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(54) **STEEL SHEET**

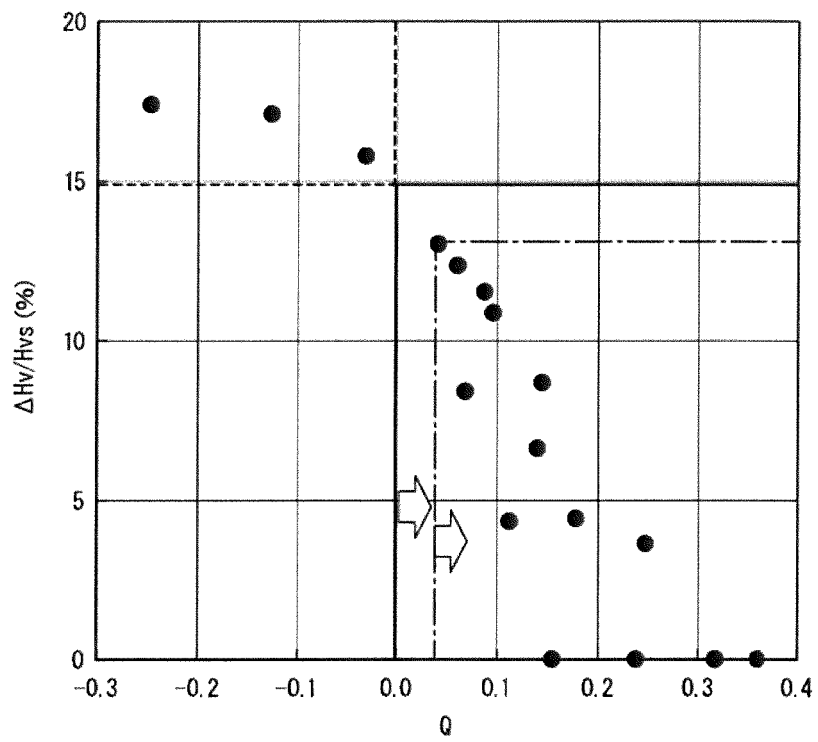
(57) A steel plate according to an aspect of the present invention has a predetermined chemical composition, an index Q obtained by Equation (1) is 0.00 or more, a carbon equivalent Ceq (%) obtained by Equation (2) is less than 0.800%, a ratio of a difference between a hardness at a surface layer portion and a hardness at a thickness center portion to the hardness at the surface layer portion at a room temperature is 15.0% or less, the hardness at the surface layer portion at a room temperature is 400 or more in terms of Vickers hardness, and a steel thickness is 40 mm or more.

$$Q = 0.18 - 1.3(\log T) + 0.75(2.7 \times [C] + [Mn] + 0.45 \times [Ni] + 0.8 \times [Cr] + 2 \times [Mo]) \dots (1) \quad (1)$$

$$Ceq (\%) = [C] + [Mn]/6 + [Si]/24 + [Ni]/40 + [Cr]/5 + [Mo]/4 + [V]/4 \dots (2) \quad (2)$$

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FIG. 3



Description

[Technical Field of the Invention]

[0001] The present invention relates to a steel plate (wear-resistant steel plate) having excellent wear resistance.
[0002] Priority is claimed on Japanese Patent Application No. 2017-121641, filed on June 21, 2017, the content of which is incorporated herein by reference.

[Related Art]

[0003] For applications such as construction machines and industrial machines, a wear-resistant steel plate that can be used over a long period of time is required even under a severe wear environment, and from the viewpoint of securing a wear margin due to an increase in steel thickness, an improvement in wear resistance is required. In general, in order to improve the wear resistance of a steel plate, it is necessary to increase the hardness of the steel plate. Particularly in a thick wear-resistant steel plate having a steel thickness of 40 mm or more, an object thereof is to secure not only the hardness in the vicinity of the surface of the steel plate (hereinafter, sometimes referred to as "hardness at a surface layer portion", and a surface layer portion is a region of 1 mm to 5 mm from the surface of the steel plate in the through-thickness direction) but also the hardness in the center portion in the through-thickness direction (hereinafter, sometimes referred to as "hardness at a thickness center portion", and the center portion is a region of ± 5 mm (10 mm in total thickness) from a position (that is, the center of the steel thickness) away from the surface of the steel plate by $1/2$ of the steel thickness T (that is, $T/2$) in the through-thickness direction) in which it is difficult to obtain hardness.

[0004] Since wear-resistant steel plates are locally exposed to a temperature higher than a room temperature and sometimes used under severe environments, there may be cases where the wear-resistant steel plates are required to have a small decrease in hardness (excellent high-temperature hardness) even in a temperature range higher than a room temperature (for example, a temperature range of about 150°C to 300°C). Steel plates in which the Si content is increased to secure hardness in a temperature range higher than a room temperature (hereinafter, sometimes referred to as "high-temperature hardness") have been proposed (for example, refer to Patent Documents 1 to 3).

[Prior Art Document]

[Patent Documents]

[0005]

[Patent Document 1] Japanese Unexamined Patent Application, First Publication No. H8-41535
 [Patent Document 2] Japanese Unexamined Patent Application, First Publication No. 2001-49387
 [Patent Document 3] Japanese Unexamined Patent Application, First Publication No. 2002-235144

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0006] For example, Patent Document 1 proposes a steel plate having a Si content of 0.40 to 1.50 mass% (hereinafter, "mass%" is simply referred to as "%") and containing Nb. However, in Patent Document 1, the steel thickness of the steel plate is 40 mm or less, the hardness at the thickness center portion thereof is not described, and there is no examination from the viewpoint of securing a wear margin due to an increase in the thickness of the steel plate.

[0007] In Patent Document 2, a severe wear environment locally exposed to a temperature higher than a room temperature is postulated, and a steel which contains Si in an amount of more than 0.5% to 1.2% in order to secure the high-temperature hardness of the steel and uses precipitation strengthening caused by V carbide is proposed. However, the steel containing a large amount of V is liable to cause cracking of cast pieces, and there is concern of a decrease in manufacturability.

[0008] Patent Document 3 proposes a steel plate containing 1.00% to 1.50% of Si in order to secure the high-temperature hardness of the steel plate. In Patent Document 3, it is considered to secure the hardness at the thickness center portion of the steel plate. However, the difference between the hardness at the surface layer portion and the hardness at the thickness center portion (hereinafter, sometimes referred to as "hardness difference between the surface layer portion and the thickness center portion", or simply "hardness difference") is not described, and there is no examination from the viewpoint of securing a wear margin due to an increase in the thickness of the steel plate.

[0009] Considering the use environment and use form of a wear-resistant steel plate, there may be cases where

maintenance of a high hardness even not only at a room temperature but also in a high-temperature environment at about 150°C to 300°C, and a sufficient hardness for the center portion in the through-thickness direction (thickness center portion) are required. Although the hardness at the thickness center portion can be easily secured by increasing the amounts of alloying elements, due to a decrease in weldability, the upper limit of a carbon equivalent needs to be provided. In order to secure the hardness of the steel plate in a high-temperature environment, addition of Si in an amount of more than 1.00% is considered to be effective. However, the inventors found that in a steel plate containing Si in an amount of more than 1.00%, there is a tendency toward a significant increase in the difference between the hardness at the surface layer portion and the hardness at the thickness center portion, which is not preferable regarding the wear resistance of the steel plate.

[0010] There has been no report on the relationship between the steel plate containing Si in an amount of more than 1.00% and the hardness difference, and there have been insufficient examinations for reducing the hardness difference at a room temperature. The present invention has been made taking the foregoing circumstances into consideration, and an object thereof is to provide a steel plate having excellent wear resistance, in which high hardness can be maintained even in a high-temperature environment as well as at a room temperature, the carbon equivalent of a steel plate particularly having a steel thickness of 40 mm or more is set to be less than 0.800%, and the difference between a hardness at a surface layer portion and a hardness at a thickness center portion at a room temperature is set to 15.0% or less of the hardness at the surface layer portion.

