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(54) THICK STEEL SHEET AND METHOD FOR PRODUCING SAME

(57) Provided is a thick steel plate which can preferably be used for members of, for example, industrial machines and transporting and conveying devices which are required to have abrasion resistance against, for example, rock, sand, ore, and slurry materials and a method for manufacturing the steel plate.

A thick steel plate having a chemical composition containing, by mass%, C: 0.200% or more and 0.350% or less, Si: 0.05% or more and 0.45% or less, Mn: 0.50% or more and 2.00% or less, P: 0.020% or less, S: 0.005% or less, Al: 0.005% or more and 0.100% or less, one, two, or more of Cu, Ni, Cr, Mo, V, Nb, Ti, B, REM, Ca, and Mg, and the balance being Fe and inevitable impurities, in which CI, which is defined by a particular equation, is 40 or more, and a steel microstructure in which the area fraction of a bainite phase is 60% or more, the area fraction of Martensite-Austenite constituent is 5% or more and less than 20%, and the remaining constituent phases are one, two, or all of a ferrite phase, a pearlite phase, and a martensite phase. After hot-rolling the steel having the chemical composition described above, accelerated cooling is performed to a temperature range of 400°C or higher and 650°C or lower.

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Description

Technical Field

[0001] The present invention relates to a thick steel plate which can preferably be used for members of, for example, industrial machines and transporting and conveying devices which are required to have abrasion resistance against, for example, rock, sand, ore, and slurry materials and a method for manufacturing the steel plate.

Background Art

[0002] The members of, for example, industrial machines such as power shovels, bulldozers, hoppers, buckets, and dump trucks and transporting and conveying devices such as steel pipes used for transporting slurry materials, which are used in the field sites of, for example, construction, civil engineering, and mines, are subjected to abrasion in use due to, for example, earth and sand.

[0003] Conventionally, it is known that there is an increase in the abrasion resistance of a steel material by increasing the hardness of the steel material. Therefore, to date, for example, steel materials whose hardness is increased by adding a large amount of alloy chemical elements have been used for some kinds of members which are required to have satisfactory abrasion resistance.

[0004] However, since it is known that increasing the hardness of steel materials in order to increase abrasion resistance is accompanied by a significant decrease in workability, there is a problem in that it is difficult to use high-hardness materials in applications in which it is necessary to perform work on the materials.

[0005] Therefore, there is a demand for a steel material excellent in terms of workability while maintaining excellent abrasion resistance. For example, Patent Literature 1 proposes a steel plate having a chemical composition containing, by mass%, C: 0.13% to 0.18%, appropriate amounts of Si, Mn, P, S, Al, B, and N, Cr: 0.5% to 2.0%, Mo: 0.03% to 0.3%, and Nb: 0.03% to 0.1%, in which the constituent chemical elements satisfy the condition that HI is 0.7 or more, in which Ceq is more than 0.50, and in which HB is 360 or more and 440 or less at a temperature of 25°C. Here, $HI = [C] + 0.59[Si] - 0.58[Mn] + 0.29[Cr] + 0.39[Mo] + 2.11([Nb]-0.02) - 0.72[Ti] + 0.56[V]$, and $Ceq = [C] + [Si]/24 + [Mn]/6 + [Ni]/40 + [Cr]/5 + [Mo]/4 + [V]/14$, where the atomic symbols respectively denote the contents (mass%) of the corresponding alloy chemical elements.

[0006] Patent Literature 1 describes that, according to the technique described above, by forming a martensite structure having a HB of about 400 by performing a quenching treatment, and by increasing the amount of a solid solution Nb, it is possible to increase high-temperature abrasion resistance.

[0007] Patent Literature 2 proposes a steel plate having a chemical composition containing, by mass%, C: 0.10% to 0.45%, appropriate amounts of Si, Mn, P, S, and N, and Ti: 0.10% to 1.0%, in which the number of TiC precipitates or compound precipitates of TiC with TiN and TiS having a grain diameter of 0.5 μm or more is 400 or more per 1 mm^2, and in which Ti*, which is expressed by a particular relational expression, is 0.05% or more and less than 0.4%.

[0008] Patent Literature 3 proposes an abrasion-resistant steel plate excellent in terms of workability, the steel plate having a chemical composition containing, by mass%, C: 0.05% to 0.35%, appropriate amounts of Si, Mn, and Al, Ti: 0.1% to 1.2%, in which DI*, which is expressed by a particular relational expression, is less than 60, and a microstructure including a ferrite phase-bainite phase structure as a matrix structure, in which hard phases are dispersed.

[0009] Patent Literature 2 and Patent Literature 3 describe that, according to the techniques described above, by forming precipitates mainly including TiC having a large grain diameter in a solidification process, it is possible to increase abrasion resistance at low cost.

Citation List

Patent Literature

[0010]

PTL 1: Japanese Patent No. 4590012
PTL 2: Japanese Patent No. 3089882
PTL 3: Japanese Unexamined Patent Application Publication No. 2010-222682

Summary of Invention

Technical Problem

[0011] However, in the case of the technique according to Patent Literature 1, it is difficult to say that good workability is achieved, because martensite structure is formed by performing a quenching process, which results in a high hardness of HB360 or more. In addition, in the case of the technique according to Patent Literature 1, since a large amount of alloy chemical elements is added, there is an increase in alloy costs.

[0012] In the case of the techniques according to Patent Literature 2 and Patent Literature 3, there is an increase in manufacturing costs, because, since TiC having a large grain diameter is formed in a solidification process, it is necessary to repair the surface of the slab before rolling is performed. In addition, it is not clear whether high-temperature abrasion resistance is achieved by using the techniques according to Patent Literature 2 and Patent Literature 3.

[0013] Therefore, an object of the present invention is to provide an inexpensive thick steel plate excellent in terms of workability and abrasion resistance and a method for manufacturing the steel plate.

