mo + 1.74 \times V)/5 + (1.74 \times Cu + 1.70 \times Ni)/15$, where the atomic symbols in the equation represent respectively the contents of the corresponding chemical elements by mass%.

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[2] The hot-rolled steel sheet for a high strength linepipe having a tensile strength of 540 MPa or more and excellent HIC resistance according to item [1], in which relational expression (2) below is satisfied in addition to having the chemical composition.

$$CM \leq 3.05 \quad \dots\dots (2),$$

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where CM is calculated from $CM = 2.37 \times Mn + 2.34 \times Mo + 0.59 \times Cr + 0.17 \times Ni$, where the atomic symbols in the equation represent respectively the contents of the corresponding chemical elements by mass%.

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[3] The hot-rolled steel sheet for a high strength linepipe having a tensile strength of 540 MPa or more and excellent HIC resistance according to item [1] or [2], in which the steel sheet has a metallographic structure including, in terms of area fraction, 95% or more of a bainitic-ferrite microstructure in a center segregation part in addition to having the chemical composition, and the average grain diameter of the bainitic-ferrite microstructure is 8.0 μm or less.

[4] A method for manufacturing a hot-rolled steel sheet for a high strength linepipe having a tensile strength of 540 MPa or more and excellent HIC resistance, the method including heating a steel slab having the chemical composition

according to item [1] or [2] at a temperature of 1100°C or higher and 1300°C or lower, performing rough rolling on the steel slab, thereafter performing finish rolling on the rough-rolled steel under condition that cumulative rolling reduction ratio is 20% or more in a temperature range of 930°C or lower, performing accelerated cooling on the finish-rolled steel sheet to a temperature of 380°C or higher and 600°C or lower at an average cooling rate of 10°C/s or more and 100°C/s or less in terms of the temperature of the central part in the thickness direction, and coiling the cooled steel sheet into a coil shape. Advantageous Effects of Invention

[0016] According to the present invention, even in the presence of some amount of inclusions, it is possible to suppress HIC by controlling to refine a microstructure in a center segregation part to be small and to manufacture a high strength hot-rolled steel sheet excellent in terms of HIC resistance which can suitably be used for an electric resistance welded steel pipe for a linepipe of X70 or more in accordance with API standards which can be used without causing any problem even in a harsh environment equivalent to a NACE solution. In addition, the hot-rolled steel sheet manufactured using the present invention can also be used for a spiral steel pipe for a linepipe of X70 or more in accordance with API standards.

Description of Embodiments

[0017] The reasons for the limitations on the constituent elements of the present invention will be described hereafter.

1. Regarding chemical composition

[0018] First, the reasons for the limitations on the chemical composition of the steel according to the present invention will be described. Here, % used when describing the chemical composition always represents mass%.

C: 0.02% or more and 0.06% or less

[0019] C is a chemical element which significantly contributes to an increase in the strength of steel, and such an effect is realized in the case where the C content is 0.02% or more, but, in the case where the C content is more than 0.06%, since a second phase such as a pearlite microstructure is easy to be formed, there is a deterioration in HIC resistance. Therefore, the C content is set to be 0.02% or more and 0.06% or less, or preferably 0.03% or more and 0.05% or less.

Si: 0.05% or more and 0.25% or less

[0020] Si is a chemical element which is added for solute strengthening and decreasing scale-off quantity when hot rolling is performed, and such an effect is realized in the case where the Si content is 0.05% or more, but, in the case where the Si content is more than 0.25%, since red scale excessively grows, cooling ununiformity occurs when hot rolling is performed, which results in a deterioration in the appearance and the uniformity of material properties. Therefore, the Si content is set to be 0.05% or more and 0.25% or less, or preferably 0.10% or more and 0.25% or less. In addition, since there is a deterioration in toughness in an electric resistance weld zone as a result of forming MnSi-based oxides when electric resistance welding is performed, it is preferable that Si be added so that the ratio Mn/Si is 4.0 or more and 12 or less.

Mn: 0.60% or more and 1.10% or less

[0021] Mn is a chemical element which contributes to an improvement in strength and toughness as a result of refining of a steel microstructure, and such an effect is realized in the case where the Mn content is 0.60% or more. On the other hand, in the case where the Mn content is increased, since a fine martensite microstructure is more likely to be formed in a center segregation part, and since MnS, which becomes the origin of HIC, is more likely to be formed, it is necessary that the Mn content be controlled to be 1.10% or less. Therefore, the Mn content is set to be 0.60% or more and 1.10% or less, preferably 0.80% or more and 1.10% or less, or more preferably 0.80% or more and 1.05% or less.