[Means for Solving the Problem]

[0011] Steels containing Si in an amount of more than 1.00% to 2.00% are advantageous in terms of wear resistance because hardness can be secured at a room temperature and high temperatures. On the other hand, it was found by the examinations of the inventors that in a steel plate containing Si in an amount of more than 1.00% and having a steel thickness of 40 mm or more, a difference between a hardness at a surface layer portion and a hardness at a thickness center portion is likely to occur at a room temperature. This is because the cooling rate at the center portion of the steel plate in the through-thickness direction is lower than that at the surface and surface layer portion, and a martensite structure is insufficiently formed. However, the influence of an increase in the Si content is not necessarily clear.

[0012] As a further examination, the inventors derives an index Q for reducing the difference between a hardness at a surface layer portion and a hardness at a thickness center portion at a room temperature in a steel plate having a steel thickness of 40 mm or more and containing Si in an amount of more than 1.00%. The index Q is obtained by Equation (1) in which the hardenability of alloying elements and the steel thickness are considered. However, in Equation (1), since attention is paid to the alloying elements (C, Mn, Ni, Cr, and Mo) other than Si, which are necessary to reduce the difference between the hardness at the surface layer portion and the hardness at the thickness center portion of the steel plate containing Si in an amount of more than 1.00%, the amount of Si is not considered. In the following description, the hardness at a room temperature is sometimes referred to as "a room-temperature hardness". In the following, simply "hardness" represents hardness at a room temperature, and a room temperature represents 22±5°C (17°C to 27°C).

[0013] The steel plate according to the present invention has a steel thickness of 40 mm or more and when the steel plate is affected by residual stress due to welding or the like, there is concern of delayed cracking due to hydrogen. Therefore, the carbon equivalent Ceq (%) obtained by Equation (2) is less than 0.800%. By causing the index Q obtained by Equation (1) to be 0.00 or more, the hardness difference between the surface layer portion and the thickness center portion at a room temperature becomes 15.0% or less of the hardness at the surface layer portion, so that a steel plate having a small hardness difference, a low carbon equivalent, a steel thickness of 40 mm or more, and excellent wear resistance can be obtained. The unit of the index Q obtained by substituting dimensionless numerical values for the steel thickness T and the amount [X] of each element X in Equation (1) is dimensionless. In addition, the unit of the carbon equivalent Ceq obtained by Equation (2) is "%".

$$Q = 0.18 - 1.3(\log T) + 0.75(2.7 \times [C] + [Mn] + 0.45 \times [Ni] + 0.8 \times [Cr] + 2 \times [Mo]) \dots (1)$$

$$Ceq (\%) = [C] + [Mn]/6 + [Si]/24 + [Ni]/40 + [Cr]/5 + [Mo]/4 + [V]/4 \dots (2)$$

[0014] Here, the index Q of Equation (1) is calculated by substituting the numerical value of the steel thickness T (mm), the numerical value of the amount [X] of each element X in terms of mass% and 0 in a case where the element X is not contained. The carbon equivalent Ceq (%) of Equation (2) is calculated by substituting the numerical value of the amount [X] of each element X in terms of mass% and 0 in a case where the element X is not contained.

[0015] The present invention has been made based on the above findings, and the gist thereof is as follows.

[1] A steel plate according to an aspect of the present invention includes, as a chemical composition, by mass%:

C: 0.20% to 0.35%;
 Si: more than 1.00% to 2.00%;
 Mn: 0.60% to 2.00%;
 Cr: 0.10% to 2.00%;
 Mo: 0.05% to 1.00%;
 Al: 0.010% to 0.100%;
 N: 0.0020% to 0.0100%;
 B: 0.0003% to 0.0020%;
 P: 0.0200% or less;
 S: less than 0.0100%;
 Cu: 0% to 0.500%;
 Ni: 0% to 1.00%;
 Nb: 0% to 0.050%;
 V: 0% to 0.120%;
 Ti: 0% to 0.025%;
 Ca: 0% to 0.050%;
 Mg: 0% to 0.050%;
 REM: 0% to 0.100%; and
 a remainder consisting of Fe and impurities,
 in which an index Q obtained by Equation (1) is 0.00 or more;
 a carbon equivalent Ceq (%) obtained by Equation (2) is less than 0.800%;
 a ratio of a difference between a hardness at a surface layer portion and a hardness at a thickness center portion
 to the hardness at the surface layer portion at a room temperature is 15.0% or less and the hardness at the
 surface layer portion at a room temperature is 400 or more in terms of Vickers hardness; and
 a steel thickness T is 40 mm or more,

$$Q = 0.18 - 1.3(\log T) + 0.75(2.7 \times [C] + [Mn] + 0.45 \times [Ni] + 0.8 \times [Cr] + 2 \times [Mo]) \dots(1)$$

$$Ceq (\%) = [C] + [Mn]/6 + [Si]/24 + [Ni]/40 + [Cr]/5 + [Mo]/4 + [V]/4 \dots(2)$$

where the index Q of Equation (1) is calculated by substituting a numerical value of the steel thickness T (mm),
 a numerical value of an amount [X] of each element X in terms of mass% and 0 in a case where the element
 X is not contained, the carbon equivalent Ceq (%) of Equation (2) is calculated by substituting a numerical value
 of an amount [X] of each element X in terms of mass% and 0 in a case where the element X is not contained.

[2] In the steel plate according to [1], the index Q may be 0.04 or more, and
 the ratio may be 13.0% or less.

[3] In the steel plate according to [1] or [2], as the chemical composition, by mass%,
 Ni is 0.05% to 1.00%.

[4] In the steel plate according to any one of [1] to [3], as the chemical composition, by mass%,
 Mn is 0.63% to 2.00%.

[Effects of the Invention]

[0016] According to the aspect of the present invention, it is possible to provide a steel plate having excellent wear
 resistance, in which high hardness can be maintained even in a high-temperature environment as well as at a room
 temperature, the carbon equivalent Ceq (%) of a steel plate particularly having a steel thickness of 40 mm or more is
 less than 0.800%, and the difference between the hardness at the surface layer portion and the hardness at the thickness
 center portion at a room temperature is set to 15.0% or less of the hardness at the surface layer portion. The steel plate
 according to the present invention can be used over a long period of time even in a severe environment at a temperature
 of about 150°C to 300°C and thus the contribution thereof to the industry is extremely remarkable.

[Brief Description of the Drawings]

[0017]

FIG. 1 is a view illustrating a change in the difference between a surface hardness of a steel plate and a reference hardness with temperature.

FIG. 2 is a view illustrating hardness distributions of steel plates in a through-thickness direction.

FIG. 3 is a view illustrating the relationship between a hardness difference ratio $\Delta H_v/H_{vs}$ of the steel plate and an index Q.

[Embodiments of the Invention]

[0018] The relationship between the Si content of a steel plate and a change in hardness with temperature will be described with reference to FIG. 1. FIG. 1 is a view illustrating a change in the difference between a surface hardness of the steel plate and a reference hardness with temperature. A result of performing hardening on steel plates having a constant C content, a varying Si content, and a steel thickness of 40 mm and measuring the Vickers hardness (surface hardness) HV5 at the surface of the steel plate from a room temperature to 400°C is shown in FIG. 1. The vertical axis in FIG. 1 is the difference between the Vickers hardness (surface hardness) HV5 at each temperature of each steel and the Vickers hardness (reference hardness) HV5 at a room temperature of a steel plate having a Si content of 0.25%. The Vickers hardness HV5 was measured by cutting out a sample from a position of 5 mm deep from the surface of the steel plate and conducting a high-temperature Vickers hardness test based on JIS Z 2252-1991 with a test force of 49.03 N (5kgf). The reference hardness was measured under the same conditions as those of the high-temperature Vickers hardness test described above except for temperature control.

[0019] From FIG. 1, it can be seen that the room-temperature hardness and the high-temperature hardness are increased by the increase in the Si content and a reduction in hardness (the difference between the surface hardness and the reference hardness) in a high-temperature environment also decreases. As described above, it can be seen that a steel plate containing Si in an amount of more than 1.00% to 2.00% can secure hardness at a room temperature and high temperatures and thus has excellent wear resistance.

