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(54) **NON-HEAT-TREATED STEEL SHEET HAVING HIGH YIELD STRENGTH IN WHICH HARDNESS OF A WELDING-HEAT-AFFECTED ZONE AND DEGRADATION OF LOW-TEMPERATURE TOUGHNESS OF THE WELDING-HEAT-AFFECTED ZONE ARE SUPPRESSED**

(57) To provide a non-heat-treated steel plate having high yield strength in which hardness of a weld heat-affected zone and degradation of low-temperature toughness of the weld heat-affected zone are suppressed. The steel wire rod of the present disclosure includes predetermined components in steel, wherein C_{eq} defined by the formula (1) below is less than 0.44, an A value defined by the formula (2) below is 2.50 or more, and a B value defined by the formula (3) below is 2.37 or more, and wherein area ratios of metal structures in a 1/4 position of a thickness of the steel plate satisfy bainite: 80% by area or more, and martensite-austenite constituent: 0% by area or more and 0.26% by area or less, and wherein a maximum hardness of the bainite is 270 HV or more.

$$C_{eq} = C + Mn/6 + (Cu + Ni)/15 + (Cr + Mo + V)/5 \quad (1)$$

$$A \text{ value} = 1.15 \times Mn + 2.20 \times Mo + 6.50 \times Nb \quad (2)$$

$$B \text{ value} = 1.20 \times Mn + 0.50 \times Ni + 4.25 \times Nb \quad (3)$$

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Description

Technical Field

[0001] The present invention relates to a non-heat-treated steel plate having high yield strength in which hardness of a weld heat-affected zone and degradation of low-temperature toughness of the weld heat-affected zone are suppressed. More specifically, the present invention relates to a non-heat-treated steel plate having a high yield strength of API standard X80 grade to be used in line pipes for transportation of oil, natural gas, and the like.

Background Art

[0002] In line pipes for transportation of natural gas and crude oil over long distances, in order to reduce an installation cost and a transportation cost, there is a growing need to limit an increase in the thickness of a pipe material itself by increasing its strength. Currently, X80 grade steel is standardized and commercialized as a high yield strength steel by American Petroleum Institute (API).

[0003] Steel plates used in line pipes mentioned above are required to have high toughness, short construction periods, and low costs, in addition to the high yield strength. Controlled rolling is exemplified as a manufacturing method to satisfy these requirements. Controlled rolling is a technique which includes refining crystal grains by appropriately controlling the temperature and rolling reduction during hot-rolling and the like, and performing accelerated cooling after the hot-rolling. The controlled rolling does not need any thermal refining, including heating after the accelerated cooling, and the like. The steel plate obtained by such a method is generally called a non-heat-treated steel plate.

[0004] Various techniques have been hitherto developed for non-heat-treated high yield strength steel plates. For example, Patent Documents 1 to 4 disclose a method for manufacturing a steel plate that has a high yield strength of API standard X80 grade in a non-heat-treated state.

Prior Art Document

Patent Document

[0005]

Patent Document 1: JP 2006-328523 A

Patent Document 2: WO 2010/052927

Patent Document 3: JP 2006-169591 A

Patent Document 4: JP 2008-261012 A

Disclosure of the Invention

Problems to be Solved by the Invention

[0006] As line pipes are installed in cold regions in many cases, it is essential for a weld heat-affected zone (HAZ) to have excellent low-temperature toughness. Furthermore, from the viewpoint of weldability, suppression of a hardness of the weld heat-affected zone has been strongly desired in recent years.

[0007] However, the steel plates mentioned in Patent Document 1 and Patent Document 2 are not controlled to have a low Ceq, which is an index for evaluating the toughness and hardness of the weld heat-affected zone. Consequently, the toughness of the weld heat-affected zone might be degraded, and the weld heat-affected zone might be hardened.

[0008] In methods mentioned in Patent Document 3 and Patent Document 4, a large amount of B, which is an element that could degrade the low-temperature toughness of a weld heat-affected zone, is added, which would degrade the low-temperature toughness of the weld heat-affected zone.

[0009] The present invention has been made in view of the foregoing circumstances, and it is an object of the present invention to provide a non-heat-treated steel plate having high yield strength in which hardness of a weld heat-affected zone and degradation of low-temperature toughness of the weld heat-affected zone are suppressed.

Means for Solving the Problems

[0010] The non-heat-treated steel plate having high yield strength in which hardness of a weld heat-affected zone and degradation of low-temperature toughness of the weld heat-affected zone are suppressed, that can solve the above-mentioned problems, according to the present invention, includes, in percent by mass: C: more than 0.04% and 0.10%

or less; Si: 0.15 to 0.50%; Mn: 1.20 to 2.50%; P: more than 0% and 0.020% or less; S: more than 0% and 0.0050% or less; Nb: 0.020 to 0.100%; Ti: 0.003 to 0.020%; N: 0.0010 to 0.0075%; Zr: 0.0001 to 0.0100%; Ca: 0.0005 to 0.0030%; REM: 0.0001 to 0.0050%; Al: 0.010 to 0.050%; B: 0.0003% or less (including 0%); and one or more elements selected from the group consisting of, Mo: more than 0% and 0.30% or less, Cu: more than 0% and 0.30% or less, Ni: more than 0% and 0.30% or less; Cr: more than 0% and 0.30% or less; and V: more than 0% and 0.050% or less, with the balance being iron and inevitable impurities, wherein C_{eq} defined by the formula (1) below is less than 0.44, an A value defined by the formula (2) below is 2.50 or more, and a B value defined by the formula (3) below is 2.37 or more, wherein area ratios of metal structures in a 1/4 position of a thickness of the steel plate satisfy bainite: 80% by area or more, and martensite-austenite constituent: 0% by area or more and 0.26% by area or less, and wherein a maximum hardness of the bainite is 270 HV or more:

$$C_{eq} = C + Mn/6 + (Cu + Ni)/15 + (Cr + Mo + V)/5 \quad (1)$$

$$A \text{ value} = 1.15 \times Mn + 2.20 \times Mo + 6.50 \times Nb \quad (2)$$

$$B \text{ value} = 1.20 \times Mn + 0.50 \times Ni + 4.25 \times Nb \quad (3)$$

where C, Mn, Cu, Ni, Cr, Mo, V, and Nb represent the contents of C, Mn, Cu, Ni, Cr, Mo, V, and Nb in percent by mass, respectively.

[0011] In a preferred embodiment of the present invention, the above-mentioned non-heat-treated steel plate is used for line pipes.

Effects of the Invention

[0012] According to the present invention, with the above-mentioned configuration, a non-heat-treated steel plate having high yield strength can be obtained in which hardness of a weld heat-affected zone and degradation of low-temperature toughness of the weld heat-affected zone are suppressed.

Brief Description of the Drawings

[0013]

Fig. 1 is a graph showing a relationship between bainite area ratio and yield strength;
Fig. 2 is a graph showing a relationship between maximum hardness of bainite and yield strength; and
Fig. 3 is a graph showing a relationship between yield strength and area ratio of a martensite-austenite constituent (hereinafter, the martensite-austenite constituent being referred to as MA in some cases).

Mode for Carrying Out the Invention

[0014] First, the present inventors have considered factors that control a yield strength of a non-heat-treated steel plate. As a result, it has been found that the yield strength of the non-heat-treated steel plate has close correlation with respective area ratios of bainite and martensite-austenite constituent in a metal structure and the maximum hardness of bainite, and by controlling these factors within predetermined ranges, the high yield strength of the API standard X80 grade can be achieved.

[0015] Furthermore, the present inventors have studied non-heat-treated steel plates from various perspectives in order to achieve a non-heat-treated steel plate having high yield strength in which hardness of a weld heat-affected zone and degradation of low-temperature toughness of the weld heat-affected zone are suppressed. As a result, it has been found that when a chemical composition is controlled to satisfy the relationships of the above-mentioned formulas (1) to (3), the degradation of the low-temperature toughness of the weld heat-affected zone can be suppressed, and further the hardness of the weld heat-affected zone can be reduced. In this way, the present invention has been completed.

