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(54) Title: WEAR-RESISTANT STEEL PLATE HAVING EXCELLENT LOW-TEMPERATURE TOUGHNESS AND CORROSION WEAR RESISTANCE

(54) 発明の名称: 低温靱性および耐腐食摩耗性に優れた耐摩耗鋼板

(57) Abstract: Provided is a wear-resistant steel plate having excellent wear resistance, low-temperature toughness, and corrosion wear resistance. A wear-resistant steel plate having excellent low-temperature toughness and corrosion wear resistance containing, in mass percent, 0.10-0.20% C, 0.05-1.00% Si, 0.1-2.0% Mn, no more than 0.020% P, no more than 0.005% S, and 0.005-0.100% Al, and further containing one or two types of elements selected from among 0.05-2.0% Cr and 0.05-1.0% Mo, and fulfilling the condition that the amount of solid-solution Cr content of the steel (Cr_{sol}) and the amount of solid-solution Mo content of the steel (Mo_{sol}) is $0.05 \leq (\text{Cr}_{\text{sol}} + 2.5 \text{ Mo}_{\text{sol}}) \leq 2.0$, having a component structure comprising a remainder of Fe and unavoidable impurities, using an as-quenched martensite phase as a main phase, having a structure in which the prior austenite grain size is no more than 30 μm, and further having the surface hardness be at least 360 in terms of a Brinell hardness of HBW 10/3000.

(57) 要約: 耐摩耗性、低温靱性および耐腐食摩耗性に優れた耐摩耗鋼板を提供する。質量%で、C: 0.10~0.20%、Si: 0.05~1.00%、Mn: 0.1~2.0%、P: 0.020%以下、S: 0.005%以下、Al: 0.005~0.100%を含み、さらに、Cr: 0.05~2.0%、Mo: 0.05~1.0%のうちから選ばれた1種または2種を含み、かつ鋼中固溶Cr量(Cr_{sol})および鋼中固溶Mo量(Mo_{sol})が $0.05 \leq (\text{Cr}_{\text{sol}} + 2.5 \text{ Mo}_{\text{sol}}) \leq 2.0$ を満足し、残部Feおよび不可避的不純物からなる成分組成を有し、焼入れままマルテンサイト相を主相とし、旧オーステナイト粒径が30 μm以下である組織を有し、さらに、表面硬さが、ブリネル硬さHBW 10/3000で360以上である低温靱性および耐腐食摩耗性に優れた耐摩耗鋼板。

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DESCRIPTION

Title of the Invention:

ABRASION RESISTANT STEEL PLATE HAVING EXCELLENT
LOW-TEMPERATURE TOUGHNESS AND EXCELLENT CORROSIVE WEAR
RESISTANCE

Technical Field

[0001]

The present invention relates to an abrasion resistant steel plate suitably used for parts of industrial machines, transporting machines and the like. The abrasion resistant steel plate according to the present invention has excellent low-temperature toughness and relates to an abrasion resistant steel plate which can be suitably used as parts which are used in places where wear or abrasion generated due to a contact of the abrasion resistant steel plate with earth and sand containing water must be particularly taken into consideration.

Background Art

[0002]

Conventionally, with respect to parts for industrial machines, transporting machines and the like such as, for example, a power shovel, a bulldozer, a hopper, a bucket or a dump truck used in a construction site, a civil engineering site, a mine or the like, wear is generated due to a contact

of the part with earth, sand or the like. Accordingly, in manufacturing the above-mentioned parts, a steel material having excellent abrasion resistance is used for extending lifetime of the parts. In an actual in-use environment, various states such as a dry state or a wet state are considered as a state of earth, sand or the like. Particularly, there may be a case where earth, sand or the like in a wet state contain a corrosive material. Accordingly, the wear due to earth, sand or the like in a wet state becomes wear in an environment which contains the corrosive material, that is, so-called corrosive wear. This corrosive wear has been known as an extremely severe wear environment. In view of the above, there has been a demand for an abrasion resistant steel material having excellent corrosive wear resistance.

[0003]

The use of these industrial machines, transporting machines and the like in a low-temperature range of 0°C or below is also considered. Accordingly, a steel material which is used for parts of these industrial machines, transporting machines and the like is requested to possess the excellent low-temperature toughness in addition to the abrasion resistance and corrosive wear resistance.