[0020] Next, FIG. 2 shows hardness distributions (Vickers hardness) of steel plates (steel thickness 40 mm) containing Si in an amount of more than 1.00% in the through-thickness direction after hardening. The Vickers hardness HV5 was measured based on JIS Z 2244: 2009 at a room temperature with a test force of 49.03 N (5 kgf). As shown in FIG. 2, a hardness at a thickness center portion is lower than a hardness at a surface layer portion. Furthermore, from the results of the Vickers hardness test, the hardness at the surface layer portion H_{vs} (the average value of Vickers hardnesses measured in a range of 1 mm to 5 mm from the surface of the steel plate in the through-thickness direction) and the hardness at the thickness center portion H_{vc} (the average value of Vickers hardnesses measured in a range of ± 5 mm (10 mm in total thickness) from the center portion of the steel plate in the through-thickness direction) were obtained, and the difference (hardness difference) ΔH_v between the hardness at the thickness center portion and the hardness at the surface layer portion at a room temperature was calculated. That is, ΔH_v is expressed by Equation (a).

$$\Delta H_v = H_{vs} - H_{vc} \quad \dots(a)$$

[0021] The results of the Vickers hardness test are shown in Table 1. From Table 1, it can be seen that ΔH_v increases with an increase in the Si content. As described above, the inventors finds that a thick steel plate having a large Si content tends to cause a difference between the hardness at the surface layer portion and the hardness at the thickness center portion at a room temperature.

[Table 1]

Test steel	ΔH_v (HV5)
0.27%C - 1.01%Si	43
0.27%C - 1.51%Si	64
0.27%C - 1.97%Si	79

[0022] Therefore, the inventors conducted examinations on a method of reducing the hardness difference between the surface layer portion and the thickness center portion at a room temperature in a steel plate containing Si in an

amount of more than 1.00% and having a steel thickness of 40 mm or more. The inventors repeatedly conducted examinations to reduce the hardness difference of the steel plate in consideration of the hardenability of alloying elements and the steel thickness.

[0023] In order to secure the hardness of the steel plate, in hot rolling, the steel plate is typically reheated to a temperature of the A_{c3} point or higher at which transformation to austenite ends when the temperature rises, and thereafter subjected to water cooling or the like (hardening). At this time, the cooling rate at the surface layer portion of the steel plate is fast and thus sufficient hardness can be secured. On the other hand, the cooling rate at the thickness center portion of the steel plate is lower than that of the hardness at the surface layer portion, so that the formation of martensite becomes insufficient, resulting in a decrease in hardness.

[0024] As described above, the cooling rate decreases at the thickness center portion of the steel plate. Therefore, in order to secure a sufficient hardness at the thickness center portion of the steel plate, it is necessary to increase the amounts of the alloying elements to increase hardenability. However, in a case where the amounts of the alloying elements are constant, there are problems that the hardenability becomes insufficient depending on the steel thickness, and the costs are increased, or weldability is impaired by including unnecessary amounts of the alloying elements. Therefore, in order to control the amounts of the alloying elements within appropriate ranges, it is necessary to consider the influence of the steel thickness on the cooling rate at the thickness center portion.

[0025] The inventors establishes the relationship between the amounts of the alloying elements having hardenability and the steel thickness, which influences the hardness difference ratio $\Delta H_v/H_v$ of various steels containing Si in an amount of more than 1.00% and having a steel thickness of 40 mm or more, and derives an index Q shown in Equation (1). The hardness difference ratio $\Delta H_v/H_v$ (%) represents the ratio obtained by dividing the difference between the hardness at the surface layer portion and the hardness at the thickness center portion at a room temperature by the hardness at the surface layer portion as a percentage. In addition, the hardness difference ratio $\Delta H_v/H_v$ (%) is expressed by Equation (b). In Equation (b), H_v is the hardness at the surface layer portion (the average value of Vickers hardnesses measured in a range of 1 mm to 5 mm from the surface of the steel plate in the through-thickness direction), and the H_c is the hardness at the thickness center portion (the average value of Vickers hardnesses measured in a range of ± 5 mm (10 mm in total thickness) from the center portion of the steel plate in the through-thickness direction).

$$\Delta H_v/H_v (\%) = 100 \times (H_v - H_c)/H_v \quad \dots(b)$$

[0026] In the related art, it has been thought that the hardenability of a steel containing Si in an amount of more than 1.00% decreases as the cooling rate decreases. However, the inventors finds that when hardenability is secured by including alloying elements (C, Mn, Ni, Cr, and Mo) in addition to Si in the steel containing Si in an amount of more than 1.00%, Si contributes to the improvement in hardenability even when the cooling rate decreases. Equation (1) is based on the finding of the inventors that it is necessary to secure hardenability by including the alloying elements (C, Mn, Ni, Cr, and Mo) in addition to Si in order to increase the hardness at the thickness center portion, and the index Q does not include a Si content term.

$$Q = 0.18 - 1.3(\log T) + 0.75(2.7 \times [C] + [Mn] + 0.45 \times [Ni] + 0.8 \times [Cr] + 2 \times [Mo]) \quad \dots(1)$$

[0027] Here, the index Q of Equation (1) is calculated by substituting the numerical value of the steel thickness T (mm), the numerical value of the amount [X] of each element X in terms of mass% and 0 in a case where the element X is not contained. The index Q is calculated by substituting dimensionless numerical values for the steel thickness T and the amount [X] of each element in Equation (1). In addition, log in Equation (1) is the logarithm to base 10, that is, the common logarithm.

[0028] FIG. 3 shows the relationship between the hardness difference ratio $\Delta H_v/H_v$ (%) and the index Q. From FIG. 3, it is found that in a case where the hardness difference ratio $\Delta H_v/H_v$ (%) is set to 15.0% or less of the hardness at the surface layer portion H_v as a criterion for causing a thick steel plate to have a long service life, it is necessary to satisfy $Q \geq 0.00$. In addition, it is found that in a case of setting the hardness difference ratio $\Delta H_v/H_v$ (%) to 13.0% or less of the hardness at the surface layer portion H_v , it is necessary to satisfy $Q \geq 0.04$.

[0029] Furthermore, since the steel plate according to this embodiment has a steel thickness of 40 mm or more, there is concern of hydrogen embrittlement cracking under the influence of residual stress due to welding. Therefore, the carbon equivalent C_{eq} (%) expressed by Equation (2) is less than 0.800%. Equation (2) includes a Si content term because the weldability of the steel plate needs to be taken into consideration.

$$C_{eq} (\%) = [C] + [Mn]/6 + [Si]/24 + [Ni]/40 + [Cr]/5 + [Mo]/4 + [V]/4 \dots (2)$$

[0030] The carbon equivalent C_{eq} (%) of Equation (2) is calculated by substituting the numerical value of the amount [X] of each element X in terms of mass%, and 0 is substituted in a case where the element X is not contained. The unit of the carbon equivalent C_{eq} obtained by Equation (2) is "%".

[0031] By causing the index Q in Equation (1) to be 0.00 or more, the hardness difference ΔH_v between the surface layer portion and the thickness center portion of the steel plate at a room temperature becomes 15.0% or less of the hardness at the surface layer portion H_{vs} , so that a steel plate having a small hardness difference, a carbon equivalent of less than 0.800%, a steel thickness of 40 mm or more, and excellent wear resistance can be obtained.

[0032] Hereinafter, the steel plate according to this embodiment will be described in detail. First, the chemical composition of the steel plate according to this embodiment will be described. Unless otherwise specified, % regarding the chemical composition means mass%.

<C: 0.20% to 0.35%>

[0033] C is an element effective for improving the hardness, and the C content is set to 0.20% or more in order to secure the hardness of the steel plate. The C content is preferably 0.22% or more, and more preferably 0.24% or more. On the other hand, when the C content exceeds 0.35%, the susceptibility to hydrogen embrittlement increases due to an increase in hardness, and there is concern of the occurrence of cracking due to hydrogen embrittlement. Therefore, the C content is set to 0.35% or less. The C content is set to preferably 0.32% or less, and more preferably 0.30% or less.

<Si: More Than 1.00% to 2.00%>

[0034] Si is a deoxidizing agent and is an element effective for improving the hardness of the steel plate. In this embodiment, Si is an extremely important element for maintaining the hardness of the steel plate in a high-temperature environment. In order to obtain the effect of containing Si, the Si content is set to be more than 1.00%. The Si content is preferably 1.10% or more, and more preferably 1.20% or more, or 1.30% or more. On the other hand, when the Si content exceeds 2.00%, the toughness of the steel plate may be impaired, so that the Si content is set to 2.00% or less. The Si content is set to preferably 1.90% or less, and more preferably 1.80% or less.