[0016] Further, such a non-heat-treated steel plate can be preferably manufactured by hot-rolling a steel material satisfying a predetermined composition through heating and then cooling the hot-rolled steel from a cooling start temperature of 730°C or higher to a cooling stop temperature of 370 to 550°C at an average cooling rate of 10 to 50°C/sec.

[0017] The term "high yield strength of the API standard X80 grade" as used herein means that the yield strength of

a steel plate in the plate width direction is 555 MPa or more and 705 MPa or less.

[0018] First, the structure of the non-heat-treated steel plate in the present invention will be described.

[0019] In the non-heat-treated steel plate according to the present invention, the area ratios of respective structures of bainite and martensite-austenite constituent to the entire metal structure in a 1/4 position of the thickness t of the steel plate satisfy bainite: 80% by area or more; and martensite-austenite constituent: 0% by area or more and 0.26% by area or less, and the maximum hardness of bainite is 270 HV or more.

Bainite: 80% by area or more

[0020] Bainite is a structure that contributes to the improvement of yield strength and further is an important structure for securing high yield strength of the API standard X80 grade. If the bainite area ratio is less than 80% by area, the yield strength of steel is reduced. For this reason, the lower limit of the bainite area ratio is 80% by area or more assuming that the area of the entire metal structure is 100%. The lower limit of the bainite area ratio is preferably 82% by area or more, and more preferably 84% by area or more.

[0021] Fig. 1 is a graph showing a relationship between bainite area ratio and yield strength in non-heat-treated steel plates manufactured using steels of types A to X shown in Table 1 of Examples to be mentioned later, under manufacturing conditions No. 1 to 24 shown in Table 2. As shown in Fig. 1, in all Examples satisfying the desired high yield strength of 555 MPa or more, the bainite area ratio in the metal structure is 80% or more. Thus, in order to satisfy the high yield strength, it is found effective to increase the bainite area ratio to 80% or more. Referring to Fig. 1, there are some examples in which the yield strength does not satisfy 555 MPa or more despite the bainite area ratio being 80% or more. However, these are examples in which the bainite hardness to be mentioned later is less than 270HV, or the MA area ratio is more than 0.26%.

Maximum Hardness of Bainite: 270 HV or more

[0022] The maximum hardness of bainite is critical for suppressing variations in yield strength to obtain a stable high yield strength, and needs to be controlled to be 270 HV or more. Thus, the high yield strength of the API standard X80 grade can be stably secured. The lower limit of the maximum hardness of bainite is preferably 275 HV or more. However, in consideration of the formability into a steel pipe, the upper limit of the maximum hardness of bainite is preferably 310 HV or less, and more preferably 300 HV or less.

[0023] Fig. 2 is a graph showing a relationship between maximum hardness of bainite and yield strength in non-heat-treated steel plates manufactured by using the steels of types A to X shown in Table 1 of Examples to be mentioned later, under manufacturing conditions No. 1 to 24 shown in Table 2. As shown in Fig. 2, in all Examples satisfying the desired value of 555 MPa or more, the maximum hardness of bainite in the metal structure is 270 HV or more. Thus, in order to satisfy the high yield strength, it is found effective to enhance the maximum hardness of bainite to 270 HV or more. Here, there are some examples in which the yield strength does not satisfy 555 MPa or more despite the maximum hardness of bainite being 270 HV or more. However, these are examples in which the bainite area ratio is less than 80%, or the MA area ratio is more than 0.26%.

[0024] Here, the term "maximum hardness of bainite" means an average value of measured values at the top three points obtained when the Vickers hardness of bainite is measured by a method mentioned in a section of Examples mentioned later. The present inventors have found that the high yield strength can be stably obtained by controlling the maximum hardness of bainite.

[0025] martensite-austenite constituent: 0% by area or more and 0.26% by area or less.

[0026] As the martensite-austenite constituent is a structure that reduces the yield strength, in order to secure the desired high yield strength, it is necessary to reduce the MA area ratio. For that reason, the upper limit of the MA area ratio is 0.26% by area or less, assuming that the area of the entire metal structure is set at 100%. The upper limit of the MA area ratio is preferably 0.25% by area or less.

[0027] Fig. 3 is a graph showing a relationship between martensite-austenite constituent area ratio and yield strength in non-heat-treated steel plates manufactured by using steels of types A to X shown in Table 1 of Examples to be mentioned later, under manufacturing conditions No. 1 to 24 shown in Table 2. As shown in Fig. 3, all Examples satisfying 555 MPa or more, the MA area ratio in the metal structure is 0.26% or less. Thus, in order to satisfy the high yield strength, it is found effective to control the MA area ratio to be 0.26% or less. Here, there are some examples in which the yield strength does not satisfy 555 MPa or more despite the MA area ratio being 0.26% or less. However, these are examples in which the bainite area ratio is less than 80%, or the maximum hardness of bainite is less than 270 HV.

[0028] The structure of the non-heat-treated steel plate according to the present invention is as mentioned above. Other remaining structures, except for those mentioned above, may include ferrite, martensite, and/or pearlite.

[0029] The components of the steel will be described below.

[0030] First, a description will be given on the relationships between each of C_{eq} , an A value, and a B value, which

are represented by the above formulas (1) to (3), respectively, and each of the yield strength, the low-temperature toughness of the HAZ, and the hardness of the HAZ.

[0031] Ceq: less than 0.44

$$Ceq = C + Mn/6 + (Cu + Ni)/15 + (Cr + Mo + V)/5 \quad (1)$$

where C, Mn, Cu, Ni, Cr, Mo, and V represent the contents of C, Mn, Cu, Ni, Cr, Mo, and V in percent by mass, respectively. Ceq defined by the formula (1) mentioned above is an index that is important for determining the low-temperature toughness of the HAZ and the hardness of the HAZ. If Ceq is 0.44 or more, the low-temperature toughness of the HAZ and the hardness property of the HAZ are drastically degraded. If Ceq is less than 0.44, the HAZ can secure satisfactory low-temperature toughness and hardness. For this reason, the upper limit of Ceq is set at less than 0.44. The upper limit of Ceq is preferably 0.43 or less, and more preferably 0.42 or less. Meanwhile, in consideration of the lower limit of the content of each element and the like, the lower limit of Ceq is preferably 0.37 or more, and more preferably 0.38 or more.

[0032] A value: 2.50 or more

$$A \text{ value} = 1.15 \times Mn + 2.20 \times Mo + 6.50 \times Nb \quad (2)$$

where Mn, Mo, and Nb represent the contents of Mn, Mo, and Nb in percent by mass, respectively.

[0033] The A value is first found by the present inventors and is a parameter that controls the respective contents of Mn and Mo, which are effective for suppressing the ferrite transformation among the elements constituting Ceq mentioned above, and further controls the content of Nb so as to satisfy the above formula (2). By setting the A value to 2.50 or more, the bainite area ratio, which is important for achieving the high yield strength, can be secured while suppressing an increase in Ceq. In order to increase the bainite area ratio, the higher the A value, the better, and hence the lower limit of the A value is set at 2.50 or more in order to secure the high yield strength of the API standard X80 grade. The lower limit of the A value is preferably 2.52 or more, and more preferably 2.54 or more. Meanwhile, in consideration of the upper limit of the content of each element and the like, the upper limit of the A value is preferably 3.00 or less, and more preferably 2.95 or less.

[0034] B value: 2.37 or more

$$B \text{ value} = 1.20 \times Mn + 0.50 \times Ni + 4.25 \times Nb \quad (3)$$

where Mn, Ni, and Nb represent the contents of Mn, Ni, and Nb in percent by mass, respectively.