Solution to Problem

[0014] The present inventors, in order to achieve the object described above, diligently conducted investigations regarding the influence of various factors on abrasion resistance, and, as a result, found that, by optimizing the chemical composition of a steel material, by controlling a value which is defined as the total content of plural alloy chemical elements in the chemical composition to be a certain value, and by forming a steel microstructure in which the area fraction of a bainite phase is 60% or more, the area fraction of Martensite-Austenite constituent (hereafter referred to as 'MA constituent') in the bainite phase is 5% or more and less than 20%, and the balance is one, two, or all of a ferrite phase, a pearlite phase, and a martensite phase, it is possible to provide a steel material with excellent abrasion resistance while maintaining good workability without excessively increasing the hardness of the steel material.

[0015] The present invention has been completed on the basis of the knowledge described above and additional investigations. That is, the subjective matter of the present invention is as follows.

[1] A thick steel plate excellent in terms of abrasion resistance, the thick steel plate having a chemical composition containing, by mass%,
C: 0.200% or more and 0.350% or less,
Si: 0.05% or more and 0.45% or less,
Mn: 0.50% or more and 2.00% or less,
P: 0.020% or less,
S: 0.005% or less,
Al: 0.005% or more and 0.100% or less, and
the balance being Fe and inevitable impurities,
in which CI, which is defined by equation (1) below,
satisfies the condition that CI is 40 or more,
and a steel microstructure in which the area fraction of a bainite phase is 60% or more, the area fraction of MA constituent in the bainite phase is 5% or more and less than 20% with respect to the whole microstructure, and the remaining constituent phases are one, or two or more of a ferrite phase, a pearlite phase, and a martensite phase.

$$CI = 60C + 8Si + 22Mn + 10(Cu + Ni) + 14Cr + 21Mo + 15V \quad \cdots (1)$$

In the equation, atomic symbols respectively denote the contents (mass%) of the corresponding alloy chemical elements. However, the content of a chemical element which is not contained is set to be 0.

[2] The thick steel plate excellent in terms of abrasion resistance according to item [1], the thick steel plate having the chemical composition further containing, by mass%, one or more selected from
Cu: 0.03% or more and 1.00% or less,
Ni: 0.03% or more and 2.00% or less,
Cr: 0.05% or more and 2.00% or less,
Mo: 0.05% or more and 1.00% or less,
V: 0.005% or more and 0.100% or less,
Nb: 0.005% or more and 0.100% or less,

Ti: 0.005% or more and 0.100% or less, and
B: 0.0003% or more and 0.0030% or less.
[3] The thick steel plate excellent in terms of abrasion resistance according to item [1] or [2], the thick steel plate having the chemical composition further containing, by mass%, one or more selected from
REM: 0.0005% or more and 0.0080% or less,
Ca: 0.0005% or more and 0.0050% or less, and
Mg: 0.0005% or more and 0.0050% or less.
[4] A method for manufacturing a thick steel plate excellent in terms of abrasion resistance, the method including:

heating a cast piece or a steel piece having the chemical composition according to any one of items [1] to [3] to a temperature of 950°C or higher and 1250°C or lower,
performing hot rolling with a finishing delivery temperature equal to or higher than Ar_3, and
performing accelerated cooling immediately after the hot rolling has been performed, at a cooling rate of 5°C/sec or
more to a temperature range of 400°C or higher and 650°C or lower.

[5] A method for manufacturing a thick steel plate excellent in terms of abrasion resistance, the method including:

heating a cast piece or a steel piece having the chemical composition according to any one of items [1] to [3] to a temperature of 950°C or higher and 1250°C or lower,
performing hot rolling,
performing air cooling to a temperature lower than 400°C,
then performing reheating to a temperature equal to or
higher than the Ac_3 and 950°C or lower, and
performing cooling immediately after the reheating has been performed, at a cooling rate of 5°C/sec or more to a temperature range of 400°C or higher and 650°C or lower.

Advantageous Effects of Invention

[0016] According to the present invention, it is possible to easily and stably manufacture an abrasion-resistant steel plate excellent in terms of workability and stably having excellent abrasion resistance, which has a marked effect on the industry.

Brief Description of Drawings

[0017] [Fig. 1] Fig. 1 is a diagram illustrating an abrasion test machine.

Description of Embodiments

[0018] In the present invention, a chemical composition and a steel microstructure are specified.

[Chemical composition]

[0019] In the description, % refers to mass%.

C: 0.200% or more and 0.350% or less

[0020] C is a chemical element which contributes to the formation of MA constituent and which is important for achieving excellent abrasion resistance. In the case where the C content is less than 0.200%, it is not possible to sufficiently realize the effects described above. On the other hand, in the case where the C content is more than 0.350%, there is a decrease in weldability and workability. Therefore, the C content is limited to be 0.200% or more and 0.350% or less, or preferably 0.210% or more and 0.300% or less.

Si: 0.05% or more and 0.45% or less

[0021] Si is an effective chemical element which functions as a deoxidizing agent for molten steel and which has a function of contributing to the formation of MA constituent by increasing hardenability. In order to realize such effects, the Si content is set to be 0.05% or more. On the other hand, in the case where the Si content is more than 0.45%, there is a decrease in weldability. Therefore, the Si content is limited to be 0.05% or more and 0.45% or less, or preferably 0.15% or more and 0.40% or less.

Mn: 0.50% or more and 2.00% or less

[0022] Mn is an effective chemical element which has a function of contributing to the formation of MA constituent by increasing hardenability. In order to realize such an effect, it is necessary that the Mn content be 0.50% or more. On the other hand, in the case where the Mn content is more than 2.00%, there is a decrease in weldability, and a large amount of MnS, which becomes the starting point at which fracturing occurs when work such as bending is performed, is formed. Therefore, the Mn content is limited to be 0.50% or more and 2.00% or less, or preferably 0.60% or more and 1.70% or less.