<Mn: 0.60% to 2.00%>

[0035] Mn is an element which increases the hardenability and improves the hardness, and needs to be contained in an amount of 0.60% or more in order to secure the hardness of the steel plate. The Mn content is preferably 0.70% or more, and more preferably 0.80% or more. On the other hand, excessive inclusion of Mn lowers the toughness and accelerates the formation of cementite, resulting in a decrease in the high-temperature hardness of the steel plate. Therefore, the Mn content is set to 2.00% or less. The Mn content is set to preferably 1.50% or less or 1.35% or less, and more preferably 1.20% or less or 1.00% or less.

<Cr: 0.10% to 2.00%>

[0036] Cr is an element which increases the hardenability, and improves the toughness and hardness of the steel plate. In order to secure the toughness and hardness of the steel plate, the Cr content is set to 0.10% or more. The Cr content is preferably 0.50% or more, and more preferably 0.80% or more. On the other hand, when the Cr content exceeds 2.00%, the toughness of the steel plate decreases, so that the Cr content is set to 2.00% or less. The Cr content is set to preferably 1.70% or less, and more preferably 1.50% or less.

<Mo: 0.05% to 1.00%>

[0037] Mo is also an element which increases the hardenability and improves the hardness of the steel plate. In addition, Mo is an element effective for maintaining the hardness of the steel plate even in a high-temperature environment. Therefore, the Mo content is set to 0.05% or more. The Mo content is set to preferably 0.10% or more, and more preferably 0.20% or more. On the other hand, when the Mo content exceeds 1.00%, the toughness of the steel plate decreases, so that the Mo content is set to 1.00% or less. The Mo content is set to preferably 0.60% or less, and more preferably 0.40% or less.

<Al: 0.010% to 0.100%>

[0038] Al is an element effective as a deoxidizing agent. In addition, Al is bonded to N to form AlN, and refines crystal grains, thereby improving the toughness of the steel plate. Therefore, the Al content is set to 0.010% or more. The Al content is set to preferably 0.020% or more, and more preferably 0.030% or more. On the other hand, when Al is excessively contained, the toughness of the steel plate decreases, so that the Al content is set to 0.100% or less. The Al content is set to preferably 0.080% or less, and more preferably 0.070% or less.

<N: 0.0020% to 0.0100%>

[0039] N is an element that is bonded to Al and Ti to form nitrides, and refines crystal grains, thereby improving the toughness of the steel plate. Therefore, the N content is set to 0.0020% or more. The N content is set to preferably 0.0030% or more, and more preferably 0.0040% or more. On the other hand, when N is excessively contained, coarse nitrides are formed and the toughness of the steel plate decreases, so the N content is set to 0.0100% or less. The N content is set to preferably 0.0080% or less, and more preferably 0.0060% or less.

<B: 0.0003% to 0.0020%>

[0040] B is an element that significantly increases the hardenability of steel and is particularly effective for improving the hardness at the thickness center portion of the steel plate. Therefore, the B content is set to 0.0003% or more. The B content is set to preferably 0.0005% or more, more preferably 0.0007% or more, and even more preferably 0.0010% or more. On the other hand, in a case where B is excessively contained, boride is formed, the hardenability decreases, and the hardness of the steel plate cannot be secured. Therefore, the B content is set to 0.0020% or less. The B content is preferably 0.0018% or less, and more preferably 0.0016% or less.

<P: 0.0200% or Less>

[0041] P is an impurity, and reduces the toughness and workability of the steel plate. Therefore, the P content is limited to 0.0200% or less. The P content is set to preferably 0.0150% or less, and more preferably 0.0100% or less. The lower limit of the P content is preferably 0%, but from the viewpoint of manufacturing costs, the P content may be 0.0001 % or more.

<S: Less Than 0.0100%>

[0042] Like P, S is an impurity and reduces the toughness of the steel plate. Therefore, the S content is limited to less than 0.0100%. The S content is set to preferably 0.0070% or less, more preferably 0.0050% or less, and even more preferably 0.0030% or less. The lower limit of the S content is preferably 0%, but from the viewpoint of manufacturing costs, the S content may be 0.0001% or more.

[0043] In the steel plate according to this embodiment, one or more of Cu, Ni, Nb, V, and Ti can be selectively contained for the purpose of improving the mechanical properties such as the hardness and toughness of the steel plate. The lower limit of the amounts of these elements is 0%.

<Cu: 0% to 0.500%>

[0044] Cu is an element that forms fine precipitates and contributes to the improvement of the strength of the steel plate, and may be contained in an amount of 0.001% or more. The Cu content is set to more preferably 0.050% or more, and even more preferably 0.100% or more. On the other hand, when Cu is excessively contained, the wear resistance of the steel plate is deteriorated, so that the upper limit of the Cu content is set to 0.500% or less. The Cu content is set to more preferably 0.450% or less, and even more preferably 0.400% or less.

<Ni: 0% to 1.00%>

[0045] Ni is an element that increases the hardenability of the steel and contributes to the improvement of the hardness of the steel plate, and may be contained in an amount of 0.05% or more. The Ni content is set to more preferably 0.10% or more, and even more preferably 0.20% or more. On the other hand, since Ni is an expensive alloying element, from the viewpoint of costs, the Ni content is set to 1.00% or less. The Ni content is set to more preferably 0.70% or less, and even more preferably 0.50% or less.

<Nb: 0% to 0.050%>

[0046] Nb is an element contributing to grain refinement by the formation of nitride and suppressing recrystallization, and may be contained in an amount of 0.005% or more in order to improve the toughness of the steel plate. The Nb content is set to more preferably 0.007% or more, and even more preferably 0.010% or more. On the other hand, when Nb is excessively contained, the toughness of the steel plate may decrease. Therefore, the Nb content is set to 0.050% or less. The Nb content is set to more preferably 0.030% or less, and even more preferably 0.020% or less.

<V: 0% to 0.120%>

[0047] V is an element that contributes to the improvement of the hardness of the steel plate, and may be contained in an amount of 0.010% or more. The V content is set to more preferably 0.020% or more, and even more preferably 0.040% or more. On the other hand, when V is excessively contained, there may be cases where cracking occurs in cast pieces and the manufacturability may be impaired. Therefore, the V content is set to 0.120% or less. The V content is set to more preferably 0.100% or less, and even more preferably 0.070% or less.

<Ti: 0% to 0.025%>

[0048] Ti is an element that forms TiN, refines crystal grains, and thus improves the toughness of the steel plate, and may be contained in an amount of 0.005% or more. The Ti content is set to more preferably 0.007% or more, and even more preferably 0.010% or more. On the other hand, excessive inclusion of Ti may reduce the toughness of the steel plate, so that the Ti content is set to 0.025% or less. The Ti content is set to more preferably 0.020% or less, and even more preferably to 0.015% or less.

[0049] In order to control the morphology and the like of the inclusions in the steel, one or more of Ca, Mg, and REM can be selectively contained. The lower limit of the amounts of these elements is 0%.

<Ca: 0% to 0.050%>

<Mg: 0% to 0.050%>

<REM: 0% to 0.100%>

[0050] Any of Ca, Mg, and REM is an element that is bonded to S to form sulfides and forms inclusions that are less likely to be stretched by hot rolling, and mainly contributes to the improvement of the toughness of the steel plate. On the other hand, when Ca, Mg and REM are excessively contained, these elements form coarse oxides with O, and there may be cases where the toughness of the steel plate may decrease. Therefore, each of the Ca content and the Mg content is set to 0.050% or less, and the REM content is set to 0.100% or less. Each of the Ca content, the Mg content, and the REM content is each set to more preferably 0.020% or less, and even more preferably 0.010% or less, or 0.005% or less. On the other hand, in order to obtain the effect of improving the toughness of the steel plate, it is preferable that each of the Ca content and the Mg content is set to 0.0005% or more, and the REM content is set to 0.001% or more. More preferably, each of the Ca content and the Mg content is set to 0.0007% or more, and the REM content is set to 0.002% or more.

[0051] REM (rare-earth metal elements) means a total of 17 elements including Sc, Y, and lanthanoid. The REM content means the total amount of these 17 elements.