[0035] The B value is first found by the present inventors and is a parameter that controls the respective contents of Mn, Ni, and Nb, which are effective for introducing dislocations at high densities, to satisfy the above formula (3) by decreasing the bainite transformation temperature. By setting the B value to 2.37 or more, the maximum hardness of bainite can be secured while suppressing an increase in Ceq. In order to enhance the maximum hardness of bainite, the higher the B value, the better, and hence the lower limit of the B value is set at 2.37 or more in order to secure the high yield strength of the API standard X80 grade. The lower limit of the B value is preferably 2.39 or more. Meanwhile, in consideration of the upper limit of the content of each element and the like, the upper limit of the B value is preferably 2.70 or less, and more preferably 2.68 or less.

C: more than 0.04% and 0.10% or less

[0036] C is an element essential to secure high yield strength of a base metal (steel plate). Thus, the lower limit of C content needs to be set at more than 0.04%. The lower limit of the C content is preferably 0.05% or more, and more preferably 0.06% or more. However, if the C content is excessive, martensite-austenite constituent are more likely to be formed, degrading the yield strength and the weldability of the steel. Thus, the upper limit of the C content needs to be set at 0.10% or less. The upper limit of C content is preferably 0.09% or less, and more preferably 0.08% or less.

Si: 0.15 to 0.50%

[0037] Si is an element that has a deoxidation function and is effective in improving the yield strength of the base metal. Thus, the lower limit of Si content is 0.15% or more. The lower limit of the Si content is preferably 0.18% or more,

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and more preferably 0.20% or more. However, if the Si content is excessive, the weldability of the steel and the low-temperature toughness of the HAZ are degraded. Thus, the upper limit of the Si content needs to be set at 0.50% or less. The upper limit of the Si content is preferably 0.45% or less, and more preferably 0.40% or less.

5 Mn: 1.20 to 2.50%

[0038] Mn is an element effective in improving the yield strength of the base metal. Thus, the lower limit of Mn content needs to be 1.20% or more. The lower limit of the Mn content is preferably 1.50% or more, and more preferably 1.70% or more. However, if the Mn content is excessive, the weldability of the steel is degraded. Thus, the upper limit of the Mn content is set at 2.50% or less. The upper limit of the Mn content is preferably 2.20% or less, and more preferably 2.00% or less.

P: more than 0% and 0.020% or less

15 [0039] P is an element inevitably contained in the steel material. If the P content exceeds 0.020%, the low-temperature toughness of the HAZ is remarkably degraded. For this reason, the upper limit of the P content is set at 0.020% or less. The upper limit of the P content is preferably 0.015% or less, and more preferably 0.010% or less. It should be noted that P is an impurity inevitably contained in the steel, and hence the P content is difficult to set at 0% in terms of industrial production.

20

S: more than 0% and 0.0050% or less

[0040] S is an element that affects the low-temperature toughness of the HAZ, like P mentioned above. If the S content exceeds 0.0050%, coarse sulfides are formed, degrading the low-temperature toughness of the HAZ. Thus, the upper limit of the S content is set at 0.0050% or less. The upper limit of the S content is preferably 0.0030% or less, and more preferably 0.0020% or less. It should be noted that S is an impurity inevitably contained in the steel, and hence the S content is difficult to set at 0% in terms of industrial production.

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Nb: 0.020 to 0.100%

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[0041] Nb is an element effective in enhancing the yield strength of the steel and the low-temperature toughness of the base metal without degrading the weldability. Thus, the lower limit of the Nb content needs to be 0.020% or more. The lower limit of the Nb content is preferably 0.030% or more, and more preferably 0.040% or more. However, if the Nb content becomes excessive to exceed 0.100%, the low-temperature toughness of the HAZ is degraded. Thus, the upper limit of Nb content is set at 0.100% or less. The upper limit of the Nb content is preferably 0.070% or less, and more preferably 0.060% or less.

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Ti: 0.003 to 0.020%

40 [0042] Ti is an element effective in improving the yield strength of the base metal. Further, Ti is the element necessary for improving the low-temperature toughness of the HAZ because Ti precipitates as TiN in steel, thereby suppressing austenite grains in the HAZ from being coarsened during welding. To effectively exhibit these effects, the lower limit of the Ti content needs to be 0.003% or more. The lower limit of the Ti content is preferably 0.005% or more, and more preferably 0.007% or more. However, if the Ti content is excessive, the low-temperature toughness of the HAZ is degraded due to an increase in the amount of solid-solution Ti or TiC precipitates. Thus, the upper limit of the Ti content is set at 0.020% or less. The upper limit of the Ti content is preferably 0.018% or less, and more preferably 0.016% or less.

45

N: 0.0010 to 0.0075%

50 [0043] N is an element necessary for improving the low-temperature toughness of the HAZ by suppressing the coarsening of austenite grains in the HAZ during welding because of the precipitation as TiN in steel. To exhibit these effects, the lower limit of the N content needs to be 0.0010% or more. The lower limit of the N content is preferably 0.0020% or more, and more preferably 0.0030% or more. However, if the N content is excessive, the low-temperature toughness of the HAZ is degraded due to the presence of solid-solution N. Thus, the upper limit of the N content is set at 0.0075% or less. The upper limit of the N content is preferably 0.0070% or less, and more preferably 0.0065% or less.

55

Zr: 0.0001 to 0.0100%

[0044] Zr is an element that forms an oxide and disperses it in the steel, thereby contributing to improvement of the low-temperature toughness of the HAZ. Thus, the lower limit of the Zr content needs to be 0.0001% or more. The lower limit of the Zr content is preferably 0.0003% or more, and more preferably 0.0005% or more. However, if the Zr content is excessive, Zr forms coarse inclusions to degrade the low-temperature toughness of the HAZ. Thus, the upper limit of the Zr content needs to be 0.0100% or less. The upper limit of the Zr content is preferably 0.0050% or less, and more preferably 0.0030% or less.

Ca: 0.0005 to 0.0030%

[0045] Ca is an element that has the function of controlling the form of a sulfide and forms CaS to suppress the formation of MnS, thereby improving the low-temperature toughness of the HAZ. Thus, the lower limit of the Ca content needs to be 0.0005% or more. The lower limit of the Ca content is preferably 0.0006% or more. However, if the Ca content becomes excessive to exceed 0.0030%, the low-temperature toughness of the HAZ is degraded. Thus, the upper limit of the Ca content is 0.0030% or less. The upper limit of the Ca content is preferably 0.0028% or less, and more preferably 0.0026% or less.

REM: 0.0001 to 0.0050%

[0046] A rare-earth metal (REM) as rare-earth element is an element effective in controlling the form of a sulfide and suppresses the formation of MnS which adversely affects the low-temperature toughness of the HAZ. To exhibit these effects, the lower limit of the REM content is set at 0.0001% or more. The REM content is preferably 0.0003% or more, and more preferably 0.0005% or more. However, even though REM is contained in a large amount, its effect is saturated. Thus, the upper limit of the REM content is set at 0.0050% or less. The upper limit of the REM content is preferably 0.0040% or less, and more preferably 0.0030% or less. It should be noted that in the present invention, REM means lanthanoid elements (15 elements from La to Lu), scandium (Sc), and yttrium (Y). Among these elements, the steel preferably contains at least one element selected from the group consisting of Ce, La, and Nd, and more preferably contains at least one of the Ce and La.

Al: 0.010 to 0.050%

[0047] Al is a strong deoxidation element. To obtain the deoxidation effect, the lower limit of the Al content needs to be 0.010% or more. The lower limit of the Al content is preferably 0.015% or more, and more preferably 0.018% or more. However, if the Al content is excessive, a large number of AlN precipitates are formed to decrease the amount of TiN precipitates, thus impairing the low-temperature toughness of the HAZ. Thus, the upper limit of the Al content needs to be 0.050% or less. The upper limit of the Al content is preferably 0.045% or less, and more preferably 0.042% or less.

B: 0.0003% or less (including 0%)

[0048] B is an element that remarkably degrades the low-temperature toughness of the HAZ. Thus, the upper limit of the B content is set at 0.0003% or less. The upper limit of the B content is preferably 0.0002% or less, and more preferably 0.0001% or less. It should be noted that if B is added in an amount exceeding 0.0003%, the combined addition of Mo and B induces an excessive increase in the yield strength of the base metal.