P: 0.008% or less

[0022] Since P is a chemical element which is contained as an inevitable impurity, and since P deteriorates HIC resistance as a result of significantly increasing the hardness of a center segregation part, it is preferable that the P content be as small as possible, but a P content of 0.008% or less is acceptable. Moreover, since there is an increase in cost due to an increase in refining time in order to markedly decrease the P content, it is preferable that the P content be 0.002% or more.

S: 0.0010% or less

5 **[0023]** Since S is, like P, a chemical element which is inevitably contained in steel, and since S forms MnS in steel, it is preferable that the S content be as small as possible, but a S content of 0.0010% or less is acceptable. The S content is preferably 0.0006% or less.

Nb: 0.020% or more and 0.060% or less

10 **[0024]** Nb is a chemical element which contributes to an increase in the strength of steel as a result of precipitating in the form of fine Nb carbonitrides in a coiling process when hot rolled steel sheets are manufactured. Also, Nb is a chemical element which contributes to an improvement in the toughness of a weld zone as a result of suppressing the growth of austenite grains when electric resistance welding is performed. Such effects are realized in the case where the Nb content is 0.020% or more. On the other hand, in the case where the Nb content is more than 0.060%, Nb carbonitrides having a large grain diameter, which become the origins of HIC, are more likely to be formed. Therefore, the Nb content is set to be 0.020% or more and 0.060% or less, or preferably 0.030% or more and 0.050% or less.

Ti: 0.001% or more and 0.020% or less

20 **[0025]** Ti is a chemical element which is added in order to render N, which significantly deteriorates the toughness of steel, harmless by fixing N in the form of TiN. Such an effect is realized in the case where the Ti content is more than 0.001%. On the other hand, in the case where the Ti content is more than 0.020%, since there is an increase in the amount of Ti carbonitrides which precipitate along the cleavage plane of Fe, there is a deterioration in the toughness of steel. Therefore, the Ti content is set to be 0.001% or more and 0.020% or less, or preferably 0.005% or more and 0.015% or less.

25 Al: 0.01% or more and 0.08% or less

30 **[0026]** Although Al is added as a deoxidation agent, in the case where the Al content is more than 0.08%, there is insufficient deoxidation effect in the case where the Al content is less than 0.01%, and, on the other hand, there is a deterioration in HIC resistance and toughness due to an increase in the amount of coarse Al-based oxides remaining in steel. Therefore, the Al content is set to be 0.01% or more and 0.08% or less, or preferably 0.01% or more and 0.05% or less.

35 Ca: 0.0005% or more and 0.0050% or less

40 **[0027]** Ca is a chemical element which is effective for improving HIC resistance by shape control of sulfide-based inclusions, and such an effect is realized in the case where the Ca content is 0.0005% or more. On the other hand, in the case where the Ca content is more than 0.0050%, such an effect becomes saturated, and, in addition, there is a deterioration in HIC resistance as a result of generation of a large amount of Ca oxides. Therefore, the Ca content is set to be 0.0005% or more and 0.0050% or less, or preferably 0.0010% or more and 0.0030% or less.

[0028] In the present invention, one or more selected from among Cu, Ni, Cr, Mo, and V may be further added in the amounts described below.

45 Cu: 0.50% or less

50 **[0029]** Cu is a chemical element which contributes to an improvement in the toughness and strength of steel through an improvement in hardenability, and, since Cu is less likely to be concentrated in a center segregation part than Mn and Mo which have similar effect as Cu, Cu can increase the strength of steel without decreasing HIC resistance. Therefore, Cu is added in accordance with the strength grade of steel. Such an effect is realized in the case where the Cu content is 0.05% or more, but, in the case where the Cu content is more than 0.50%, the effect becomes saturated and there is an unnecessary increase in cost in such case. Therefore, the Cu content is 0.50% or less, or preferably 0.40% or less.

55 Ni: 0.50% or less

[0030] Ni is, like Cu, a chemical element which contributes to an improvement in the toughness and strength of steel through an improvement in hardenability, and, since Ni is less likely to be concentrated in a center segregation part than Mn and Mo which have a similar effect, Ni can increase the strength of steel without deteriorating HIC resistance.