[0052] The remainder of the chemical composition of the steel plate according to this embodiment consists of Fe and impurities. Here, the impurities mean elements that are incorporated when a steel plate is industrially manufactured, due to various factors in a manufacturing process including raw materials such as ore and scrap, and are acceptable within a range in which the characteristics of the steel plate according to this embodiment are not adversely affected. However, in the steel plate according to this embodiment, the upper limits of P and S among the impurities need to be specified as described above.

[0053] Furthermore, there may be cases where one or more of O, Sb, Sn, and As may be incorporated as impurities in the steel. Even if these impurities are incorporated, there is no particular problem as long as these impurities are in a typical incorporation level (content range) of wear-resistant steel. Therefore, the amounts thereof are limited to the typical incorporation level of the wear-resistant steel as described below. The lower limit of the amounts of these impurities is 0%.

<O: 0.006% or Less>

[0054] O may be incorporated as an impurity in the steel in some cases. However, since O is an element that forms coarse oxides, the O content is preferably small. In particular, when the O content exceeds 0.006%, coarse oxides are formed in the steel and the wear resistance of the steel plate deteriorates. Therefore, the O content is set to 0.006% or less. The O content is set to preferably 0.005% or less, and more preferably to 0.004% or less.

<Sb: 0.01% or Less>

[0055] Sb is an element incorporated from scrap as a steel raw material. In particular, when Sb is excessively contained, the wear resistance of the steel plate deteriorates, so that the Sb content is set to 0.01% or less. The Sb content is set to preferably 0.007% or less, or 0.005% or less.

<Sn: 0.01% or Less>

[0056] Like Sb, Sn is an element incorporated from scrap as a steel raw material. In particular, when Sn is excessively contained, the wear resistance of the steel plate deteriorates, so that the Sn content is set to 0.01% or less. The Sn content is set to preferably 0.007% or less, or 0.005% or less.

<As: 0.01% or Less>

[0057] Like Sb and Sn, As is an element incorporated from scrap as a steel raw material. In particular, when As is excessively contained, the wear resistance of the steel plate deteriorates, so that the As content is set to 0.01% or less. The As content is set to preferably 0.007% or less, or 0.005% or less.

[0058] In the steel plate according to this embodiment, the index Q obtained by Equation (1) is set to 0.00 or more so that the hardness difference between the surface layer portion and the thickness center portion of the steel plate at a room temperature is small and the ratio of the hardness difference to the hardness at the surface layer portion is 15.0% or less. The index Q is calculated by substituting dimensionless numerical values for the numerical value of the steel thickness T (mm) and the numerical value of the amount [X] of each element X in terms of mass%, and [X] is set to 0 in a case where the element X is not contained. In order to reduce the hardness difference between the surface layer portion and the thickness center portion of the steel plate, the index Q is set to preferably 0.01 or more, more preferably 0.04 or more, even more preferably 0.05 or more, and still more preferably 0.10 or more. The upper limit of the index Q is not particularly specified. However, since the carbon equivalent Ceq (%) also increases as the index Q increases, the index Q is limited by itself. In order to secure the weldability by causing the carbon equivalent Ceq (%) to be less than 0.800%, the index Q is preferably 1.10 or less. The index Q is set to more preferably 0.80 or less or 0.50 or less, and more preferably 0.30 or less or 0.20 or less.

$$Q = 0.18 - 1.3(\log T) + 0.75(2.7 \times [C] + [Mn] + 0.45 \times [Ni] + 0.8 \times [Cr] + 2 \times [Mo]) \dots(1)$$

[0059] In the steel plate according to this embodiment, in order to suppress weld cracking and secure the weldability of the steel plate, the carbon equivalent Ceq (%) is set to be less than 0.800%. The carbon equivalent Ceq (%) is calculated by substituting the numerical value of the amount [X] of each element in terms of mass%, and [X] is set to 0 in a case where the element X is not contained. The lower limit of the carbon equivalent is not particularly specified. However, since the index Q also increases as the carbon equivalent Ceq (%) decreases, the carbon equivalent Ceq (%) is limited by itself. In order to reduce the hardness difference by setting the index Q to 0.00 or more, the carbon equivalent Ceq (%) is preferably 0.507% or more. In order to increase the wear resistance of the steel plate, the carbon equivalent Ceq (%) is set to more preferably 0.600% or more, and more preferably 0.650% or more. The carbon equivalent Ceq (%) is set to even more preferably 0.700% or more. In order to enhance the weldability of the steel plate, the carbon equivalent Ceq (%) may be 0.785% or less, 0.770% or less, or 0.760% or less.

$$Ceq (\%) = [C] + [Mn]/6 + [Si]/24 + [Ni]/40 + [Cr]/5 + [Mo]/4 + [V]/4 \dots(2)$$

[0060] In the steel plate according to this embodiment, since the difference (hardness difference) between the hardness at the surface layer portion and the hardness at the thickness center portion at a room temperature is small and the ratio of the difference between the hardness at the surface layer portion and the hardness at the thickness center portion to

the hardness at the surface layer portion is 15.0% or less, excellent wear resistance can be exhibited over a long period of time. It is preferable that the hardness difference ratio $\Delta H_v/H_v$ (%) is as small as possible. However, it is difficult to set the hardness difference ratio $\Delta H_v/H_v$ (%) to be less than 0% or less than 1.0%. Therefore, the lower limit thereof may be set to 0% or 1.0%. In consideration of an increase in costs due to an increase in the amounts of the alloying elements, the hardness difference ratio $\Delta H_v/H_v$ (%) may be 3.0% or more. The hardness at the surface layer portion and the hardness at the thickness center portion are Vickers hardnesses HV5 at a room temperature and are measured based on JIS Z 2244:2009. The hardness at the surface layer portion is measured using a section parallel to the rolling direction and the through-thickness direction of the steel plate as a measurement surface, and is the average value of Vickers hardnesses HV5 measured in a range of 1 mm to 5 mm from the surface of the steel plate in the through-thickness direction. In the measurement of the hardness at the surface layer portion and the steel plate, Vickers hardnesses at a total of 25 points, 5 points at least every 1 mm in the range are measured. The hardness at the thickness center portion is the average value of Vickers hardnesses HV5 measured in a range of ± 5 mm (10 mm in total thickness) from the thickness center portion of the steel plate in the through-thickness direction on the measurement surface. In the measurement of the hardness at the thickness center portion of the steel plate, Vickers hardnesses at a total of 55 points, 5 points at least every 1 mm in the range are measured.

[0061] In the steel plate according to this embodiment, the hardness at the surface layer portion H_{vs} at room temperature is 400 or more in terms of Vickers hardness (HV5). When the hardness at the surface layer portion H_{vs} is less than 400 in terms of Vickers hardness (HV5), the strength of the hardness at the surface layer portion of the steel plate is insufficient, and cannot be used for applications such as construction machines and industrial machines. In order to improve the wear resistance, the hardness at the surface layer portion H_{vs} at room temperature may be 440 or more, 460 or more, 480 or more, or 500 or more in terms of Vickers hardness (HV5).

[0062] The steel plate according to this embodiment exhibit very high hardness from the hardness at the surface layer portion to the hardness at the thickness center portion and very high tensile strength. As necessary, the tensile strength (TS) thereof at room temperature may be set to 1000 MPa or more, 1200 MPa or more, 1350 MPa or more, or 1500 MPa or more. The upper limit of the tensile strength does not need to be particularly determined, but may be 2300 MPa or less. The tensile strength is measured based on JIS Z 2241:2011 by extracting an overall thickness test piece (that is, a plate-shaped test piece) or a round bar test piece from a position (T/4) away from the surface of the steel plate by 1/4 of the steel thickness T.

[0063] The steel plate according to this embodiment is a steel plate manufactured by hot rolling and is a steel plate having a steel thickness of 40 mm or more, preferably 42 mm or more or 50 mm or more, and more preferably 60 mm or more or 80 mm or more. The upper limit of the steel thickness is not particularly specified, and may be 150 mm depending on the application. In consideration homogenization of the properties of the steel plate in the through-thickness direction, the steel thickness may be set to 100 mm or less.