[0049] One or more elements selected from the group consisting of Mo: more than 0% and 0.30% or less, Cu: more than 0% and 0.30% or less, Ni: more than 0% and 0.30% or less, Cr: more than 0% and 0.30% or less, and V: more than 0% and 0.050% or less

[0050] Mo, Cu, Ni, Cr, and V are elements effective in improving the yield strength of the steel. These elements may be added alone or in combination. The reasons for setting the content ranges of these elements are as follows.

Mo: more than 0% and 0.30% or less

[0051] Mo is an element effective in improving the yield strength of a base metal. Thus, the lower limit of the Mo content is preferably 0.01% or more. The lower limit of the Mo content is more preferably 0.05% or more, and even more preferably 0.10% or more. However, if the Mo content exceeds 0.30%, the low-temperature toughness of the HAZ and the weldability are degraded. Thus, the upper limit of the Mo content is 0.30% or less. The upper limit of the Mo content is preferably 0.25% or less, and more preferably 0.20% or less.

Cu: more than 0% and 0.30% or less

[0052] Cu is an element effective in enhancing the yield strength. Thus, the lower limit of the Cu content is preferably 0.01% or more. The lower limit of the Cu content is more preferably 0.05% or more, and even more preferably 0.10% or more. However, if the Cu content is excessive, MA is more likely to be formed. Thus, the upper limit of the Cu content is set at 0.30% or less. The upper limit of Cu content is preferably 0.27% or less, and more preferably 0.25% or less.

Ni: more than 0% to 0.30% or less

[0053] Ni is an element effective in improving the yield strength of a base metal. Thus, the lower limit of the Ni content is preferably 0.01% or more. The lower limit of the Ni content is more preferably 0.05% or more, and even more preferably 0.10% or more. However, if the Ni content is excessive, MA is more likely to be formed. Further, since a structural steel material having such an excessive Ni content becomes extremely expensive. Thus, the upper limit of the Ni content is set at 0.30% or less. The upper limit of the Ni content is preferably 0.27% or less, and more preferably 0.25% or less.

Cr: more than 0% and 0.30% or less

[0054] Cr is an element effective in improving the yield strength. Thus, the lower limit of the Cr content is preferably 0.01% or more. The lower limit of the Cr content is more preferably 0.05% or more, and even more preferably 0.10% or more. However, if the Cr content exceeds 0.30%, MA is more likely to be formed. Thus, the upper limit of the Cr content is 0.30% or less. The upper limit of the Cr content is preferably 0.27% or less, and more preferably 0.25% or less.

V: more than 0% and 0.050% or less

[0055] V is an element effective in improving the yield strength. Thus, the lower limit of the V content is preferably 0.001% or more. The lower limit of the V content is more preferably 0.002% or more, and even more preferably 0.003% or more. However, if the V content exceeds 0.050%, MA is more likely to be formed. Thus, the upper limit of the V content is set at 0.050% or less. The upper limit of the V content is preferably 0.030% or less, and more preferably 0.010% or less.

[0056] The elements of the steel used in the present invention have been mentioned above, with the balance substantially being iron. It should be noted that inevitable impurities are allowed to be brought and contained in steel, depending on the situations, including raw materials, other materials, facilities, and the like. The above-mentioned inevitable impurities can include, for example, As, Sb, Sn, O, H, and the like.

[0057] A method for manufacturing the above-mentioned steel plate will be described below.

[0058] The steel plate of the present invention can be manufactured, for example, by producing a cast strip, such as a slab, heating and hot-rolling the obtained cast strip, followed by accelerated cooling.

[0059] The respective steps will be described in detail below.

[0060] First, in a casting step, to control the form of sulfides by use of REM and Ca, it is preferred that REM and Ca are added to steel material after deoxidation by adding Al and Zr to steel material and forming Al_2O_3 and ZrO. In particular, Ca is an element which easily forms oxides, and Ca forms an oxide (CaO) more easily than a sulfide (CaS). To prevent sulfur recovery from CaS, the time up to completion of the casting is preferably controlled. For that reason, when Al, Zr, REM, and Ca are added in this order in a molten steel treatment step, solidification of the molten steel is preferably completed within 200 minutes after the addition of Ca. It should be noted that the time from the addition of REM to the addition of Ca, which has a higher sulfide formation capability than REM, is preferably secured for four minutes or more. In such a step, Ca and REM tend to be present in the form of sulfides without forming any oxide.

[0061] After the casting in the manner mentioned above, the cast strip is heated and hot-rolled.

[0062] The heating temperature at which the cast strip is heated is preferably set in a range of 1,000 to 1,200°C. If the heating temperature is extremely low, Nb in the steel cannot be solid-soluted sufficiently, failing to secure the high yield strength. Thus, the lower limit of the heating temperature is more preferably 1,100°C or higher, and even more preferably 1,120°C or higher. However, if the heating temperature is extremely high, austenite grains are coarsened, degrading the low-temperature toughness of the base metal. Thus, the upper limit of the heating temperature is more preferably 1,180°C or lower.

[0063] Then, hot-rolling is performed. A hot-rolling start temperature is preferably 900 to 1,100°C. If the hot-rolling start temperature is extremely low, rolling in a austenite recrystallization region cannot be secured, thereby making austenite grains coarse, which might degrade the low-temperature toughness of the base metal. Thus, the lower limit of the hot-rolling start temperature is more preferably 930°C or higher, and even more preferably 950°C or higher. Meanwhile, if the hot-rolling start temperature is extremely high, austenite grains become coarse after recrystallization, which might degrade the low-temperature toughness of the base metal. Thus, the upper limit of the hot-rolling start temperature is more preferably 1,090°C or lower, and even more preferably 1,080°C or lower.

[0064] The rolling reduction performed at temperatures from 950°C to a hot-rolling end temperature is preferably 40 to 80%. If the rolling reduction is extremely low at temperatures from 950°C to the hot-rolling end temperature, strain to be introduced into austenite grains cannot be secured, so that the grains after the bainite transformation become coarse, which might degrade the low-temperature toughness of the base metal. Thus, the lower limit of the rolling reduction is more preferably 50% or more, and even more preferably 60% or more. Meanwhile, if the rolling reduction performed at temperatures from 950 °C to the hot-rolling end temperature is extremely high, excessive strain is introduced into austenite grains, thus degrading the hardenability of the steel. Thus, the upper limit of the rolling reduction is more preferably 77% or less, and even more preferably 75% or less.

[0065] The hot-rolling end temperature is preferably 770 to 880°C. If the hot-rolling end temperature is extremely low, excessive strain is introduced into austenite grains, thus degrading the hardenability of the steel. Thus, the lower limit of the hot-rolling end temperature is more preferably 790°C or higher, and even more preferably 800°C or higher. Meanwhile, if the hot-rolling end temperature is extremely high, strain to be introduced into austenite grains cannot be secured, making the grains after the bainite transformation coarse, which might degrade the low-temperature toughness of the base metal. Thus, the upper limit of the hot-rolling end temperature is more preferably 860°C or lower, and even more preferably 850°C or lower.

[0066] After the end of the hot-rolling, accelerated cooling is preferably performed in the following manner. It should be noted that the cooling is not necessarily limited to this condition.

[0067] A cooling start temperature after the end of the hot-rolling is preferably 730°C or higher. If the cooling start temperature is lower than 730°C, ferrite transformation is promoted to precipitate ferrite, so that the metal structure does not become bainite, thus making it difficult to secure the high yield strength of the base metal in some cases. Thus, the lower limit of the cooling start temperature is more preferably 735°C or higher, and even more preferably 740°C or higher. The upper limit of the cooling start temperature is not particularly limited, but is more preferably 860°C or lower, and even more preferably 850°C or lower.