[0004]

To satisfy such a request, for example, patent literature 1 proposes a method of manufacturing a high-hardness abrasion

resistant steel having excellent low-temperature toughness, wherein hot rolling is applied to a steel slab having the composition containing by mass%: 0.30% to 0.50% C, proper amounts of Si, Mn, Al, N, Ti, Nb and B respectively, and 0.10% to 0.50% Cr and 0.05% to 1.00% Mo, thereafter, quenching treatment is applied to the hot rolled steel plate from a temperature of A_{r3} transformation point or above and, subsequently, the quenched plate is tempered thus obtaining high-strength abrasion resistant steel. According to the description of the technique described in patent literature 1, the improvement of hardenability and the improvement of low-temperature toughness through strengthening of grain boundaries are achieved by allowing the steel to contain a large amount of Cr and a large amount of Mo. Further, according to the description of the technique described in patent literature 1, the further enhancement of low-temperature toughness is achieved by applying tempering treatment to the steel.

[0005]

Patent literature 2 proposes a high toughness abrasion resistant steel plate which has the composition containing by mass%: 0.18% to 0.25% C, 0.10% to 0.30% Si, 0.03% to 0.10% Mn, proper amounts of Nb, Al, N and B respectively, 1.00% to 2.00% Cr, and more than 0.50% to 0.80% Mo, and exhibits excellent toughness and excellent delayed fracture resistance after

water quenching and tempering. According to the description of a technique described in patent literature 2, by suppressing the content of Mn to a low level, and by allowing the steel plate to contain a large amount of Cr and a large amount of Mo, hardenability can be enhanced so that predetermined hardness can be ensured and, at the same time, toughness and delayed fracture resistance can be enhanced. Further, according to the description of the technique described in patent literature 2 further improves low-temperature toughness by further applying tempering.

[0006]

Patent literature 3 proposes a high toughness and abrasion resistant steel which has the composition containing by mass%: 0.30% to 0.45% C, 0.10% to 0.50% Si, 0.30% to 1.20% Mn, 0.50% to 1.40% Cr, 0.15% to 0.55% Mo, 0.0005% to 0.0050% B, 0.015% to 0.060% sol. Al, and proper amounts of Nb and/or Ti. According to the description of the technique described in patent literature 3, the steel contains a large amount of Cr and a large amount of Mo and hence, hardenability is enhanced and, at the same time, grain boundaries are strengthened thus enhancing low-temperature toughness.

[0007]

Patent literature 4 proposes a method of manufacturing an abrasion resistant steel, wherein hot-rolling is applied to steel having the composition containing by mass%: 0.05% to

0.40% C, 0.1% to 2.0% Cr, proper amounts of Si, Mn, Ti, B, Al and N respectively and, further, Cu, Ni, Mo, and V as arbitrary components at a cumulative reduction ratio of 50% or more in an austenitic non-recrystallized temperature range at a temperature of 900°C or below, thereafter, quenching is applied to a hot-rolled plate from a temperature of A_{r3} transformation point or above and, subsequently, the quenched plate is tempered thus abrasion resistant steel being obtained. According to the description of this technique, directly quenching and tempering elongated austenite grains result the tempered martensitic structure where prior austenite grains are elongated. The tempered martensitic structure of the elongated grains remarkably enhances low-temperature toughness.

[0008]

Further, patent literature 5 proposes an abrasion resistant steel plate having excellent low-temperature toughness and having the composition containing by mass%: 0.10% to 0.30% C, 0.05% to 1.0% Si, 0.1% to 2.0% Mn, 0.10% to 1.40% W, 0.0003% to 0.0020% B, 0.005% to 0.10% Ti and/or 0.035% to 0.1% Al. In the description of the technique described in patent literature 5, the abrasion resistant steel plate may further contain one or more kinds of elements selected from a group consisting of Cu, Ni, Cr and V. Due to such composition, in the technique described in patent literature 5, it is

considered that the abrasion resistant steel plate has high surface hardness and exhibits excellent abrasion resistance and excellent low-temperature toughness.

[0009]

Further, in patent literature 6, an abrasion resistant steel plate having excellent bending property is described. The abrasion resistant steel plate described in patent literature 6 is an abrasion resistant steel plate having the composition containing by mass%: 0.05% to 0.30% C, 0.1% to 1.2% Ti, and not more than 0.03% solute C, and having the structure wherein a matrix is formed of a ferrite phase and a hard phase is dispersed in the matrix. The abrasion resistant steel plate may further contain one or two kinds of components selected from a group consisting of Nb and V, one or two kinds of components selected from a group consisting of Mo and W, one or two kinds of components selected from a group consisting of Si, Mn and Cu, one or two kinds of components selected from a group consisting of Ni and B, and Cr. Due to such composition, in the technique described in patent literature 6, it is considered that both abrasion resistance and bending property against abrasion caused by earth and sand can be enhanced without inducing remarkable increase of hardness.