EP 2 927 338 A1

Therefore, Ni is added in accordance with the strength grade. Such an effect is realized in the case where the Ni content is 0.05% or more, but, in the case where the Ni content is more than 0.50%, the effect becomes saturated and there is an unnecessary increase in cost in such case. Therefore, the Ni content is 0.50% or less, or preferably 0.40% or less.

5 Cr: 0.50% or less

[0031] Cr is a chemical element which is effective for improving the toughness and strength of steel by improving hardenability, and such an effect is realized in the case where the Cr content is 0.05% or more. However, Cr significantly deteriorates the toughness of a weld zone as a result of forming Cr oxides when electric resistance welding is performed. In order to suppress such a deterioration, the Cr content is set to be 0.50% or less, or preferably 0.30% or less.

Mo: 0.50% or less

[0032] Mo is a chemical element which is very effective for improving the toughness and strength of steel by improving hardenability, and such an effect is realized in the case where the Mo content is 0.05% or more, but, in the case where the Mo content is more than 0.50%, the effect becomes saturated and there is an unnecessary increase in cost in such case. Therefore, the Mo content is set to be 0.50% or less, or preferably 0.30% or less.

V: 0.10% or less

[0033] V is a chemical element which contributes to an increase in the strength of steel through solute strengthening and precipitation strengthening in the case where the V content is 0.005% or more, but, in the case where the V content is more than 0.10%, since there is an increase in the hardness of a center segregation part, there is a deterioration in HIC resistance. Therefore, the V content is set to be 0.10% or less, or preferably 0.080% or less.

CP: 0.60 or more and 0.90 or less

[0034] In the present invention, a CP value, which is determined by the contents of various alloy chemical elements, satisfies relational expression (1) below.

$$0.60 \leq CP \leq 0.90 \quad \dots\dots (1),$$

where CP is calculated from $CP = 4.46 \times C + 2.37 \times Mn/6 + (1.18 \times Cr + 1.95 \times Mo + 1.74 \times V)/5 + (1.74 \times Cu + 1.70 \times Ni)/15$, where the atomic symbols in the equation represent respectively the contents of the corresponding chemical elements by mass%, where the atomic symbol corresponding to a chemical element which is not added being assigned a value of 0.

[0035] The CP value is an index indicating the hardenability of a center segregation part. It is possible to obtain a fine bainitic-ferrite microstructure having a grain diameter of 8.0 μm or less in the center segregation part by controlling the chemical composition of steel so that the CP value is 0.60 or more. On the other hand, in the case where the CP value is more than 0.90, there is an excessive improvement in hardenability, and therefore there is an increase in the hardness of a center segregation part. Accordingly, the CP value is set to be 0.60 or more and 0.90 or less, or preferably 0.70 or more and 0.90 or less.

CM: 3.05 or less

[0036] A fine martensite microstructure which is formed in a center segregation part deteriorates HIC resistance. The chemical elements which contribute to the formation of a fine martensite microstructure are Mn, Mo, Cr, and Ni, and the degree of influence of these chemical elements on the amount of a fine martensite microstructure formed is numerically represented by a CM value. It is necessary that the value of CM shown below satisfy relational expression (2) below in order to control the area fraction of a fine martensite microstructure which is formed in a center segregation part to be less than 5%.

$$CM \leq 3.05 \quad \dots\dots (2),$$

where CM is calculated from $CM = 2.37 \times Mn + 2.34 \times Mo + 0.59 \times Cr + 0.17 \times Ni$, where the atomic symbols in the

equation represent respectively the contents of the corresponding chemical elements by mass%. It is preferable that the value of CM be 2.95 or less.

[0037] Here, the remainder of the chemical composition other than constituents described above is Fe and inevitable impurities. However, other small amounts of elements may be added as long as the effects of the present invention are not decreased.

2. Regarding metallographic structure

[0038] Subsequently, the metallographic structure of the present invention will be described.