[0068] After the end of the hot-rolling, the accelerated cooling is quickly performed preferably at an average cooling rate of 10 to 50°C/sec. Preferably, by setting an average cooling rate of the accelerated cooling to 10°C/sec or higher, the untransformed austenite is caused to be transformed into a bainite structure, thereby making it possible to prevent the precipitation of ferrite. Furthermore, the maximum hardness of bainite is enhanced, thereby easily improving the yield strength of the steel. Thus, the lower limit of the average cooling rate is more preferably 13°C/sec or higher, and even more preferably 15°C/sec or higher. Meanwhile, at an average cooling rate exceeding 50°C/sec, martensite transformation occurs in the vicinity of the surface of the steel plate, so that the yield strength of the steel plate is enhanced, but the hardness of the surface of the steel plate is remarkably increased, which easily degrades the formability into a steel pipe. Thus, the upper limit of the average cooling rate is preferably 50°C/sec or lower. The upper limit of the average cooling rate is more preferably 45°C/sec or lower in consideration of the formability into a steel pipe.

[0069] The cooling stop temperature is preferably set at 370 to 550°C. The cooling stop temperature is set at 370 to 550°C, so that the MA area ratio is reduced, and the high yield strength of 555 MPa or more can be easily obtained. Thus, the lower limit of the cooling stop temperature is more preferably 390°C or higher, and even more preferably 400°C or higher. The upper limit of the cooling stop temperature is more preferably 540°C or lower, and even more preferably 530°C or lower.

[0070] The non-heat-treated steel plate of the present invention can be obtained by cooling the steel plate to a temperature between 370 and 550°C, followed by normal cooling, such as allowing the steel plate to cool, to room temperature. Specifically, the average cooling rate at this time is preferably approximately 0.1 to 5°C/sec.

[0071] The plate thickness of the steel plate according to the present invention is not particularly limited, but when using the steel plate as the material for line pipes, the lower limit of the plate thickness is preferably 6 mm or more, and more preferably 10 mm or more. Meanwhile, the upper limit of the plate thickness of the steel plate is preferably 32 mm or less, and more preferably 30 mm or less from the viewpoint of suppressing precipitation of ferrite while securing a necessary cooling rate.

[0072] The non-heat-treated steel plate obtained in the way mentioned above is suitable for use, particularly, in line pipes. A line pipe obtained by using the non-heat-treated steel plate of the present invention reflects the properties of the non-heat-treated steel plate, so that the line pipe has excellent low-temperature toughness and hardness property of the HAZ and excellent yield strength.

[0073] This application claims priority based on Japanese Patent Application No. 2015-237839 filed on December 4, 2015, the disclosures of which is incorporated by reference herein.

Examples

[0074] The present invention will be more specifically described below by way of Examples but is not limited to the following Examples. Various modifications and changes can be made to these Examples and implemented as long as they are adaptable to the above-mentioned and below-mentioned concepts, and they are all included within the technical

scope of the present invention.

[0075] Steels of the types A to X having the compositions (with the balance being iron and inevitable impurities) shown in Table 1 below were melted into slabs, and then heated and hot-rolled under conditions shown in Table 2 below, followed by cooling under conditions shown in Table 2 below, thereby producing steel plates having a plate thickness of 20 mm.

[0076] Specifically, in Examples, 35Fe-30REM-35Si alloys containing 50% of Ce and 20% of La were used as REM. In the molten steel treatment step, after deoxidation with Al and Zr, REM and Ca were added. REM and Ca were added in this order, and the time from the addition of REM to the addition of Ca was set at 4 minutes or more. Further, a cast strip was produced so that solidification was completed within 200 minutes after the addition of Ca.

[0077] Further, after cooling to the cooling stop temperature shown in Table 2, the steel plate was allowed to cool to room temperature. The average cooling rate at this time is approximately 1°C/sec.

Measurement of Bainite Area Ratio

[0078] A test piece with dimensions of 20 mm × 15 mm × 15 mm was cut out of the above-mentioned steel plate, and its cross section parallel to the rolling direction was polished and subjected to nital corrosion. Then, the structure of the test piece at the 1/4 position of the plate thickness t was observed using an optical microscope at a magnification of 100 times, and a bainite area ratio was measured by image analysis assuming that the entire metal structure was set at 100%. The bainite area ratio was measured for three fields of view in total of each test piece, and an average of the measured values was determined. In Examples, the same observation as in bainite was performed on the remaining structure except for MA.

Measurement of MA Area Ratio

[0079] A test piece with dimensions of 20 mm × 15 mm × 15 mm was cut out of the above-mentioned steel plate, and its cross section parallel to the rolling direction was polished and subjected to repeller corrosion. Then, the structure of the test piece at the 1/4 position of the plate thickness t was observed using an optical microscope at a magnification of 1,000 times, and a MA area ratio was measured by image analysis assuming that the entire metal structure was 100%. The MA area ratio was measured for three fields of view in total of each test piece, and an average of the measured values was determined.

Measurement of Maximum Hardness of Bainite

[0080] A test piece with dimensions of 20 mm × 15 mm × 15 mm was cut out of the above-mentioned steel plate, and its cross section parallel to the rolling direction was exposed. Then, the bainite hardness of the structure of each test piece at a 1/4 position of the thickness t was measured in 20 points at equal intervals within a range of 100 μm × 100 μm with a Vickers tester under a load of 5 gf (0.049 N). Among these, an average value of measured values at the top three hardnesses refers to the maximum hardness of bainite.

Measurement of Yield Strength

[0081] A test piece was cut out of the above-mentioned steel plate based on the API5L standard such that the direction of the steel plate perpendicular to the rolling direction is oriented along the longitudinal side of the test piece. Then, 0.5% proof stress of each test piece was measured as the yield strength. Test pieces having a yield strength of the API standard X80grade, namely, 555 MPa or more and 705 MPa or less, were rated as pass.

Evaluation on Low-Temperature Toughness of Weld Heat-Affected Zone (HAZ)

[0082] A test piece with dimensions of 12 mm × 32 mm × 55 mm was cut from each of the above-mentioned steel plates Nos. 1 to 24 shown in Table 2 such that the direction of the steel plate perpendicular to the rolling direction is oriented along the longitudinal side of the test piece. This test piece was regarded as a reproducible heat cycle test piece. A heat cycle was applied to the reproducible heat cycle test piece. In the heat cycle, the maximum heating temperature was 1,350°C while simulating a coarse-grain heat affected zone in the vicinity of a melting line. In detail, the heat cycle includes heating at 1,350°C and holding at this temperature for 5 seconds, and then cooling in a temperature range of 800 to 500°C for 30 seconds. The low-temperature toughness of the HAZ was then evaluated by performing a Charpy impact test in the way specified by the API5L standard. The low-temperature toughness of the HAZ was evaluated by performing the Charpy impact test at -10°C. Test pieces having an absorption energy of 27 J or more were rated as pass.

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Evaluation on Hardness Property of Weld Heat-Affected Zone (HAZ)

[0083] A reproducible heat cycle test piece was taken out of each of the steel plates Nos. 1 to 24 shown in Table 2, in the same manner as the evaluation on the low-temperature toughness of the weld heat-affected zone. The heat cycle was applied to the test pieces. Then, the Vickers hardness test was performed on each test piece to evaluate the hardness property of the HAZ. The hardness of the HAZ refers to the maximum value of the Vickers hardness among the measured values at three points under a load of 98 N. Regarding the hardness property of the HAZ, test pieces having a hardness of the HAZ of less than 225 HV were rated as pass.

[0084] These results are shown in Table 2. The remaining structure, other than bainite and MA, was ferrite in all test pieces.