P: 0.020% or less

[0023] In the case where the P content in steel is large, there is a decrease in toughness. Therefore, it is preferable that the P content be as small as possible. In the present invention, it is acceptable that the P content be 0.020% or less. Therefore, the P content is limited to be 0.020% or less. Here, since excessively decreasing the P content causes an increase in refining costs, it is preferable that the P content be 0.005% or more.

S: 0.005% or less

[0024] In the case where the S content in steel is large, since S is precipitated in the form of MnS, there is a decrease in toughness, and MnS becomes the starting point at which fracturing occurs when work is performed. Therefore, it is preferable that the S content be as small as possible. In the present invention, it is acceptable that the S content be 0.005% or less. Therefore, the S content is limited to be 0.005% or less. Here, since excessively decreasing the S content causes an increase in refining costs, it is preferable that the S content be 0.0005% or more.

Al: 0.005% or more and 0.100% or less

[0025] Al is an effective chemical element which functions as a deoxidizing agent for molten steel. In order to realize such an effect, it is necessary that the Al content be 0.005% or more. In the case where the Al content is less than 0.005%, it is not possible to sufficiently realize such an effect. On the other hand, in the case where the Al content is more than 0.100%, there is a decrease in weldability and toughness. Therefore, the Al content is limited to be 0.005% or more and 0.100% or less, or preferably 0.015% or more and 0.040% or less.

$$CI = 60C + 8Si + 22Mn + 10(Cu + Ni) + 14Cr + 21Mo + 15V \geq 40$$

[0026] In the equation, atomic symbols respectively denote the contents (mass%) of the corresponding alloy chemical elements, and the content of a chemical element which is not contained is set to be 0.

[0027] In the case where CI is less than 40, since the steel microstructure described above is not formed due to insufficient quench hardenability, it is not possible to achieve good abrasion resistance. Therefore, CI is limited to be 40 or more, or preferably 44 or more. In addition, in the case where CI is excessively large, since there is an excessive increase in quench hardenability, there is a case where the steel microstructure described above is not formed due to an increase in the amount of martensite formed. Therefore, it is preferable that CI be 80 or less, or more preferably 75 or less.

[0028] The chemical composition described above is the basic chemical composition, and the balance is Fe and inevitable impurities. In the present invention, in order to improve properties, one, or two or more selected from among Cu, Ni, Cr, Mo, V, Nb, Ti, B, REM, Ca, and Mg may be added as selective chemical elements.

Cu: 0.03% or more and 1.00% or less

[0029] Cu is a chemical element which has an effect of contributing to the formation of MA constituent by increasing quench hardenability. In order to realize such an effect, it is necessary that the Cu content be 0.03% or more. On the other hand, in the case where the Cu content is more than 1.00%, there is a decrease in hot workability, and there is an increase in manufacturing costs. Therefore, in the case where Cu is added, it is preferable that the Cu content be limited to be 0.03% or more and 1.00% or less. Here, it is more preferable that the Cu content be limited to be 0.03% or more and 0.50% or less from the viewpoint of inhibiting a decrease in hot workability and of decreasing cost.

Ni: 0.03% or more and 2.00% or less

[0030] Ni is a chemical element which increases quench hardenability and which contributes to an increase in low-temperature toughness. In order to realize such effects, it is necessary that the Ni content be 0.03% or more. On the other hand, in the case where the Ni content is more than 2.00%, there is an increase in manufacturing costs. Therefore, in the case where Ni is added, it is preferable that the Ni content be limited to be 0.03% or more and 2.00% or less. Here, it is more preferable that the Ni content be limited to be 0.03% or more and 0.50% or less from the viewpoint of decreasing cost.

Cr: 0.05% or more and 2.00% or less

[0031] Cr is a chemical element which has an effect of contributing to the formation of MA constituent by increasing quench hardenability. In order to realize such an effect, it is necessary that the Cr content be 0.05% or more. On the other hand, in the case where the Cr content is more than 2.00%, there is a decrease in weldability, and there is an increase in manufacturing costs. Therefore, in the case where Cr is added, the Cr content is limited to be 0.05% or more and 2.00% or less, preferably 0.07% or more and 1.50% or less, or more preferably 0.20% or more and 1.00% or less.

Mo: 0.05% or more and 1.00% or less

[0032] Mo is a chemical element which has an effect of contributing to the formation of MA constituent by increasing quench hardenability. In order to realize such an effect, it is necessary that the Mo content be 0.05% or more. On the other hand, in the case where the Mo content is more than 1.00%, there is a decrease in weldability, and there is an increase in manufacturing costs. Therefore, in the case where Mo is added, the Mo content is limited to be 0.05% or more and 1.00% or less, preferably 0.10% or more and 0.80% or less, or more preferably 0.20% or more and 0.50% or less.

V: 0.005% or more and 0.100% or less

[0033] V is a chemical element which increases quench hardenability and which contributes to an increase in toughness through the effect of decreasing the grain diameter of a microstructure as a result of being precipitated in the form of carbonitrides. In order to realize such effects, it is necessary that the V content be 0.005% or more. On the other hand, in the case where the V content is more than 0.100%, there is a decrease in weldability. Therefore, in the case where V is added, the V content is limited to be 0.005% or more and 0.100% or less.

Nb: 0.005% or more and 0.100% or less

[0034] Nb is a chemical element which effectively contributes to an increase in toughness through the effect of decreasing the grain diameter of a microstructure as a result of being precipitated in the form of carbonitrides. In order to realize such an effect, it is necessary that the Nb content be 0.005% or more. On the other hand, in the case where the Nb content is more than 0.100%, there is a decrease in weldability. Therefore, in the case where Nb is added, the Nb content is limited to be 0.005% or more and 0.100% or less. Here, it is preferable that the Nb content be 0.010% or more and 0.030% or less from the viewpoint of decreasing the grain diameter of a microstructure.