[0039] It is necessary that the metallographic structure of the present invention be a bainitic-ferrite microstructure having excellent toughness. In the case where other kinds of microstructures such as a fine martensite microstructure, an upper bainite microstructure, and a pearlite microstructure are present in a bainitic-ferrite microstructure, since these other kinds of microstructures become hydrogen trapping sites, there is a deterioration in HIC resistance. Therefore, it is preferable that the fractions of the microstructures other than a bainitic-ferrite microstructure be as small as possible. However, in the case where the area fractions of the microstructures other than a bainitic-ferrite microstructure are markedly small, since the influences of the microstructures other than a bainitic-ferrite microstructure are negligibly small, the microstructures other than a bainitic-ferrite microstructure may be included to some extent. Specifically, a case where the total area fraction of the steel microstructures (such as a fine martensite microstructure, an upper bainite microstructure, and a pearlite microstructure) other than a bainitic-ferrite microstructure in the center segregation part is 5% or less is included in the present invention.

[0040] Average grain diameter of a bainitic-ferrite microstructure: 8.0 μm or less

[0041] It is necessary that the average grain diameter of a bainitic-ferrite microstructure be 8.0 μm or less in order to achieve sufficient toughness ($v\text{Trs} \leq -80^\circ\text{C}$) for a steel sheet used for a linepipe. Also, it is desirable that the average grain diameter of a bainitic-ferrite microstructure be 8.0 μm or less in order to improvement the crack propagation resistance of HIC. It is preferable that the average grain diameter of a bainitic-ferrite microstructure be 6.0 μm or less.

3. Regarding manufacturing conditions

[0042] Subsequently, manufacturing conditions for achieving the steel microstructure described above will be described.

[0043] A slab heating temperature is set to be 1100°C or higher and 1300°C or lower. In the case where the temperature is lower than 1100°C, since the temperature is not high enough for carbides, which are formed in steel when continuous casting is performed, to be solid-solute completely, the required strength is not achieved. On the other hand, in the case where the temperature is higher than 1300°C, since there is a marked coarsening of austenite grain, there is a deterioration in toughness. Here, this temperature refers to the temperature of the interior of the heating furnace, and the center of the slab is presumed to be heated to this temperature.

[0044] In the finish rolling step, it is necessary that finish rolling be performed under the condition that cumulative rolling reduction ratio is 20% or more in a temperature range of 930°C or lower. In the case where the cumulative rolling reduction ratio is less than 20%, since there are an insufficient number of nucleation sites of a bainitic-ferrite microstructure, the microstructure becomes coarse, which results in a deterioration in toughness. However, in the case where the cumulative rolling reduction is more than 80%, since the effect becomes saturated, and since a so high load is applied to a rolling mill, it is preferable that the upper limit of cumulative rolling reduction ratio be 80% or less.

[0045] The average cooling rate of the central part in the thickness direction of a steel sheet is set to be 10°C/s or more and 100°C/s or less. In the case where the cooling rate is less than 10°C/s, the area fractions of a ferrite microstructure and/or a pearlite microstructure become more than 5% even if hardenability increasing chemical elements such as Cu, Ni, and Cr are added. Therefore, it is necessary that the cooling rate be 10°C/s or more. On the other hand, in the case where the cooling rate is more than 100°C/s, the area fraction of a martensite microstructure becomes more than 5%. The cooling rate of the central part in the thickness direction of a steel sheet was calculated by using the temperature history of the central part in the thickness direction of the steel sheet by performing heat-transfer calculation using the cooling capacity and heat-transfer coefficient of a run-out, which had been investigated in advance, and the surface temperature of the steel sheet, which had been determined using a radiation thermometer on the run-out.

[0046] The cooling stop temperature is set to be 380°C or higher and 600°C or lower. In the case where the cooling stop temperature is higher than 600°C, since there is coarsening of precipitation strengthening grains such as Nb carbonitrides, there is a decrease in strength. Moreover, since there is an enhancement of increase in the concentration of carbon in a center segregation part, a fine martensite microstructure, an upper bainite microstructure, and a pearlite microstructure tend to be formed. On the other hand, in the case where the cooling stop temperature is lower than 380°C, since there is an improvement in the deformation resistance of a steel sheet, it is difficult to coil the steel sheet into a coil shape, and there is a decrease in strength due to precipitation strengthening grains such as Nb carbonitrides not

being precipitated.

EXAMPLE 1

5 **[0047]** By performing hot rolling on steel materials having the chemical compositions given in Table 1 under the hot rolling conditions and the cooling conditions given in Table 2, and by coiling the hot-rolled steel sheets into a coil shape, hot-rolled steel sheets having the thicknesses given in Table 2 were obtained.