[Table 1]

Steel type	Composition (% by mass)														Formula (1)		Formula (2)		Formula (3)		
	C	Si	Mn	P	S	Nb	Ti	N	Zr	Ca	REM	Al	B	Mo	Cu	Ni	Cr	V	Ceq	A value	B value
A	0.07	0.30	1.92	0.007	0.0006	0.050	0.013	0.0039	0.0011	0.0015	0.0021	0.031	0.0000	0.25	0.00	0.00	0.00	0.000	0.44	3.08	2.52
B	0.07	0.30	1.59	0.007	0.0008	0.030	0.013	0.0039	0.0013	0.0017	0.0019	0.030	0.0008	0.00	0.00	0.00	0.25	0.000	0.39	2.02	2.04
C	0.07	0.30	1.60	0.007	0.0008	0.030	0.025	0.0038	0.0010	0.0018	0.0017	0.030	0.0007	0.10	0.00	0.00	0.10	0.000	0.38	2.26	2.05
D	0.07	0.31	1.60	0.007	0.0008	0.030	0.012	0.0048	0.0010	0.0017	0.0018	0.030	0.0000	0.10	0.00	0.00	0.25	0.000	0.41	2.26	2.05
E	0.07	0.30	1.80	0.007	0.0005	0.030	0.012	0.0047	0.0013	0.0015	0.0019	0.029	0.0000	0.00	0.00	0.24	0.00	0.000	0.39	2.27	2.41
F	0.07	0.31	1.86	0.007	0.0006	0.030	0.012	0.0043	0.0009	0.0017	0.0017	0.031	0.0000	0.15	0.00	0.00	0.00	0.000	0.41	2.66	2.36
G	0.07	0.30	1.50	0.007	0.0010	0.050	0.012	0.0040	0.0012	0.0015	0.0020	0.030	0.0000	0.00	0.00	0.00	0.25	0.000	0.32	2.05	2.01
H	0.04	0.30	1.79	0.007	0.0010	0.049	0.013	0.0047	0.0011	0.0018	0.0017	0.032	0.0000	0.15	0.00	0.00	0.25	0.000	0.42	2.71	2.36
I	0.07	0.11	1.89	0.007	0.0005	0.030	0.012	0.0044	0.0011	0.0016	0.0022	0.029	0.0000	0.00	0.00	0.00	0.25	0.000	0.43	2.37	2.40
J	0.06	0.30	1.06	0.007	0.0007	0.030	0.012	0.0042	0.0009	0.0015	0.0020	0.029	0.0000	0.00	0.16	0.19	0.20	0.000	0.30	1.41	1.49
K	0.06	0.30	1.06	0.007	0.0005	0.015	0.012	0.0045	0.0009	0.0016	0.0018	0.030	0.0001	0.00	0.16	0.19	0.20	0.000	0.30	1.32	1.43
L	0.07	0.30	1.51	0.007	0.0010	0.015	0.012	0.0043	0.0008	0.0018	0.0020	0.029	0.0000	0.00	0.00	0.00	0.25	0.000	0.32	1.83	1.88
M	0.07	0.30	1.62	0.007	0.0010	0.030	0.013	0.0047	0.0011	0.0014	0.0020	0.031	0.0000	0.00	0.00	0.39	0.25	0.000	0.42	2.06	2.27
N	0.07	0.32	1.61	0.007	0.0009	0.030	0.013	0.0042	0.0013	0.0018	0.0020	0.029	0.0000	0.00	0.00	0.00	0.40	0.000	0.42	2.05	2.06
O	0.06	0.31	1.06	0.007	0.0005	0.030	0.013	0.0044	0.0012	0.0015	0.0016	0.029	0.0000	0.00	0.16	0.19	0.40	0.000	0.34	1.41	1.49
P	0.07	0.31	1.50	0.007	0.0012	0.030	0.013	0.0042	0.0010	0.0018	0.0018	0.030	0.0001	0.00	0.00	0.00	0.00	0.060	0.33	1.92	1.93
Q	0.07	0.31	1.86	0.007	0.0012	0.050	0.013	0.0035	0.0011	0.0015	0.0018	0.032	0.0001	0.12	0.01	0.01	0.02	0.002	0.41	2.73	2.45
R	0.07	0.31	1.85	0.005	0.0008	0.050	0.012	0.0036	0.0010	0.0016	0.0018	0.035	0.0001	0.12	0.02	0.01	0.02	0.003	0.41	2.72	2.44
S	0.05	0.20	1.84	0.005	0.0005	0.045	0.012	0.0045	0.0008	0.0014	0.0019	0.032	0.0001	0.12	0.25	0.22	0.02	0.002	0.42	2.67	2.51
T	0.07	0.30	1.81	0.007	0.0005	0.049	0.013	0.0044	0.0009	0.0014	0.0017	0.031	0.0000	0.15	0.00	0.24	0.00	0.000	0.42	2.73	2.50
U	0.06	0.29	1.86	0.007	0.0005	0.051	0.012	0.0037	0.0012	0.0016	0.0018	0.030	0.0000	0.10	0.00	0.00	0.15	0.005	0.42	2.70	2.45
V	0.07	0.26	1.81	0.007	0.0006	0.051	0.013	0.0044	0.0008	0.0015	0.0021	0.030	0.0000	0.15	0.21	0.19	0.00	0.000	0.43	2.74	2.48
W	0.07	0.30	1.93	0.007	0.0006	0.050	0.013	0.0038	0.0009	0.0016	0.0017	0.031	0.0000	0.15	0.00	0.00	0.00	0.000	0.42	2.87	2.53
X	0.07	0.30	1.92	0.007	0.0005	0.051	0.013	0.0046	0.0010	0.0016	0.0020	0.031	0.0000	0.00	0.00	0.25	0.00	0.000	0.41	2.54	2.65

[Table 2]

No.	Steel type	Manufacturing conditions							Metal structure			Base metal property	Weld heat-affected zone (HAZ) properties	
		Heating temperature (°C)	Hot-rolling temperature (°C)	Rolling reduction from 950°C to hot-rolling end temperature (%)	Hot-rolling temperature (°C)	Average cooling rate (°C/sec)	Cooling start temperature (°C)	Cooling stop temperature (°C)	Bainite area ratio (%)	Maximum hardness of bainite (HV)	MA ratio (%)	Yield strength (MPa)	vE ₋₁₀ (J)	Maximum hardness (HV)
1	A	1,150	1,035	70	830	20	800	460	99	287	0.15	635	21	230
2	B	1,150	1,010	70	828	12	800	440	61	259	0.24	478	23	220
3	C	1,150	1,006	70	828	20	798	450	99	293	0.12	600	19	222
4	D	1,150	1,014	70	830	12	791	455	72	233	0.21	460	46	215
5	E	1,150	997	70	828	21	800	450	68	271	0.19	519	141	212
6	F	1,150	959	70	830	22	800	440	98	265	0.16	541	85	216
7	G	1,150	993	70	827	22	808	420	60	229	0.23	506	123	199
8	H	1,150	997	70	826	20	798	440	93	241	0.11	553	361	206
9	I	1,150	1,007	70	831	21	808	450	79	276	0.25	545	46	198
10	J	1,150	1,014	70	839	12	821	417	16	231	0.15	438	321	187
11	K	1,150	1,011	70	841	12	819	416	20	228	0.11	316	329	179
12	L	1,150	1,011	70	810	13	789	401	52	201	0.21	432	62	188
13	M	1,150	981	70	828	19	795	413	79	274	0.27	522	138	219
14	N	1,150	1,006	70	826	19	799	417	61	245	0.28	501	107	206
15	O	1,150	1,019	70	839	11	821	416	25	239	0.43	465	264	193
16	P	1,150	1,001	70	809	14	791	402	50	217	0.44	457	112	198
17	Q	1,160	997	73	828	37	740	460	99	288	0.18	619	48	222
18	R	1,130	1,048	73	835	39	740	430	99	285	0.15	622	42	219
19	S	1,150	1,071	73	817	35	770	520	96	277	0.13	579	487	209

(continued)

No.	Steel type	Manufacturing conditions								Metal structure			Base metal property	Weld heat-affected zone (HAZ) properties	
		Heating temperature (°C)	Hot-rolling temperature (°C)	Rolling reduction from 950°C to hot-rolling end temperature (%)	Hot-rolling temperature (°C)	Average cooling rate (°C/sec)	Cooling start temperature (°C)	Cooling stop temperature (°C)	Bainite area ratio (%)	Maximum hardness of bainite (HV)	MA ratio (%)	Yield strength (MPa)		vE ₋₁₀ (J)	Maximum hardness (HV)
20	T	1,150	981	70	831	27	800	460	99	280	0.11	604	45	215	
21	U	1,150	977	70	829	31	780	440	97	278	0.15	589	66	217	
22	V	1,150	995	70	827	22	816	445	99	279	0.04	610	64	222	
23	W	1,150	1,005	70	830	21	799	430	100	280	0.13	606	46	221	
24	X	1,150	972	70	829	25	800	400	84	276	0.25	563	31	216	

[0085] From these results, the following consideration can be made.