Citation List

Patent Literature

[0010]

PTL 1: JP-A-H08-41535
PTL 2: JP-A-H02-179842
PTL 3: JP-A-S61-166954
PTL 4: JP-A-2002-20837
PTL 5: JP-A-2007-92155
PTL 6: JP-A-2007-197813

Summary of Invention

Technical Problem

[0011]

However, the respective techniques described in patent literatures 1 to 5 aim at the acquisition of the steel plates having low-temperature toughness and abrasion resistance. Further, the technique described in patent literature 6 aims at the acquisition of the steel plate having both bending property and abrasion resistance. However, in none of these patent literatures, the wear in an environment which contains a corrosive material such as earth and sand in a wet state has been studied and hence, there exists a drawback that consideration has not been made with respect to corrosive wear resistance.

[0012]

Further, in the respective techniques described in patent literatures 1 to 4, tempering treatment is a requisite and hence, there exists a drawback that a manufacturing cost is increased. In the technique described in patent literature

5, the steel plate contains W as an indispensable component and hence, there exists a drawback that a manufacturing cost is increased. In the technique described in patent literature 6, the main phase is formed of ferrite and hence, surface hardness is low whereby the steel plate cannot acquire sufficient abrasion resistance.

[0013]

The present invention has been made to overcome the above-mentioned drawbacks of the related art. It would be advantageous if at least preferred embodiments of the present invention were to provide an abrasion resistant steel plate which can be manufactured at a low cost, and possesses excellent abrasion resistance, having all of excellent low-temperature toughness and excellent corrosive wear resistance.

Solution to Problem

[0014]

The inventors of the present invention have made extensive studies on the influence of various factors exerted on abrasion resistance, low-temperature toughness and corrosive wear resistance. As a result of the studies, the inventors have found that the corrosive wear resistance of a steel plate can be remarkably enhanced by making the steel plate have the composition containing proper amounts of Cr and/or Mo as indispensable components, and by adjusting the content of solute Cr in steel

and the content of solute Mo in steel such that the following formula (1) is satisfied.

$$0.05 \leq (\text{Cr}_{\text{sol}} + 2.5\text{Mo}_{\text{sol}}) \leq 2.0 \quad \dots (1)$$

(Here, Cr_{sol} : the content of solute Cr in steel (mass%), Mo_{sol} : the content of solute Mo in steel (mass%))

It is supposed that by allowing the steel plate to contain proper amounts of Cr and/or Mo as indispensable components and by allowing the steel plate to ensure proper amounts of solute Cr and solute Mo, even when the steel plate is exposed to earth and sand in a wet state having pH in a wide range, Cr and/or Mo exist as an oxyacid and hence, corrosive wear is suppressed.

[0015]

The inventors also have found that abrasion resistance and corrosive wear resistance against abrasion caused by earth and sand can be remarkably enhanced by maintaining surface hardness at a high level provided that the steel plate has the above-mentioned composition.

[0016]

The inventors also have found that hardenability of the steel plate can be enhanced by allowing the steel plate to contain proper amounts of Cr and/or Mo as indispensable components and by adjusting the composition of the steel plate such that the steel plate contains proper amounts of at least C, Si, Mn, P, S and Al, in addition, the excellent low-temperature toughness can also be surely acquired by

ensuring the structure where an as-quenched martensitic phase forms a main phase and a grain size of prior austenite (γ) grains is 30 μm or less.

[0017]

The present invention has been made based on the above-mentioned findings and has been completed after further study of the findings. That is, the gist of the invention is as follows.

(1) An abrasion resistant steel plate having excellent low temperature toughness and excellent corrosive wear resistance, the steel plate having a composition consisting of by mass%: 0.10% to 0.20% C; 0.05% to 1.00% Si; 0.1% to 2.0% Mn; 0.005% to 0.020% P; 0.0005% to 0.005% S; 0.005% to 0.100% Al; one or two kinds of components selected from a group consisting of 0.05% to 2.0% Cr and 0.05% to 1.0% Mo; optionally one or two or more kinds of components selected from a group consisting of 0.005% to 0.1% Nb, 0.005% to 0.1% Ti, 0.005% to 0.1% V, 0.005% to 0.2% Sn, 0.005% to 0.2% Sb, 0.03% to 1.0% Cu, 0.03% to 2.0% Ni, 0.0003% to 0.0030% B, 0.0005% to 0.008% REM, 0.0005% to 0.005% Ca, and 0.0005% to 0.005% Mg; and remaining Fe and unavoidable impurities as a balance; wherein the content of solute Cr in steel and the content of solute Mo in steel satisfy a following formula (1), the steel plate having a structure where an as-quenched martensitic phase forms a main phase and a grain size of prior austenite grains

is 30 μm or less, and surface hardness of the steel plate being 360 or more at Brinel hardness HBW10/3000.