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[Table 1]

Steel Grade	C	Si	Mn	P	S	Nb	Ti	Al	Ca	Cu	Ni	Cr	Mo	V	CP Value*1	CM Value*2	Note
A	0.04	0.19	1.01	0.006	0.0005	0.050	0.012	0.047	0.0022	0.34	0.34	-	-	0.07	0.81	2.45	Example
B	0.05	0.13	1.02	0.007	0.0005	0.044	0.010	0.040	0.0025	0.46	0.46	-	-	-	0.89	2.50	Example
C	0.05	0.13	0.85	0.005	0.0004	0.042	0.008	0.038	0.0028	0.01	0.01	0.23	0.12	0.02	0.78	2.43	Example
D	0.04	0.15	1.05	0.005	0.0004	0.030	0.009	0.033	0.0030	0.17	0.16	0.13	0.18	0.06	0.86	3.01	Example
E	0.03	0.10	0.74	0.005	0.0006	0.042	0.008	0.045	0.0025	-	-	-	0.10	0.02	0.58	1.99	Comparative Example
F	0.05	0.13	1.05	0.006	0.0004	0.040	0.010	0.034	0.0021	0.30	0.30	0.15	0.25	-	0.97	3.21	Comparative Example
G	0.04	0.19	1.45	0.006	0.0009	0.034	0.009	0.040	0.0025	0.01	0.01	-	-	0.02	0.89	3.44	Comparative Example
H	0.04	0.21	1.00	0.007	0.0005	0.005	0.008	0.045	0.0024	0.01	0.01	-	0.10	-	0.77	2.61	Comparative Example

Annotation: An underlined portion indicates a value out of the range according to the present invention.

*1 $CP = 4.46 \times C + 2.37 \times Mn / 6 + (1.18 \times Cr + 1.95 \times Mo + 1.74 \times V) / 5 + (1.74 \times Cu + 1.70 \times Ni) / 15$, where the atomic symbols in the equation represent respectively the contents of the corresponding chemical elements by mass%.

*2 $CM = 2.37 \times Mn + 2.34 \times Mo + 0.59 \times Cr + 0.17 \times Ni$, where the atomic symbols in the equation represent respectively the contents of the corresponding chemical elements by mass%.

[Table 2]

Steel Sheet No.	Steel Grade	Thickness (mm)	Slab Heating Temperature (°C)	Cumulative Rolling Reduction Ratio in Finish Rolling (%)	Finish Rolling Delivery Temperature (°C)	Average Cooling Rate of Central Part in Thickness Direction (°C/s)	Cooling Stop Temperature(°C)	Note
1	A	16	1200	25	840	25	450	Example
2	A	20	1200	45	840	15	500	Example
3	A	10	1200	55	810	50	520	Example
4	A	8	1150	65	810	70	420	Example
5	B	12	1200	55	810	10	520	Example
6	C	12	1200	65	810	25	560	Example
7	D	25	1200	40	820	60	420	Example
8	D	25	1200	40	820	55	480	Example
9	D	25	1200	55	810	30	530	Example
10	A	16	1350	55	810	10	510	Comparative Example
11	A	20	1200	10	830	15	500	Comparative Example
12	A	10	1250	40	820	120	520	Comparative Example
13	A	8	1150	50	830	20	650	Comparative Example
14	E	19	1150	55	810	10	510	Comparative Example
15	F	19	1200	33	830	15	500	Comparative Example
16	G	19	1250	40	820	15	520	Comparative Example
17	H	16	1150	50	830	20	500	Comparative Example

EP 2 927 338 A1

[0048] Test pieces were collected from the obtained hot-rolled steel sheets, and by performing microstructure observation, a tensile test, a Charpy impact test, hardness determination, and a HIC resistance test, tensile properties, toughness, and HIC resistance were evaluated.

5 **[0049]** By collecting a test piece for microstructure observation from the obtained hot-rolled steel sheet, by polishing a cross section of the test piece in the rolling direction, by immersing the test piece in a 2% nital solution for 30 seconds or more in order to expose segregation lines, and by then using an electron scanning microscope (at a magnification of 2000 times), photographs were taken for 5 microscopic fields or more at the segregation position in order to determine the kinds of microstructures, the grain size of a bainitic-ferrite microstructure, and the area fractions of harmful second phases such as a fine martensite microstructure, an upper bainite microstructure, and a pearlite microstructure. The steel microstructure was identified using the test piece for microstructure observation which was collected from the position located at 1/4t in the thickness direction of the steel sheet.