[0086] Steel plates Nos. 17 to 24 shown in Table 2 were manufactured using steel types Q to X shown in Table 1, satisfying the composition specified by the present invention, under manufacturing conditions for Nos. 17 to 24 shown in Table 2, satisfying the preferable requirements specified by the present invention. It is found that these steel plates thus obtained had satisfactory low-temperature toughness and hardness property of the HAZ as well as high yield strength of 555 MPa or more.

[0087] In contrast, the following steel plates Nos. 1 to 16 did not satisfy any one of the requirements specified by the present invention.

[0088] The steel plate No. 1 shown in Table 2 was an example in which individual elements of the composition satisfied the requirements specified by the present invention. However, this steel plate used the steel type A in Table 1 having a large Ceq. Consequently, the maximum hardness of the HAZ was increased due to the large Ceq, resulting in reduced low-temperature toughness of the HAZ.

[0089] The steel plate No. 2 shown in Table 2 was an example of using the steel type B shown in Table 1, in which a content of B was large and the A value and B value were small. Consequently, the yield strength was reduced because the bainite area ratio was small and the maximum hardness of bainite was low, and the low-temperature toughness of the HAZ was reduced because the B content was large.

[0090] The steel plate No. 3 shown in Table 2 was an example of using the steel type C shown in Table 1, in which the contents of B and Ti were large, and the A value and B value were small. Consequently, the low-temperature toughness of the HAZ was reduced because of the large contents of B and Ti. It should be noted that in this steel plate, although the A value and B value were small, the B content exceeded 0.0003%, and Mo was added in a complex manner, whereby the bainite area ratio, the maximum hardness of bainite, and the yield strength were increased.

[0091] The steel plate No. 4 shown in Table 2 was an example of using the steel type D shown in Table 1, in which the A value and B value were small. Consequently, the bainite area ratio was small, and the maximum hardness of bainite was low, resulting in reduced yield strength.

[0092] The steel plate No. 5 shown in Table 2 was an example of using the steel type E shown in Table 1, in which the A value was small. Consequently, the bainite area ratio was small, thus resulting in reduced yield strength.

[0093] The steel plate No. 6 shown in Table 2 was an example of using the steel type F shown in Table 1, in which the B value was small. Consequently, although the bainite area ratio was 80% by area or more, the maximum hardness of bainite was low, thus resulting in reduced yield strength.

[0094] The steel plate No. 7 shown in Table 2 was an example of using the steel type G shown in Table 1, in which Mo, Cu, Ni, Cr, and V were not contained, and the A value and B value were small. Consequently, none of Mo, Cu, Ni, Cr, and V was included, the bainite area ratio was small, and the maximum hardness of bainite was low, thus resulting in reduced yield strength.

[0095] The steel plate No. 8 shown in Table 2 was an example of using the steel type H shown in Table 1, in which the C content was small and the B value was small. Consequently, the C content was small, and the maximum hardness of bainite was low, thus resulting in reduced yield strength.

[0096] The steel plate No. 9 shown in Table 2 was an example of using the steel type I shown in Table 1, in which the Si content was small and the A value was small. Consequently, the Si content was small and the bainite area ratio was small, thus resulting in reduced yield strength.

[0097] The steel plate No. 10 shown in Table 2 was an example of using the steel type J shown in Table 1, in which the Mn content was small and the A value and B value were small. Consequently, the Mn content was small, the bainite area ratio was small, and the maximum hardness of bainite was low, thus resulting in reduced yield strength.

[0098] The steel plate No. 11 shown in Table 2 was an example of using the steel type K shown in Table 1, in which the Mn content and the Nb content were small, and the A value and B value were small. Consequently, the Mn content and the Nb content were small, the bainite area ratio was small, and the maximum hardness of bainite was low, thus resulting in reduced yield strength.

[0099] The steel plate No. 12 shown in Table 2 was an example of using the steel type L shown in Table 1, in which the Nb content was small, Mo, Cu, Ni, Cr, and V were not contained, and the A value and B value were small. Consequently, the Nb content was small and none of Mo, Cu, Ni, Cr, and V was contained, the bainite area ratio was small, and the maximum hardness of bainite was low, thus resulting in reduced yield strength.

[0100] The steel plate No. 13 shown in Table 2 was an example of using the steel type M shown in Table 1, in which the Ni content was large, and the A value and B value were small. Consequently, the amount of MA became large, and the bainite area ratio became small, thus resulting in reduced yield strength.

[0101] The steel plate No. 14 shown in Table 2 was an example of using the steel type N shown in Table 1, in which the Cr content was large and the A value and B value were small. Consequently, the amount of MA was large, the bainite area ratio was small, and the maximum hardness of bainite became low, thus resulting in reduced yield strength.

[0102] The steel plate No. 15 shown in Table 2 was an example of using the steel type O shown in Table 1, in which the Mn content was small, the Cr was large, and the A value and B value were small. Consequently, the Mn content

was small, the amount of MA was large, the bainite area ratio was small, and the maximum hardness of bainite became low, thus resulting in reduced yield strength.

[0103] The steel plate No. 16 shown in Table 2 was an example of using the steel type P shown in Table 1, in which the V content was large, and the A value and B value were small. Consequently, the amount of MA was large, the bainite area ratio was small, and the maximum hardness of bainite became low, thus resulting in reduced yield strength.

Claims

1. A non-heat-treated steel plate having high yield strength in which hardness of a weld heat-affected zone and degradation of low-temperature toughness of the weld heat-affected zone are suppressed, comprising, in percent by mass:

C: more than 0.04% and 0.10% or less;

Si: 0.15 to 0.50%;

Mn: 1.20 to 2.50%;

P: more than 0% and 0.020% or less;

S: more than 0% and 0.0050% or less;

Nb: 0.020 to 0.100%;

Ti: 0.003 to 0.020%;

N: 0.0010 to 0.0075%;

Zr: 0.0001 to 0.0100%;

Ca: 0.0005 to 0.0030%;

REM: 0.0001 to 0.0050%;

Al: 0.010 to 0.050%;

B: 0.0003% or less (including 0%); and

one or more elements selected from the group consisting of Mo: more than 0% and 0.30% or less, Cu: more than 0% and 0.30% or less, Ni: more than 0% and 0.30% or less; Cr: more than 0% and 0.30% or less; and V: more than 0% and 0.050% or less, with the balance being iron and inevitable impurities, wherein C_{eq} defined by the formula (1) below is less than 0.44, an A value defined by the formula (2) below is 2.50 or more, and a B value defined by the formula (3) below is 2.37 or more, and wherein area ratios of metal structures in a 1/4 position of a thickness of the steel plate satisfy bainite: 80% by area or more, and martensite-austenite constituent: 0% by area or more and 0.26% by area or less, and wherein a maximum hardness of the bainite is 270 HV or more:

$$C_{eq} = C + Mn/6 + (Cu + Ni)/15 + (Cr + Mo + V)/5 \quad (1)$$

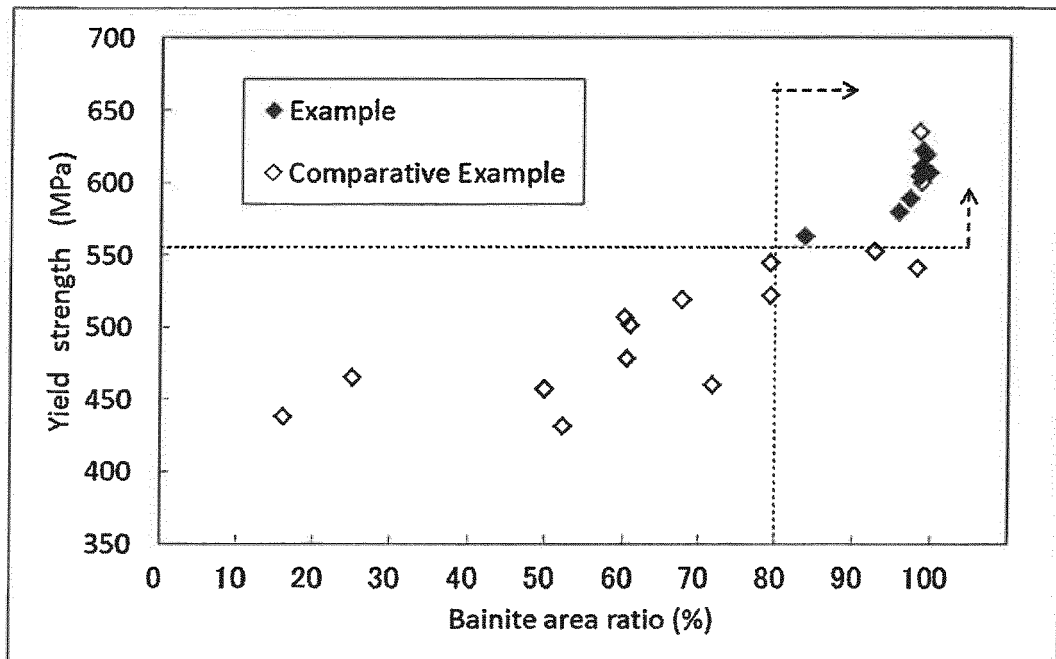
$$A \text{ value} = 1.15 \times Mn + 2.20 \times Mo + 6.50 \times Nb \quad (2)$$

$$B \text{ value} = 1.20 \times Mn + 0.50 \times Ni + 4.25 \times Nb \quad (3)$$

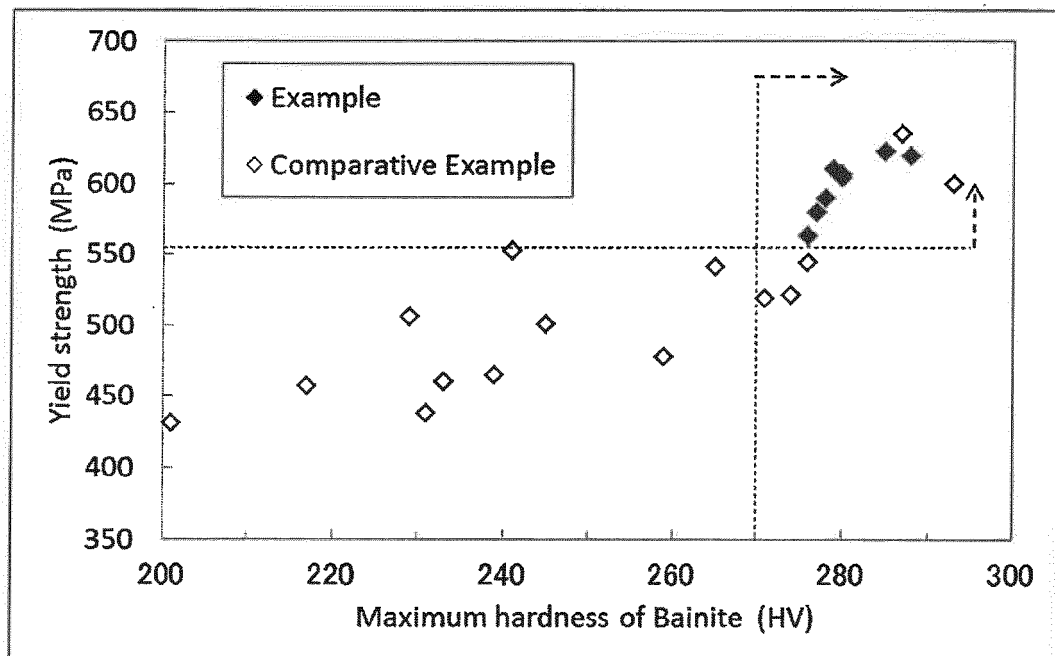
where C, Mn, Cu, Ni, Cr, Mo, V, and Nb represent the contents of C, Mn, Cu, Ni, Cr, Mo, V, and Nb in percent by mass, respectively.

2. The non-heat-treated steel plate according to claim 1, which is used for line pipes.

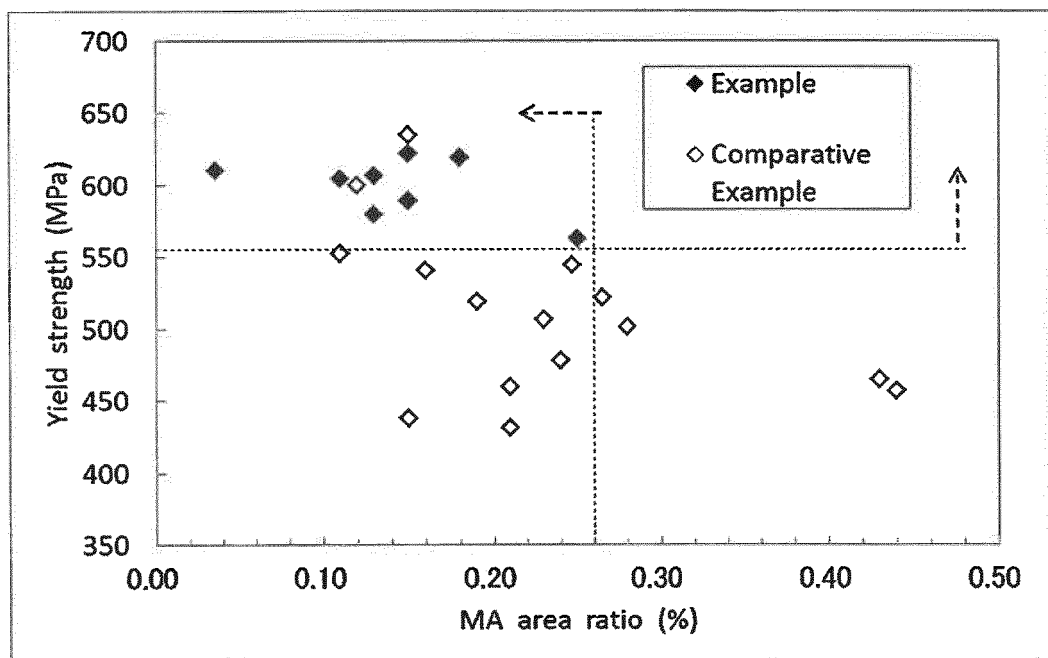
[Fig. 1]



[Fig. 2]



[Fig. 3]



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/084857

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00(2006.01)i, C22C38/58(2006.01)i, C21D8/02(2006.01)n

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)

C22C38/00-38/60, C21D8/02

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 1996-2017

Kokai Jitsuyo Shinan Koho 1971-2017 Toroku Jitsuyo Shinan Koho 1994-2017

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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A	JP 2003-160833 A (Kobe Steel, Ltd.), 06 June 2003 (06.06.2003), (Family: none)	1-2
A	JP 2011-6772 A (JFE Steel Corp.), 13 January 2011 (13.01.2011), & WO 2010/134220 A1 & EP 2434027 A1 & TW 201041683 A1 & KR 10-2012-0010260 A & CN 102428198 A	1-2
A	JP 2012-193411 A (Kobe Steel, Ltd.), 11 October 2012 (11.10.2012), & CN 102676950 A & KR 10-2012-0106613 A	1-2

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

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Date of the actual completion of the international search
16 February 2017 (16.02.17)Date of mailing of the international search report
28 February 2017 (28.02.17)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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REFERENCES CITED IN THE DESCRIPTION

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