$$0.05 \leq (\text{Cr}_{\text{sol}} + 2.5\text{Mo}_{\text{sol}}) \leq 2.0 \quad \dots (1)$$

where, Cr_{sol} : the content of solute Cr in steel (mass%), Mo_{sol} : the content of solute Mo in steel (mass%)

(2) In the abrasion resistant steel plate described in (1), the steel composition contains by mass% one or two or more kinds of components selected from a group consisting of 0.005% to 0.1% Nb, 0.005% to 0.1% Ti, and 0.005% to 0.1% V.

(3) In the abrasion resistant steel plate described in (1) or (2), the steel composition contains by mass% one or two kinds of components selected from a group consisting of 0.005% to 0.2% Sn and 0.005% to 0.2% Sb.

(4) In the abrasion resistant steel plate described in any of (1) to (3), the steel composition contains by mass% one or two or more kinds of components selected from a group consisting of 0.03% to 1.0% Cu, 0.03% to 2.0% Ni, and 0.0003% to 0.0030% B.

(5) In the abrasion resistant steel plate described in any of (1) to (4), the steel composition contains by mass% one or two or more kinds of components selected from a group consisting of 0.0005% to 0.008% REM, 0.0005% to 0.005% Ca, and 0.0005% to 0.005% Mg.

Advantageous Effects of Invention

[0018]

According to the present invention, it is possible to manufacture, easily and in a stable manner, an abrasion resistant steel plate having excellent corrosive wear resistance in an earth-and-sand abrasion environment in a wet

state, having excellent low-temperature toughness, and excellent abrasion resistance in a stable manner without lowering surface hardness.

Description of Embodiments

[0019]

Firstly, the reasons for limiting the composition of the abrasion resistance steel plate of the present invention are explained. In the explanation made hereinafter, mass% is simply expressed by % unless otherwise specified.

[0020]

C: 0.10% to 0.20%

C is an important element for increasing hardness of the steel plate and for enhancing abrasive resistance. When the content of C is less than 0.10%, the steel plate cannot acquire sufficient hardness. On the other hand, when the content of C exceeds 0.20%, weldability, low-temperature toughness and workability are lowered. Accordingly, the content of C is limited to a value which falls within a range from 0.10% to 0.20%. The content of C is preferably limited to a value which falls within a range from 0.14% to 0.17%.

[0021]

Si: 0.05% to 1.00%

Si is an effective element acting as a deoxidizing agent for molten steel. Si is also an element which effectively contributes to the enhancement of strength of the steel plate

by solid solution strengthening. The content of Si is set to 0.05% or more to ensure such effects. When the content of Si is less than 0.05%, a deoxidizing effect cannot be sufficiently acquired. On the other hand, when the content of Si exceeds 1.0%, ductility and toughness are lowered, and the content of inclusions in the steel plate is increased. Accordingly, the content of Si is limited to a value which falls within a range from 0.05% to 1.0%. The content of Si is preferably limited to a value which falls within a range from 0.2% to 0.5%.

[0022]

Mn: 0.1% to 2. 0%

Mn is an effective element having an action of enhancing hardenability. To ensure such an effect, the content of Mn is set to 0.1% or more. On the other hand, when the content of Mn exceeds 2.0%, weldability is lowered. Accordingly, the content of Mn is limited to a value which falls within a range from 0.1% to 2.0%. The content of Mn is preferably limited to a value which falls within a range from 0.4% to 1.6%. It is more preferable that the content of Mn is limited to a value which falls within a range from 0.7% to 1.4%.

[0023]

P: 0.020% or less

When the content of P in steel is large, lowering of low-temperature toughness is induced and hence, it is desirable that the content of P be as small as possible. In

the present invention, the permissible content of P is 0.020%. Accordingly, the content of P is limited to 0.020% or less. The excessive reduction of the content of P induces the sharp rise in a refining cost and hence, it is desirable to set the content of P to 0.005% or more.