Ti: 0.005% or more and 0.100% or less

[0035] Ti is a chemical element which contributes to an increase in toughness through fixing of solid solution N as a result of being precipitated in the form of TiN. In order to realize such an effect, it is necessary that the Ti content be 0.005% or more. On the other hand, in the case where the Ti content is more than 0.100%, since carbonitrides having a large grain diameter are precipitated, there is a decrease in toughness. Therefore, in the case where Ti is added, the Ti content is limited to be 0.005% or more and 0.100% or less. Here, it is preferable that the Ti content be limited to be 0.005% or more and 0.030% or less from the viewpoint of decreasing cost.

B: 0.0003% or more and 0.0030% or less

[0036] B is a chemical element which contributes to an increase in quench hardenability when added in small amounts. In order to realize such an effect, it is necessary that the B content be 0.0003% or more. On the other hand, in the case where the B content is more than 0.0030%, there is a decrease in toughness. Therefore, in the case where B is added, the B content is limited to be 0.0003% or more and 0.0030% or less.

REM: 0.0005% or more and 0.0080% or less

[0037] REM inhibits a decrease in toughness and the formation of MnS, which causes fracturing when work is performed, by fixing S. In order to realize such effects, it is necessary that the REM content be 0.0005% or more. On the other hand, in the case where the REM content is more than 0.0080%, since there is an increase in the amount of inclusions in steel, there is a decrease in toughness. Therefore, in the case where REM is added, the REM content is limited to be 0.0005% or more and 0.0080% or less, and preferably 0.0005% or more and 0.0020% or less.

Ca: 0.0005% or more and 0.0050% or less

[0038] Ca inhibits a decrease in toughness and the formation of MnS, which causes fracturing when work is performed, by fixing S. In order to realize such effects, it is necessary that the Ca content be 0.0005% or more. On the other hand, in the case where the Ca content is more than 0.0050%, since there is an increase in the amount of inclusions in steel, there is a decrease in toughness. Therefore, in the case where Ca is added, the Ca content is limited to be 0.0005% or more and 0.0050% or less, or preferably 0.0005% or more and 0.0030% or less.

Mg: 0.0005% or more and 0.0050% or less

[0039] Mg inhibits a decrease in toughness and the formation of MnS, which causes fracturing when work is performed, by fixing S. In order to realize such effects, it is necessary that the Mg content be 0.0005% or more. On the other hand, in the case where the Mg content is more than 0.0050%, since there is an increase in the amount of inclusions in steel, there is a decrease in toughness. Therefore, in the case where Mg is added, it is preferable that the Mg content be limited to be 0.0005% or more and 0.0050% or less, and more preferably 0.0005% or more and 0.0040% or less.

[Steel microstructure]

[0040] A steel microstructure including a bainite phase in an amount of 60% or more in terms of area fraction (also referred to as area ratio), MA constituent in the bainite phase in an amount of of 5% or more and less than 20% in terms of area fraction with respect to the whole microstructure, and the balance being one, or two or more of a ferrite phase, a pearlite phase, and a martensite phase is formed. By controlling the phase fractions as described above, there is an increase in the plastic deformation capability of a steel plate, which results in good workability. In addition, it is possible to achieve excellent abrasion resistance without excessively increasing the hardness of the steel plate.

Bainite phase: 60% or more in terms of area fraction

[0041] In the case where the area fraction of a bainite phase is less than 60%, it is not possible to achieve the desired abrasion resistance or the desired workability. Therefore the content of a bainite phase is set to be 60% or more, and preferably 80% or more, in terms of area fraction.

MA constituent: 5% or more and less than 20% in terms of area fraction

[0042] Since MA constituent finely disperses in a bainite phase and has a high hardness, MA constituent contributes to an increase in abrasion resistance. In the case where the area fraction of MA constituent is less than 5% with respect to the whole microstructure, it is not possible to achieve the desired abrasion resistance. On the other hand, in the case where the area fraction described above is 20% or more, the effect of increasing abrasion resistance becomes saturated, and there is an excessive increase in the hardness of a steel plate, which results in a decrease in workability and toughness. Therefore, the area fraction described above is set to be 5% or more and less than 20%. Here, since MA constituent is formed between the laths of a bainite phase or at the grain boundaries of a bainite phase, and has a small grain diameter, it is difficult to distinguish between a bainite phase and MA constituent by using an optical microscope. Therefore, MA constituent is seen as a part of a bainite phase. That is, in the calculation of the above-described area fraction of the bainite phase, the area of MA constituent is included in the area of the bainite phase. However, the area fraction of MA constituent is calculated with respect to the whole microstructure.

[0043] The remaining constituent phases of the steel microstructure other than a bainite phase are one, or two or more of a ferrite phase, a pearlite phase, and a martensite phase.

[0044] Hereafter, a method for manufacturing the thick steel plate according to the present invention will be described.

[0045] In the case where a steel material having the chemical composition described above has the specified temperature after casting has been performed, the steel material is subjected to hot rolling without cooling the steel material or after having first cooled and then heated the steel material in order to obtain a steel plate having specified dimensions and shape. Although it is not necessary to impose particular limitations on what method is used for manufacturing a steel material, it is preferable that molten steel be prepared by using a known casting method such as one using a converter and that the molten steel be made into a slab having specified dimensions by using a known method such as a continuous casting method. An ingot casting-slabbing method may also be used in order to obtain a slab.

[0046] The slab heating temperature is limited to be 950°C or higher and 1250°C or lower. In the case where the heating temperature is lower than 950°C, since there is an excessive increase in rolling load due to an increase in deformation resistance, there is a decrease in rolling efficiency. In addition, in order to stably achieve satisfactory abrasion resistance, it is necessary to uniformly form MA constituent across the whole steel plate. In the case where the heating temperature is lower than 950°C, since there is insufficient diffusion of segregated chemical elements such as C and Mn existing in a micro-segregation portion in a steel material, MA constituent is preferentially formed in the segregation portion, which results in an uneven distribution of MA constituent. On the other hand, in the case where the heating temperature is higher than 1250°C, since an excessive amount of scale is formed, there is a decrease in yield ratio, and there is an increase in energy consumption. Therefore, the heating temperature is limited to be 950°C or higher and 1250°C or lower. Here, "slab heating temperature" refers to an average temperature in the thickness direction of the slab derived by thermal transfer-thermal conduction calculation. The average temperature in the thickness direction of a slab is almost equal to the temperature at a position located at 1/4 of the thickness.