10 **[0050]** A tensile test piece was collected from the obtained hot-rolled steel sheet so that the longitudinal direction was at a right angle to the rolling direction (C direction), and a tensile test was performed at room temperature in accordance with API-5L specification in order to determine yield stress YS (deformation stress for a nominal strain of 0.5%) and tensile stress TS.

15 **[0051]** A V-notched test piece was collected from the central part in the thickness direction of the obtained hot-rolled steel sheet so that the longitudinal direction was at a right angle to the rolling direction (C direction), and absorbed energy and a percent brittle fracture were determined by performing Charpy impact tests at temperatures in the range of -140°C to 0°C in accordance with JIS Z 2242 in order to determine a temperature (fracture transition temperature) at which the percent brittle fracture was 50%. Here, three test pieces were used for one temperature in order to obtain the respective arithmetic averages of the determined absorbed energy and percent brittle fracture.

20 **[0052]** A case where the fracture transition temperature (vTrs) was -80°C or lower was judged as satisfactory (O).

25 **[0053]** A HIC test piece having the thickness of the steel sheet, a width of 20 mm, and a length of 100 mm was collected from the obtained hot-rolled steel sheet so that the longitudinal direction was the rolling direction of the steel sheet, and a HIC resistance test was performed using an A solution in accordance with NACE TM 0284 in order to evaluate HIC resistance. Here, 10 test pieces were used for one coil, and a compressive strain of 10% was applied in the width direction to the test pieces in advance in order to simulate influence of plastic strain applied to a steel sheet in a process of forming an electric resistance welded steel pipe. From the test results, in the case where the crack length ratios (CLR) of all the test pieces for one coil were 15% or less, the coil was judged as satisfactory (O) in terms of HIC resistance. In the case where the crack length ratios of one or more of the test pieces for one coil were more than 15%, the coil was judged as unsatisfactory (x) in terms of HIC resistance.

30 **[0054]** The obtained results are given in Table 3.

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[Table 3]

Steel Sheet No.	Steel Grade	Metallographic structure of Non-segregation Part	Metallographic structure of Center Segregation Part	BF Grain Diameter in Center Segregation Part (μm)	Phase Fraction Other than BF in Center Segregation Part (%)	Yield Strength (MPa)	Tensile Strength (MPa)	Charpy (vTrs)	HIC Resistance	Note
1	A	BF	BF	4.0	0.0	502	568	-80	○	Example
2	A	BF	BF	5.4	0.0	506	573	-100	○	Example
3	A	BF	BF+M	5.6	0.2	526	598	-90	○	Example
4	A	BF	BF	4.2	0.0	510	566	-130	○	Example
5	B	BF	BF+M	3.6	0.5	501	565	-100	○	Example
6	C	BF	BF	6.0	0.0	493	575	-95	○	Example
7	D	BF	BF+M	4.5	0.5	502	567	-95	○	Example
8	D	BF	BF+M	4.8	0.8	536	606	-95	○	Example
9	D	BF	BF+M	5.2	1.2	548	637	-85	○	Example
10	A	BF	BF	<u>8.7</u>	0.0	516	585	-45	×	Comparative Example
11	A	BF	BF	6.6	0.0	511	575	-55	○	Comparative Example
12	A	B+M	B+M	-	B: 30, M: 70	648	770	-15	×	Comparative Example
13	A	BF+F+P	F+P	-	F:80,P:20	504	600	-40	×	Comparative Example
14	E	BF	BF	<u>8.5</u>	0.0	429	<u>477</u>	-110	×	Comparative Example
15	F	BF+M	BF+M	3.5	<u>7.5</u>	507	617	-90	×	Comparative Example
16	G	BF	BF+M	4.0	<u>9.0</u>	518	595	-80	×	Comparative Example

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(continued)

Steel Sheet No.	Steel Grade	Metallographic structure of Non-segregation Part	Metallographic structure of Center Segregation Part	BF Grain Diameter in Center Segregation Part (μm)	Phase Fraction Other than BF in Center Segregation Part (%)	Yield Strength (MPa)	Tensile Strength (MPa)	Charpy (VTrs)	HIC Resistance	Note
17	<u>H</u>	BF	BF	7.6	0.0	379	<u>430</u>	-40	○	Comparative Example

Annotation: BF: bainitic-ferrite, B: bainite, M: martensite, F: ferrite, P: pearlite
An underlined portion indicates a value out of the range according to the present invention.