[0064] A method of manufacturing the steel plate according to this embodiment will be described. In this embodiment, the steel piece having the above-described chemical composition can be manufactured by a known method such as a continuous casting method of an ingot-making and blooming method after melting in a typical refining process using a converter, an electric furnace, or the like, and there is no particular limitation.

[0065] In this embodiment, the steel piece obtained by casting is hot-rolled, water-cooled as it is or air-cooled, and thereafter reheated and hardened, thereby manufacturing the steel plate. However, the steel plate is hardened but is not subjected to a heat treatment such as tempering.

[0066] A steel may be subjected to melting, casting, and thereafter hot rolling as it is. However, a steel piece may be once cooled to room temperature, reheated to a temperature of the Ac₃ point or higher, and then hot rolled. The Ac₃ point is a temperature at which the structure of the steel becomes austenite (austenitic transformation is completed) due to a temperature rise. The heating temperature of the hot rolling is set to preferably 900°C or higher, and more preferably 1000°C or higher in order to reduce the deformation resistance. On the other hand, when the heating temperature of the hot rolling is too high, the structure becomes coarse and the low-temperature toughness of the steel plate sometimes decreases. Therefore, the heating temperature is preferably 1250°C or lower. The heating temperature is more preferably 1200°C or lower, and even more preferably 1150°C or lower.

[0067] It is preferable that the hot rolling is ended at the Ar₃ point or higher, which is the temperature at which ferritic transformation starts by a temperature decrease. The Ac₃ point and the Ar₃ point can be obtained by extracting a test piece from a steel piece and obtaining a thermal expansion behavior at the time of heating and cooling. The steel plate is hardened to a temperature of 250°C or lower immediately after the hot rolling, or is air-cooled after the hot rolling, reheated to a temperature of the Ac₃ point or higher, hardened to a temperature of 250°C or lower.

[Examples]

[0068] Hereinafter, the present invention will be described in more detail by employing examples of the steel plate according to the present invention. However, the present invention is not limited to the following examples as a matter

of course, and can be embodied by appropriately adding changes within a range that is appropriate for the gist of the present invention, and all such changes are included in the technical scope of the present invention.

[0069] A steel having a chemical composition shown in Table 2 was melted, cast, thereafter hot-rolled into a steel plate having a steel thickness shown in Table 3, and air-cooled to room temperature. Thereafter, a steel plate having a steel thickness of 40 mm or more was manufactured by increasing the temperature to a hardening temperature shown in Table 3 and performing hardening thereon. A test piece was extracted from the obtained steel plate, and using a section of the steel plate parallel to the rolling direction and the through-thickness direction as a test surface, the Vickers hardnesses at the surface layer portion and the thickness center portion were measured based on JIS Z 2244:2009 at room temperature with a test force of 49.03 N (5 kgf). The Vickers hardness (a hardness at the surface layer portion) H_{vs} of at the surface layer portion was obtained by measuring Vickers hardnesses at a total of 25 points, 5 points every 1 mm, in a range (surface layer portion) of 1 mm to 5 mm from the surface of the steel plate in the through-thickness direction, and obtaining the average value (arithmetic mean) thereof. The Vickers hardness (hardness at a thickness center portion) H_{vc} of the thickness center portion was obtained by measuring Vickers hardnesses at a total of 55 points, 5 points every 1 mm, in a range of ± 5 mm (10 mm in total thickness) from the thickness center portion of the steel plate in the through-thickness direction, and obtaining the average value (arithmetic mean) thereof. Using the values of the hardness at the surface layer portion H_{vs} and the hardness at the thickness center portion H_{vc} obtained as described above, the hardness difference ratio $\Delta H_v/H_{vs}$ (%) representing the hardness difference between the surface layer portion and the thickness center portion of the steel plate at a room temperature was obtained. The hardness difference ratio $\Delta H_v/H_{vs}$ (%) is expressed by Equation (b).

$$\Delta H_v/H_{vs} (\%) = 100 \times (H_{vs} - H_{vc})/H_{vs} \quad \dots(b)$$

[0070] In addition, a sample was cut out from the steel plate, and a high-temperature Vickers hardness test was conducted thereon based on JIS Z 2252-1991 at 400°C with a test force of 9.807 N (1 kgf). Accordingly, the high-temperature hardness (HV1) at the surface layer portion of the steel plate was obtained. The measurement of the high-temperature hardness at the surface layer portion was performed under the same condition as the surface layer portion Vickers hardness test (room temperature) except for the temperature control and test force. Furthermore, a full-size V notch Charpy test piece in a direction parallel to the rolling direction was cut out from a position (T/4) away from the surface of the steel plate by 1/4 of the steel thickness T, and a Charpy absorbed energy (vE₀) at 0°C was measured based on JIS Z 2242:2005.

[0071] The criteria of evaluation items are as follows. Regarding both the hardness at the surface layer portion H_{vs} (HV5) and the hardness at the thickness center portion H_{vc} (HV5), a hardness of 400 or more was determined to be good from the viewpoint of wear resistance, and a hardness of 600 or less was determined to be good from the viewpoint of cutting workability. Regarding the high-temperature hardness (HV5) at the surface layer portion, a hardness of 300 or more was determined to be good from the viewpoint of wear resistance at high temperatures. A Charpy absorbed energy at 0°C of 15 J or more was determined to be good.

[0072] The results are shown in Table 3. In Nos. 1 to 18, the parameters of the chemical composition including the index Q and the carbon equivalent C_{eq} (%) and the steel thickness T are within the ranges of the present invention, and the hardness difference ratio $\Delta H_v/H_{vs}$ between the surface layer portion and the center portion is 15.0% or less. Any of these steels is a steel plate excellent in the hardness at the surface layer portion H_{vs}, the hardness at the thickness center portion H_{vc}, the high-temperature hardness at the surface layer portion, and the Charpy absorbed energy at 0°C.

[Table 2]

Steel No.	Chemical composition (mass%) remainder consisting of Fe and impurities																	Ceq (%)	Remarks
	C	Si	Mn	Cr	Mo	Al	N	B	P	S	Cu	Ni	Nb	V	Ti	Ca	Mg		
A1	0.27	1.02	0.90	0.99	0.25	0.042	0.0052	0.0011	0.0075	0.0019			0.015	0.101	0.019				0.748
A2	0.28	1.49	0.80	0.99	0.24	0.042	0.0040	0.0011	0.0075	0.0019			0.012	0.091	0.012				0.756
A3	0.27	1.93	1.05	0.99	0.20	0.062	0.0047	0.0011	0.0075	0.0019									0.773
A4	0.31	1.05	0.61	1.17	0.24	0.035	0.0045	0.0014	0.0055	0.0042			0.014		0.015				0.749
A5	0.32	1.52	0.63	1.23	0.15	0.042	0.0051	0.0013	0.0051	0.0061			0.016	0.020	0.020				0.777
A6	0.22	1.15	0.62	1.50	0.45	0.068	0.0055	0.0013	0.0085	0.0028			0.018	0.040					0.794
A7	0.22	1.10	0.90	0.65	0.35	0.042	0.0039	0.0011	0.0080	0.0010		0.40	0.020		0.012				0.643
A8	0.28	1.11	0.92	1.10	0.18	0.066	0.0042	0.0012	0.0071	0.0025		0.07							0.746
A9	0.25	1.06	0.66	1.06	0.65	0.044	0.0045	0.0011	0.0061	0.0021			0.013		0.013				0.779
A10	0.23	1.08	1.56	1.18	0.06	0.063	0.0056	0.0012	0.0053	0.0012		0.06	0.017			0.002			0.788
A11	0.34	1.60	0.65	1.25	0.08	0.076	0.0047	0.0015	0.0080	0.0064				0.050		0.002			0.798
A12	0.25	1.05	0.89	1.30	0.07	0.065	0.0052	0.0015	0.0061	0.0044		0.32					0.001		0.728
A13	0.28	1.09	0.71	1.40	0.25	0.071	0.0059	0.0015	0.0057	0.0057								0.007	0.786
A14	0.29	1.18	0.81	1.21	0.08	0.043	0.0050	0.0011	0.0069	0.0026			0.013	0.030	0.020				0.744
A15	0.23	1.31	0.92	1.10	0.18	0.040	0.0043	0.0012	0.0072	0.0021			0.016	0.085	0.014				0.724
A16	0.24	1.61	1.12	1.05	0.22	0.041	0.0044	0.0011	0.0056	0.0014			0.016		0.017				0.759
A17	0.26	1.16	0.72	1.29	0.18	0.048	0.0042	0.0012	0.0073	0.0044		0.07			0.014				0.733
A18	0.25	1.03	0.64	1.56	0.23	0.064	0.0038	0.0016	0.0077	0.0021	0.420	0.35	0.017	0.040					0.788
B1	0.18	1.40	1.50	0.80	0.05	0.035	0.0049	0.0008	0.0055	0.0023			0.014		0.012				0.661
B2	0.32	1.80	1.20	0.50	0.10	0.028	0.0055	0.0014	0.0051	0.0031			0.016		0.022				0.770
B3	0.24	0.90	1.45	1.10	0.05	0.034	0.0050	0.0007	0.0080	0.0021					0.012				0.752
B4	0.24	2.10	1.45	0.80	0.06	0.037	0.0047	0.0016	0.0077	0.0046					0.012				0.744
B5	0.27	1.42	0.45	1.48	0.06	0.044	0.0072	0.0008	0.0091	0.0029		0.46	0.011		0.022				0.727
B6	0.27	1.52	2.11	0.30	0.05	0.039	0.0068	0.0008	0.0082	0.0041			0.011		0.022				0.758
B7	0.23	1.12	1.92	0.08	0.06	0.046	0.0047	0.0015	0.0083	0.0047			0.011						0.628
B8	0.21	1.14	0.61	2.07	0.06	0.038	0.0052	0.0016	0.0057	0.0061		0.45	0.022		0.021				0.799
B9	0.24	1.06	0.81	1.55	0.04	0.043	0.0049	0.0018	0.0051	0.0028			0.016		0.012				0.739
B10	0.26	1.62	0.62	0.40	1.10	0.046	0.0051	0.0014	0.0087	0.0041			0.011		0.014				0.786
B11	0.23	1.12	1.78	0.22	0.09	0.028	0.0041	0.0002	0.0076	0.0047			0.017		0.017				0.640
B12	0.23	1.24	1.75	0.21	0.11	0.024	0.0038	0.0030	0.0096	0.0038			0.014		0.012				0.643