[0047] Hot rolling is performed with a finishing delivery temperature equal to or higher than Ar_3. In the case where the finishing delivery temperature is lower than the Ar_3, since ferrite is formed, a sufficient amount of bainite is not formed. Therefore, the finishing delivery temperature is set to be equal to or higher than the Ar_3. In addition, in the case where the finishing delivery temperature is excessively high, since austenite grains grow, there is an increase in austenite grain diameter. Therefore, since there is an excessive increase in the amount of martensite formed due to an excessive increase in quench hardenability, it is difficult to form the desired microstructure. Therefore, it is preferable that the upper limit of the finishing delivery temperature be 930°C or lower. Here, it is possible to determine the Ar_3 transformation temperature from a thermal expansion curve obtained when cooling is performed from a temperature range for forming austenite. In addition, "finishing delivery temperature" refers to the surface temperature of a steel plate.

[0048] Accelerated cooling is started immediately after the hot rolling has been performed. "Immediately" means "within 30 seconds" after the hot rolling has been performed. The cooling rate is set to be 5°C/sec or more, and the cooling stop temperature is set to be 400°C or higher and 650°C or lower. In the case where the cooling rate is less than 5°C/sec, since ferrite is formed, a sufficient amount of bainite is not formed. Therefore, the cooling rate is set to be 5°C/sec or more. In addition, although there is no particular limitation on the upper limit of the cooling rate, since the upper limit of the cooling rate of accelerated cooling is dependent on thermal transfer at the surface of the steel plate, practical cooling rate is 80°C/sec or less. Here, "cooling rate" refers to an average cooling rate at a position located at 1/4 of the thickness between the time accelerated cooling is started and the time accelerated cooling is stopped. In the present invention, the cooling start temperature, the cooling rate, the cooling stop temperature are specified in terms of the temperature at a position located at 1/4 of the thickness, because it is considered that the temperature at a position located at 1/4 of the thickness represent a temperature intermediate between that of the surface of the steel plate and that at a position at 1/2 of the thickness of the steel plate, and represents the average temperature of the whole thickness of the steel plate.

[0049] In the case where the cooling stop temperature is lower than 400°C, since bainite transformation is completed, a sufficient amount of MA constituent is not formed. On the other hand, in the case where the cooling stop temperature is higher than 650°C, since C is expended by pearlite formed when air cooling is further continued, a sufficient amount of MA constituent is not formed. Therefore, the cooling stop temperature is set to be 400°C or higher and 650°C or lower. Here, "cooling stop temperature" refers to the temperature at a position located at 1/4 of the thickness when accelerated cooling is stopped.

[0050] Instead of performing an accelerated cooling process after hot rolling has been performed, the accelerated cooling process may be performed after a process in which radiation cooling is performed after hot rolling has been performed to a temperature lower than 400°C in terms of the temperature at a position located at 1/4 of the thickness at which ferrite transformation or bainite transformation is completed and in which reheating is then performed to a temperature equal to or higher than Ac_3 and 950°C or lower. It is necessary that the accelerated cooling process be started before the temperature of the steel plate is lowered and ferrite transformation begins. Therefore, it is preferable that the accelerated cooling process be started within 30 seconds after the steel plate has been brought out of a reheating furnace.

[0051] In the case where the reheating temperature is lower than Ac_3, reverse transformation from ferrite to austenite does not sufficiently occur. Since it is necessary that the microstructure of the whole steel plate be transformed into austenite in the reheating process, reheating is performed to a temperature equal to or higher than the Ac_3 in terms of the temperature at a position located at 1/2t of the steel plate. In the case where the reheating temperature is higher than 950°C, there is a negative effect on toughness due to an increase in austenite grain diameter, and there is an increase in energy consumption. Therefore, the reheating temperature is set to be equal to or higher than the Ac_3 and 950°C or lower. "Reheating temperature" refers to the temperature at a position located at 1/2t of a steel plate, and the reheating temperature is derived by thermal transfer-thermal conduction calculation. Here, it is possible to determine the Ac_3 transformation temperature from a thermal expansion curve obtained when heating is performed from a temperature range for forming ferrite to a temperature range for forming austenite.

EXAMPLES

[0052] By preparing molten steels having the chemical compositions given in Table 1 by using a vacuum melting furnace, and by casting the molten steel into a casting mold, 150 kg of steel ingots (slabs) were manufactured. The obtained slabs were heated and subjected to hot rolling, and then accelerated cooling was performed. Here, some of the steel plates were cooled with air after hot rolling had been performed, further reheated, and then subjected to accelerated cooling.

[0053] By taking test pieces from the obtained steel plates, microstructure observation and an abrasion test were performed. The testing methods are as follows.

(1) Microstructure observation

[0054] By taking a test piece for microstructure observation from a position located at 1/4 of the thickness of the obtained steel plate so that the observation surface is a cross section parallel to the rolling direction, by then performing mirror polishing on the surface, and by performing nital etching, the microstructure was exposed. Subsequently, by observing three fields of view selected at random by using an optical microscope at a magnification of 400 times in order to obtain photographs, and by identifying a bainite phase through a visual test, an area ratio (bainite phase fraction) was calculated. Moreover, by performing mirror polishing again on the same test piece for microstructure observation, and by performing two-step etching, MA constituent was exposed. Subsequently, and by observing ten fields of view in a portion in which a bainite structure was formed by using a scanning electron microscope at a magnification of 2,000 times in order to obtain photographs, the area ratio of MA constituent (MA constituent phase fraction) was calculated by using image analysis software. Here, "area ratios" of a bainite phase and MA constituent refer to area ratios with respect to the whole microstructure.