[0055] The examples of the present inventions are all steel sheets having a high strength of 540 MPa or more and excellent HIC resistance. On the other hand, the comparative examples, which were out of the range according to the present invention, did not achieve the desired properties as a hot rolled steel sheet for high strength electric resistance welded steel pipes excellent in terms of HIC resistance, because the desired strength or toughness was not achieved, or because there was a deterioration in HIC resistance.

Claims

1. A hot-rolled steel sheet for a high strength linepipe having a tensile strength of 540 MPa or more, the steel sheet having a chemical composition containing, by mass%, C: 0.02% or more and 0.06% or less, Si: 0.05% or more and 0.25% or less, Mn: 0.60% or more and 1.10% or less, P: 0.008% or less, S: 0.0010% or less, Nb: 0.020% or more and 0.060% or less, Ti: 0.001% or more and 0.020% or less, Al: 0.01% or more and 0.08% or less, Ca: 0.0005% or more and 0.0050% or less, one or more selected from among Cu: 0.50% or less, Ni: 0.50% or less, Cr: 0.50% or less, Mo: 0.50% or less, and V: 0.10% or less, and the balance being Fe and inevitable impurities, wherein the relational expressions (1) and (2) below are satisfied:

$$0.60 \leq CP \leq 0.90 \quad \dots\dots (1),$$

where CP is calculated from $CP = 4.46 \times C + 2.37 \times Mn/6 + (1.18 \times Cr + 1.95 \times Mo + 1.74 \times V)/5 + (1.74 \times Cu + 1.70 \times Ni)/15$, where the atomic symbols in the equation represent respectively the contents of the corresponding chemical elements by mass%; and

$$CM \leq 3.05 \quad \dots\dots (2);$$

where CM is calculated from $CM = 2.37 \times Mn + 2.34 \times Mo + 0.59 \times Cr + 0.17 \times Ni$, where the atomic symbols in the equation represent respectively the contents of the corresponding chemical elements by mass%.

2. The hot-rolled steel sheet for a high strength linepipe having a tensile strength of 540 MPa or more according to Claim 1, wherein the steel sheet has a metallographic structure including, in terms of area fraction, 95% or more of a bainitic-ferrite microstructure in a center segregation part in addition to having the chemical composition, and the average grain diameter of the bainitic-ferrite microstructure is 8.0 μm or less.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/000319

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A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, C21D8/02(2006.01)i, C22C38/50(2006.01)i

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

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B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00, C21D8/02, C22C38/50

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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	1996-2014
Kokai Jitsuyo Shinan Koho	1971-2014	Toroku Jitsuyo Shinan Koho	1994-2014

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 2005-240051 A (JFE Steel Corp.), 08 September 2005 (08.09.2005), claims; paragraphs [0001], [0022], [0023], [0032]; example 1; tables 1, 2 & US 2005/0183798 A1 & EP 1568792 A1 & CN 1661126 A & KR 10-2005-0086375 A & CA 2491307 A & RU 2005104964 A	1 1,2
X Y	JP 2005-264217 A (JFE Steel Corp.), 29 September 2005 (29.09.2005), claims; paragraphs [0001], [0029], [0049]; examples; tables 1, 2, 3 (Family: none)	1 1,2

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

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* Special categories of cited documents:	"T" 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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"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	

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Date of the actual completion of the international search 13 February, 2014 (13.02.14)	Date of mailing of the international search report 25 February, 2014 (25.02.14)
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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2014/000319

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 7-216500 A (Sumitomo Metal Industries, Ltd.), 15 August 1995 (15.08.1995), claims; paragraphs [0001], [0028], [0029]; examples; tables 2, 5 (Family: none)	1 1, 2
Y	JP 6-271974 A (Nippon Steel Corp.), 27 September 1994 (27.09.1994), claims; paragraphs [0001], [0015], [0017]; examples; tables 1, 2 (Family: none)	1, 2
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Form PCT/ISA/210 (continuation of second sheet) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

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