Blank means that the element is not intentionally contained.

Underlined means out of the range of the present invention.

[Table 3]

No.	Steel No.	Hardening temperature (°C)	Steel thickness (mm)	Q	Hvs (HV5)	Hvc (HV5)	$\Delta H_v/H_v$ (%)	High-temperature hardness (HV5)	vE_0 (J)	Remarks
1	A1	910	50	0.16	518	483	6.8	332	30	Example
2	A2	930	42	0.19	541	486	10.2	376	26	
3	A3	950	70	0.01	555	477	14.1	405	22	
4	A4	910	50	0.12	544	518	4.8	340	22	
5	A5	930	50	0.05	571	522	8.6	381	20	
6	A6	910	102	0.05	469	445	5.1	312	47	
7	A7	910	50	0.14	465	433	6.9	315	45	
8	A8	910	60	0.08	526	458	12.9	357	33	
9	A9	910	122	0.08	495	434	12.3	325	41	
10	A10	910	80	0.14	478	437	8.6	310	22	
11	A11	930	42	0.12	591	538	9.0	455	28	
12	A12	910	42	0.24	492	476	3.3	359	48	
13	A13	910	70	0.10	536	497	7.3	372	46	
14	A14	910	42	0.11	538	493	8.4	375	30	
15	A15	930	50	0.06	487	435	10.7	329	27	
16	A16	950	55	0.20	515	449	12.8	385	23	
17	A17	910	48	0.13	507	459	9.5	343	28	
18	A18	910	85	0.06	491	447	9.0	315	26	
101	A1	910	80	-0.10	505	415	17.8	324	32	
102	A5	930	80	-0.21	545	441	19.1	372	21	
103	A9	910	70	-0.05	481	407	15.4	345	38	
104	B1	930	42	0.11	392	338	13.8	255	41	
105	B2	950	42	0.17	621	580	6.6	465	23	
106	B3	910	55	0.23	498	486	2.4	284	38	

(continued)

No.	Steel No.	Hardening temperature (°C)	Steel thickness (mm)	Q	Hvs (HV5)	Hvc (HV5)	$\Delta H_v/H_v$ (%)	High-temperature hardness (HV5)	vE_0 (J)	Remarks
107	B4	950	55	0.06	531	468	11.9	402	13	Comparative Example
108	B5	930	42	0.09	389	338	13.1	275	36	
109	B6	930	42	0.45	531	525	1.1	365	14	
110	B7	910	42	0.11	387	347	10.3	293	9	
111	B8	910	50	0.34	472	466	1.3	308	12	
112	B9	910	50	0.05	416	355	14.7	298	14	
113	B10	910	50	0.85	520	505	2.9	371	12	
114	B11	910	42	0.14	325	301	7.4	243	34	
115	B12	910	42	0.14	356	315	11.5	254	33	

Underlined means out of the range of the present invention or out of the range of preferable properties.

[0073] On the other hand, Nos. 101 to 115 in Table 3 are comparative examples, and the chemical compositions including the Q value are out of the ranges of the present invention. Nos. 101 to 103 are examples in which the Q value was low in relation to the steel thickness and the hardness difference ratio $\Delta H_v/H_v$ (%) exceeded 15.0%.

[0074] No. 106 is an example in which the Si content was insufficient and the high-temperature hardness at the surface layer portion had decreased. On the other hand, No. 107 is an example in which the Si content was large and the toughness had decreased.

[0075] Nos. 104, 108 and 114 are examples in which the C content, the Mn content, and the B content were insufficient, respectively, and the hardness at the surface layer portion H_{vs} , the hardness at the thickness center portion H_{vc} , and the high-temperature hardness at the surface layer portion had decreased.

[0076] No. 110 in which the Cr content was insufficient is an example in which the toughness had decreased in addition to the hardness at the surface layer portion H_{vs} , the hardness at the thickness center portion H_{vc} , and the high-temperature hardness at the surface layer portion.

[0077] No. 112 in which the Mo content was insufficient is an example in which the hardness at the thickness center portion H_{vc} , the high-temperature hardness at the surface layer portion, and the toughness had decreased.

[0078] No. 105 is an example in which the C content was large and the hardness at the surface layer portion H_{vs} was excessively high.

[0079] No. 109 with a high Mn content, No. 111 with a high Cr content, and No. 113 with a high Mo content are examples in which the toughness had decreased.

[0080] No. 115 with an excessive B content is an example in which the hardness at the surface layer portion H_{vs} , the hardness at the thickness center portion H_{vc} , and the high-temperature hardness at the surface layer portion had decreased.

[0081] In all the examples, the O content was 0.006% or less, and all the Sb content, the Sn content, and the As content were 0.01% or less.

[0082] As described above, in Comparative Examples Nos. 101 to 115 in which any one or more of the chemical composition and the Q value were out of the ranges of the present invention, at least one of the hardness difference ratio $\Delta H_v/H_v$, the hardness at the surface layer portion H_{vs} , the hardness at a thickness center portion H_{vc} , the high-temperature hardness at the surface layer portion, and the toughness did not reach the evaluation criteria determined to be good.

Claims

1. A steel plate comprising, as a chemical composition, by mass%:

C: 0.20% to 0.35%;

Si: more than 1.00% to 2.00%;

Mn: 0.60% to 2.00%;

Cr: 0.10% to 2.00%;

Mo: 0.05% to 1.00%;

Al: 0.010% to 0.100%;

N: 0.0020% to 0.0100%;

B: 0.0003% to 0.0020%;

P: 0.0200% or less;

S: less than 0.0100%;

Cu: 0% to 0.500%;

Ni: 0% to 1.00%;

Nb: 0% to 0.050%;

V: 0% to 0.120%;

Ti: 0% to 0.025%;

Ca: 0% to 0.050%;

Mg: 0% to 0.050%;

REM: 0% to 0.100%; and

a remainder consisting of Fe and impurities,

wherein an index Q obtained by Equation (1) is 0.00 or more,

a carbon equivalent C_{eq} (%) obtained by Equation (2) is less than 0.800%,

a ratio of a difference between a hardness at a surface layer portion and a hardness at a thickness center portion to the hardness at the surface layer portion at a room temperature is 15.0% or less and the hardness at the

surface layer portion at a room temperature is 400 or more in terms of Vickers hardness, and a steel thickness T is 40 mm or more,

$$Q = 0.18 - 1.3(\log T) + 0.75(2.7 \times [C] + [Mn] + 0.45 \times [Ni] + 0.8 \times [Cr] + 2 \times [Mo]) \dots(1)$$

$$Ceq (\%) = [C] + [Mn]/6 + [Si]/24 + [Ni]/40 + [Cr]/5 + [Mo]/4 + [V]/4 \dots(2)$$

where the index Q of Equation (1) is calculated by substituting a numerical value of the steel thickness T (mm), a numerical value of an amount [X] of each element X in terms of mass% and 0 in a case where the element X is not contained, the carbon equivalent Ceq (%) of Equation (2) is calculated by substituting a numerical value of an amount [X] of each element X in terms of mass% and 0 in a case where the element X is not contained.