(2) Abrasion test

[0055] By taking an abrasion test piece (having a thickness of 10 mm, a width of 25 mm, and a length of 75 mm) from the obtained steel plate so that a position located at 0.5 mm from the surface of the steel plate was a testing surface (abrasion surface), and by mounting the test piece on an abrasion test machine illustrated in Fig. 1, an abrasion test was performed.

[0056] The abrasion test piece was mounted in a direction at a right angle to the rotational axis of the rotor of the abrasion test machine so that the surface of 25 mm x 75 mm faces in the tangential direction of the circumference of the rotational circle, and then an abrasion material was loaded into the drum. Silica stone having an average grain diameter of 30 mm was used as an abrasion material.

[0057] The test was performed by rotating the rotor and the drum respectively at rotational speeds of 600 rpm and 45 rpm. After having rotating the rotor 10,000 times in total, the test was finished. After the test had been performed, the weight of each test piece was determined. By calculating the difference (= decrease in weight) between the weight after the test had been performed and the initial weight,
and by using the decrease in weight of SS400 (JIS G 3101 "Rolled steels for general structure") as a standard value, an abrasion resistance ratio ((standard value)/(decrease in weight of the test piece)) was calculated. A case where the abrasion resistance ratio was 1.5 or more was judged as the case of "excellent abrasion resistance".

(3) Bending workability

[0058] A 180-degree bending test was performed on a steel sample (having a width of 100 mm, a length of 300 mm, and the thickness of the original steel plate (t mm)) by using a pressing bend method with a bending radius of 2.0t (t: thickness) in accordance with JIS Z 2248 (2006). By performing a visual test, a case where a defect such as a crack or other was not found in the sample after the bending test had been performed was judged as the case of good bending workability.

[0059] The results of the tests described above are given along with the manufacturing conditions in Table 2. In the case of the examples of the present invention, that is, Nos. 1 through 15, 17, 18, and 20, the abrasion resistance ratio was 1.5 or more, which clarifies that these examples had excellent abrasion resistance. On the other hand, in the case of the comparative example No. 16 where the bainite phase fraction and the MA constituent phase fraction in the steel microstructure did not satisfy the requirements of the present invention, bending workability was poor. In addition, in the case of the comparative example No. 19 where the bainite phase fraction and the MA constituent phase fraction in the steel microstructure did not satisfy the requirements of the present invention, abrasion resistance was poor. In the case of Nos. 21 through 23 where the MA constituent phase fraction in the steel microstructure did not satisfy the requirements of the present invention, abrasion resistance was poor.

[Table 1]

(mass%)

Steel No.	C	Si	Mn	P	S	Al	Cr	Mo	Cu	Ni	V	Nb	Ti	B	REM	Ca	Mg	CI	Ac3 (°C)	Ar3 (°C)	Class
A	0.212	0.38	1.12	0.009	0.0025	0.025												40.4	835	755	Example
B	0.269	0.35	1.21	0.010	0.0023	0.030												45.6	805	730	Example
C	0.337	0.41	1.16	0.008	0.0026	0.030												49.0	777	713	Example
D	0.254	0.25	0.61	0.009	0.0023	0.026	0.87											42.8	814	769	Example
E	0.287	0.35	1.75	0.011	0.0030	0.029	0.36	0.23			0.041							69.0	797	657	Example
F	0.310	0.25	1.01	0.009	0.0025	0.024	0.70	0.09				0.023				0.0031		54.5	783	715	Example
G	0.223	0.30	1.86	0.007	0.0022	0.033			0.36	0.34			0.014	0.0013				63.7	798	666	Example
H	0.310	0.21	0.78	0.012	0.0021	0.022	0.51	0.16	0.09	0.08	0.067	0.021	0.010	0.0011	0.0041		0.0016	50.6	796	725	Example
I	0.221	0.31	0.73	0.008	0.0021	0.026	0.73					0.019	0.012	0.0009				42.0	832	772	Example
J	0.314	0.36	0.82	0.008	0.0025	0.024	0.56					0.018	0.011	0.0008				47.5	789	739	Example
K	0.287	0.32	0.99	0.008	0.0021	0.029	0.52	0.21			0.025	0.021	0.015	0.0011				53.6	808	717	Example
L	0.214	0.29	0.81	0.007	0.0026	0.024	0.47	0.13				0.022	0.013	0.0010				42.3	839	761	Example
M	0.231	0.36	0.93	0.008	0.0030	0.021	0.75	0.27			0.040	0.017	0.015	0.0011				54.0	842	731	Example
N	0.291	0.27	1.29	0.007	0.0020	0.036	0.10	0.14				0.023	0.015	0.0012				52.3	794	704	Example
O	0.279	0.38	0.69	0.007	0.0020	0.031	0.38	0.16				0.022	0.011	0.0011				43.6	818	750	Example
P	0.158	0.34	1.31	0.011	0.0025	0.034	0.17		0.21			0.014						45.5	850	749	Comparative Example
Q	0.297	0.41	0.48	0.013	0.0031	0.036	0.13	0.26		0.18	0.081	0.019						42.0	823	747	Comparative Example
R	0.243	0.29	0.89	0.013	0.0031	0.036	0.13	0.05				0.023						39.4	821	758	Comparative Example

Chemical composition is expressed in the units of mass%.

Note 1: An underlined portion indicates a value out of the range according to the present invention.

Note 2: CI = 60C + 8Si + 22Mn + 10(Cu + Ni) + 14Cr + 21Mo + 15V (the content of each chemical element is expressed in the units of mass%)

[Table 2]

Sample No.	Steel No.	Ac3 (°C)	Ar3 (°C)	Thickness (mm)	Heating Temperature (°C)	Rolling	Accelerated Cooling		Heating Treatment			Microstructure			Abrasion Resistance	Bending Workability(3	Class
						Finish Rolling Temperature (°C)	Cooling Rate (°C/s)	Accelerated Cooling Stop Temperature (°C)	Reheating Temperature (°C)	Cooling Rate (°C/s)	Cooling Stop Temperature (°C)	Bainite Phase Fraction (%)	Martensite-Austenite constituent Phase Fraction (%)	Other(2 (%)			
1	A	835	755	15	1120	910	51	480	-	-	-	87.8	5.4	12.2(M)	1.5	○	Example
2	B	805	730	20	1180	880	42	450	-	-	-	94.6	7.0	5.4(M)	1.7	○	Example
3	C	777	713	25	1100	850	29	530	-	-	-	93.4	8.1	6.6(M)	1.9	○	Example
4	D	814	769	35	1050	910	21	620	-	-	-	72.1	6.9	27.9(F+P)	1.6	○	Example
5	E	797	657	18	1120	820	45	520	-	-	-	86.0	9.9	14(M)	1.9	○	Example
6	F	783	715	15	1140	870	50	500	-	-	-	90.8	10.6	9.2(M)	2.1	○	Example
7	G	798	666	20	1180	890	40	430	-	-	-	94.1	8.9	5.9(M)	1.8	○	Example
8	H	796	725	25	1080	850	30	480	-	-	-	96.5	9.5	3.5(M)	2.0	○	Example
9	I	832	772	18	1050	910	47	600	-	-	-	80.9	7.3	19.1(M)	1.7	○	Example
10	J	789	739	20	1020	880	41	620	-	-	-	76.2	6.3	23.8(F)	1.6	○	Example
11	J	789	739	15	1120	820	-	-	900	48	500	94.2	9.6	5.8(M)	1.9	○	Example
12	K	808	717	32	1150	900	25	470	-	-	-	98.9	16.8	1.1(M)	2.6	○	Example
13	L	839	761	25	1150	870	30	550	-	-	-	86.3	8.9	13.7(M)	1.7	○	Example
14	M	842	731	20	1120	880	41	500	-	-	-	99.2	13.9	0.8(M)	2.4	○	Example
15	M	842	731	32	1180	890	-	-	890	24	600	93.2	10.6	6.8(F)	2.0	○	Example
16	M	842	731	15	1120	840	50	300	-	-	-	2.3	0.2	97.7(M)	2.1	×	Comparative Example
17	N	794	704	20	1120	860	41	450	-	-	-	94.9	11.3	5.1(M)	2.2	○	Example
18	N	794	704	25	1150	880	-	-	870	28	530	89.0	8.8	11(M)	2.0	○	Example
19	N	794	704	15	1080	840	52	700	-	-	-	2.2	0.1	97.8(F+P)	1.1	○	Comparative Example
20	O	818	750	32	1150	900	26	580	-	-	-	82.4	9.2	17.6(M)	2.1	○	Example
21	P	850	749	20	1180	910	41	500	-	-	-	81.3	0.9	18.7(M)	1.1	○	Comparative Example
22	Q	823	747	15	1120	880	50	550	-	-	-	76.6	3.1	23.4(M)	1.3	○	Comparative Example
23	R	821	758	30	1080	900	24	470	-	-	-	84.3	1.5	15.7(M)	1.3	○	Comparative Example

Note 1: An underlined portion indicates a value out of the range according to the present invention.
Note 2: F: ferrite, P: pearlite, M: martensite
Note 3: bending workability ○: without a crack, ×: with a crack

Claims

1. A thick steel plate having a chemical composition containing, by mass%,
   C: 0.200% or more and 0.350% or less,
   Si: 0.05% or more and 0.45% or less,
   Mn: 0.50% or more and 2.00% or less,
   P: 0.020% or less,
   S: 0.005% or less,
   Al: 0.005% or more and 0.100% or less, and
   the balance being Fe and inevitable impurities,
   wherein CI, which is defined by equation (1) below,
   satisfies the condition that CI is 40 or more,
   and a steel microstructure in which the area fraction of a bainite phase is 60% or more, the area fraction of Martensite-Austenite constituent in the bainite phase is 5% or more and less than 20% with respect to the whole microstructure, and
   the remaining constituent phases are one, or two or more of a ferrite phase, a pearlite phase, and a martensite phase:

   $$CI = 60C + 8Si + 22Mn + 10(Cu + Ni) + 14Cr + 21Mo + 15V \quad \cdot\cdot\ (1),$$

   where, in the equation, atomic symbols respectively denote the contents (mass%) of the corresponding alloy chemical elements, and where the content of a chemical element which is not contained is set to be 0.

2. The thick steel plate according to Claim 1, the thick steel plate having the chemical composition further containing, by mass%, one or more selected from
   Cu: 0.03% or more and 1.00% or less,
   Ni: 0.03% or more and 2.00% or less,
   Cr: 0.05% or more and 2.00% or less,
   Mo: 0.05% or more and 1.00% or less,
   V: 0.005% or more and 0.100% or less,
   Nb: 0.005% or more and 0.100% or less,
   Ti: 0.005% or more and 0.100% or less, and
   B: 0.0003% or more and 0.0030% or less.

3. The thick steel plate according to Claim 1 or 2, the thick steel plate having the chemical composition further containing, by mass%, one or more selected from
   REM: 0.0005% or more and 0.0080% or less,
   Ca: 0.0005% or more and 0.0050% or less, and
   Mg: 0.0005% or more and 0.0050% or less.