2. The steel plate according to claim 1, wherein the index Q is 0.04 or more, and the ratio is 13.0% or less.
3. The steel plate according to claim 1 or 2, comprising, as the chemical composition, by mass%, Ni is 0.05% to 1.00%.
4. The steel plate according to any one of claims 1 to 3, comprising, as the chemical composition, by mass%, Mn is 0.63% to 2.00%.

FIG. 1

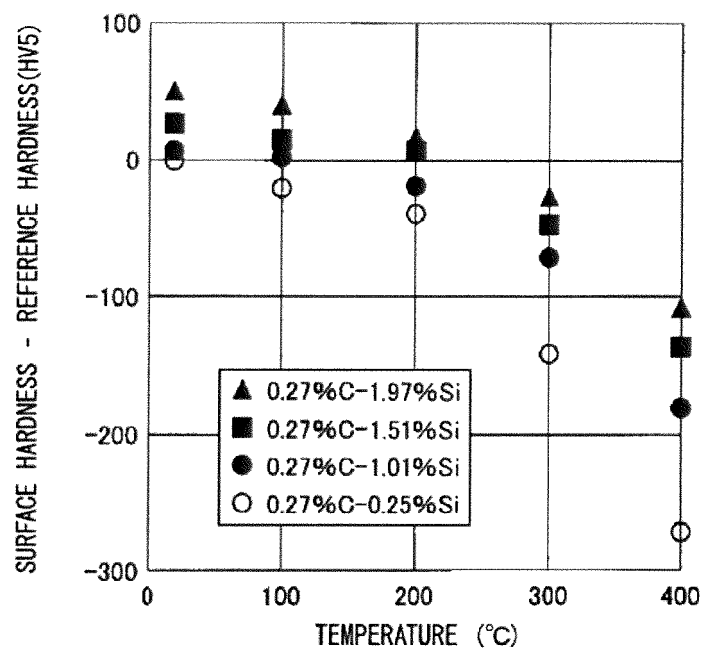


FIG. 2

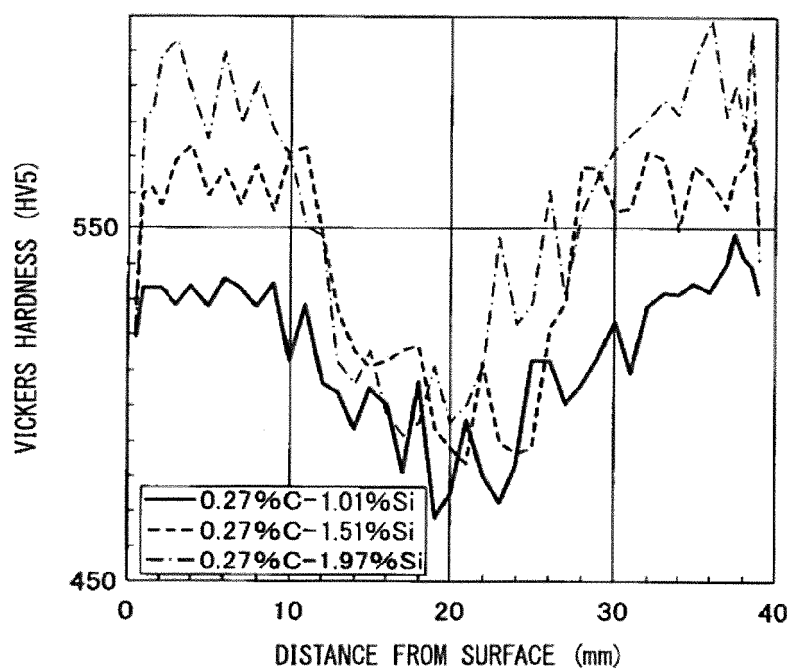
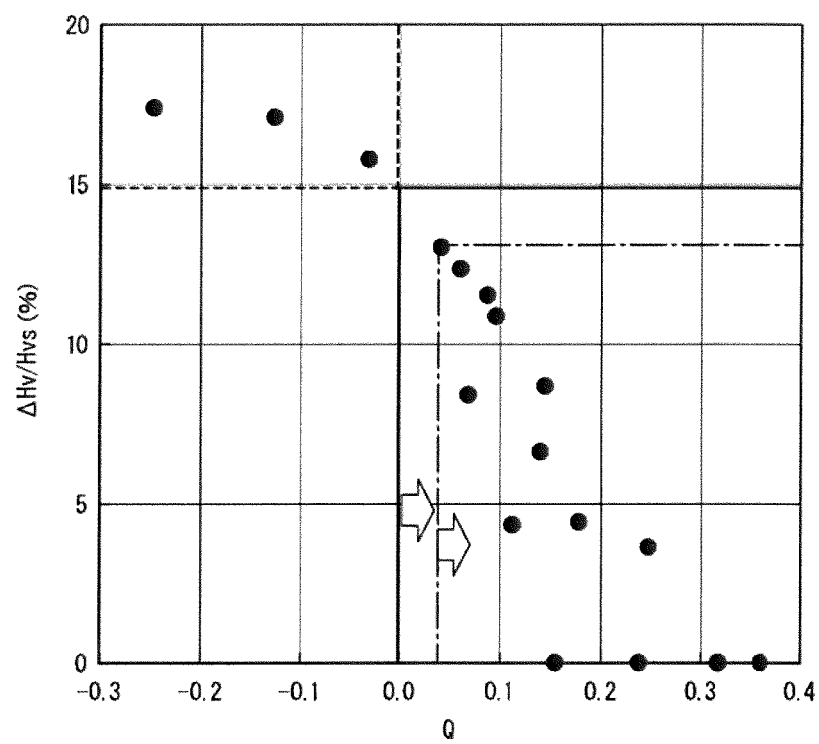


FIG. 3



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2018/007161

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. C22C38/00 (2006.01) i, C22C38/38 (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)

Int. Cl. C22C38/00, C22C38/38, C22C38/58, C21D8/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996

Published unexamined utility model applications of Japan 1971-2018

Registered utility model specifications of Japan 1996-2018

Published registered utility model applications of Japan 1994-2018

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.
A	JP 10-251800 A (KAWASAKI STEEL CORP.) 22 September 1998, claim 2, paragraphs [0014], [0027], tables 1, 2 (Family: none)	1-4
A	JP 2015-113504 A (JFE STEEL CORP.) 22 June 2015, claims 1, 2, paragraphs [0065]-[0067], [0072], table 1 (steel type E, F), table 3 (Family: none)	1-4
A	JP 2002-235144 A (KOMATSU LTD.) 23 August 2002, claim 1, paragraphs [0012], [0015], table 1 (Family: none)	1-4
A	JP 2001-49387 A (NIPPON STEEL CORP.) 20 February 2001, claim 1, paragraphs [0004], [0010], table 1 (no. 15) (Family: none)	1-4



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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"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

"X"

document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y"

document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&"

document member of the same patent family

Date of the actual completion of the international search
19.04.2018

Date of mailing of the international search report
01.05.2018

Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
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Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2018/007161
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 8-41535 A (NIPPON STEEL CORP.) 13 February 1996, claim 1, paragraph [0012], table 1 (steel C) (Family: none)	1-4

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2017121641 A [0002]
- JP H841535 B [0005]
- JP 2001049387 A [0005]
- JP 2002235144 A [0005]