4. A method for manufacturing a thick steel plate, the method comprising:

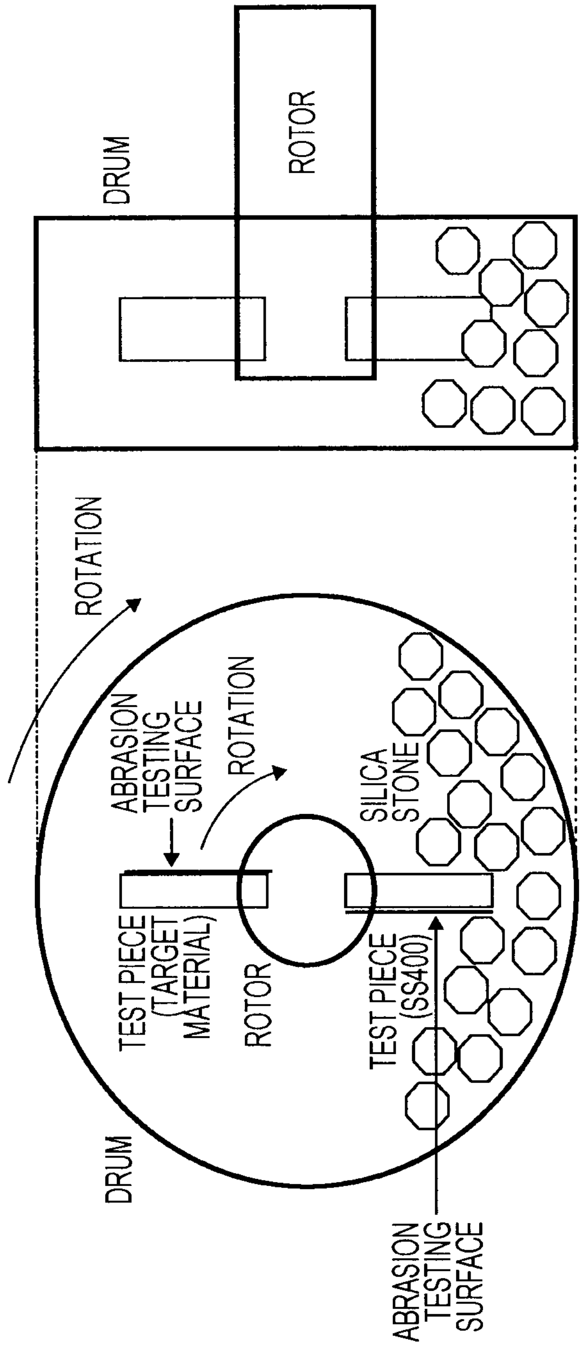
   heating a cast piece or a steel piece having the chemical composition according to any one of Claims 1 to 3 to a temperature of 950°C or higher and 1250°C or lower,
   performing hot rolling with a finishing delivery temperature equal to or higher than Ar_3, and
   performing accelerated cooling immediately after the hot rolling has been performed, at a cooling rate of 5°C/sec or
   more to a temperature range of 400°C or higher and 650°C or
   lower.

5. A method for manufacturing a thick steel plate, the method comprising:

   heating a cast piece or a steel piece having the chemical composition according to any one of Claims 1 to 3 to a temperature of 950°C or higher and 1250°C or lower,
   performing hot rolling,
   performing air cooling to a temperature lower than 400°C,

then performing reheating to a temperature equal to or
higher than the Ac_3 and 950°C or lower, and
performing cooling immediately after the reheating has been performed, at a cooling rate of 5°C/sec or more to a temperature range of 400°C or higher and 650°C or lower.

FIG. 1


DRUM
ROTOR
ROTATION
ABRASION TESTING SURFACE
ROTATION
SILICA STONE
TEST PIECE (TARGET MATERIAL)
ROTOR
TEST PIECE (SS400)
DRUM
ABRASION TESTING SURFACE

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2015/001559

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D8/02*(2006.01)i, *C22C38/06*(2006.01)i, *C22C38/58*(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00-38/60, 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	1996-2015
Kokai Jitsuyo Shinan Koho	1971-2015	Toroku Jitsuyo Shinan Koho	1994-2015

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	JP 62-174322 A (Kobe Steel, Ltd.), 31 July 1987 (31.07.1987), claims; page 5, line 6 to page 6, line 11; table 1, steel D; table 2, comparative steel D1 (Family: none)	2 1,3-5
X A	JP 2010-174343 A (JFE Steel Corp.), 12 August 2010 (12.08.2010), paragraphs [0032], [0040] to [0047]; table 1, steel no.C, O; table 2, steel plate no.14; table 3, steel plate no.26 (Family: none)	2-4 1,5

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

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"E" earlier application or patent but published on or after the international filing date	"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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"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	"&" document member of the same patent family

Date of the actual completion of the international search 22 May 2015 (22.05.15)	Date of mailing of the international search report 02 June 2015 (02.06.15)
Name and mailing address of the ISA/ Japan Patent Office 3-4-3,Kasumigaseki,Chiyoda-ku, Tokyo 100-8915,Japan	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2015/001559

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	JP 2010-222682 A (JFE Steel Corp.), 07 October 2010 (07.10.2010), paragraphs [0052] to [0064]; table 1, steel I; table 2, steel plate no.10 (Family: none)	2,4 1,3,5
X A	WO 2001/042523 A1 (NKK Corp.), 14 June 2001 (14.06.2001), page 12, line 1 to page 13, line 8; table 1, steel type D; table 2, comparative example 6 & AU 200117325 A	2,4 1,3,5
X A	JP 10-251794 A (Nisshin Steel Co., Ltd.), 22 September 1998 (22.09.1998), paragraphs [0014] to [0022]; table 1, steel type 2 (Family: none)	4 1-3,5
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A	JP 2008-214736 A (JFE Steel Corp.), 18 September 2008 (18.09.2008), claims 1 to 5 (Family: none)	1-5
A	JP 2010-174342 A (JFE Steel Corp.), 12 August 2010 (12.08.2010), claims 1 to 7 (Family: none)	1-5

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- JP 3089882 B **[0010]**
- JP 2010222682 A **[0010]**