[0024]

S: 0.005% or less

When the content of S in steel is large, S is precipitated as MnS. In high strength steel, MnS becomes an initiation point of the occurrence of fracture and induces deterioration of toughness. Accordingly, it is desirable that the content of S be as small as possible. In the present invention, the permissible content of S is 0.005%. Accordingly, the content of S is limited to 0.005% or less. The excessive reduction of the content of S induces the sharp rise of a refining cost and hence, it is desirable to set the content of S to 0.0005% or more.

[0025]

Al: 0.005% to 0.100%

Al is an effective element acting as a deoxidizing agent for molten steel. Further, Al contributes for the enhancement of low-temperature toughness due to refining of crystal grains. To acquire such an effect, the content of Al is set to 0.005% or more. When the content of Al is less than 0.005%, such an effect cannot be sufficiently acquired. On the other hand,

when the content of Al exceeds 0.100%, weldability is lowered. Accordingly, the content of Al is limited to a value which falls within a range from 0.005% to 0.100%. The content of Al is preferably limited to a value which falls within a range from 0.015% to 0.050%.

[0026]

One or two kinds of components selected from 0.05% to 2.0% Cr or 0.05% to 1.0% Mo

Both Cr and Mo have an action of suppressing corrosive wear, and the steel plate optionally contains one kind or two kinds of Cr and Mo.

[0027]

Cr has an effect of increasing hardenability thus making a martensitic phase finer so as to enhance low-temperature toughness. Accordingly, in the present invention, Cr is an important element. Further, in a corrosive wear environment where a contact between a steel plate and earth and sand or the like in a wet state becomes a problem, Cr is dissolved as chromate ion due to an anodic reaction, and suppresses corrosion due to an inhibitor effect thus giving rise to an effect of enhancing corrosive wear resistance. To acquire such an effect, the content of Cr is set to 0.05% or more. When the content of Cr is less than 0.05%, the steel plate cannot exhibit such an effect sufficiently. On the other hand, when the content of Cr exceeds 2.0%, weldability is lowered and a

manufacturing cost is sharply increased. Accordingly, the content of Cr is limited to a value which falls within a range from 0.05% to 2.0%. It is preferable to limit the content of Cr to a value which falls within a range from 0.07% to 1.20%.

[0028]

Mo has an effect of increasing hardenability thus making a martensitic phase finer so as to enhance low-temperature toughness. Accordingly, in the present invention, Mo is an important element. Further, in a corrosive wear environment where a contact between a steel plate and earth and sand or the like in a wet state becomes a problem, Mo is dissolved as molybdate ion due to an anodic reaction, and suppresses corrosion by an inhibitor effect thus giving rise to an effect of enhancing corrosive wear resistance. To acquire such an effect, the content of Mo is set to 0.05% or more. When the content of Mo is less than 0.05%, the steel plate cannot exhibit such an effect sufficiently. On the other hand, when the content of Mo exceeds 1.0%, weldability is lowered and a manufacturing cost is sharply increased. Accordingly, the content of Mo is limited to a value which falls within a range from 0.05% to 1.0%. It is preferable to limit the content of Mo to a value which falls within a range from 0.10% to 0.50%.

[0029]

By containing both Cr and Mo, it is expected that corrosive wear resistance can be enhanced remarkably. It is

based on the estimation that corrosive wear caused by earth and sand or the like in a wet state having pH in a wide range can be suppressed, since Cr and Mo have different pH regions respectively where Cr or Mo can exist as an oxygen acid.

[0030]

To enhance corrosive wear resistance, in the present invention, the steel plate contains Cr and Mo which fall within the above-mentioned ranges, and the content of solute Cr in steel and the content of solute Mo in steel can be adjusted so as to satisfy the following formula (1).

$$0.05 \leq (\text{Cr}_{\text{sol}} + 2.5\text{Mo}_{\text{sol}}) \leq 2.0 \quad \text{..... (1)}$$

(Cr_{sol}: the content of solute Cr in steel (mass%), Mo_{sol}: the content of solute Mo in steel (mass%))

When Cr and Mo form carbides or the like and carbides or the like are precipitated as precipitates, the content of solute Cr or the content of solute Mo is decreased around the precipitates. Accordingly, the above-mentioned inhibitor effect is decreased so that corrosive wear resistance is lowered. According to the present invention, the content of solute Cr in steel (Cr_{sol}) and the content of solute Mo in steel (Mo_{sol}) are adjusted so as to satisfy the above-mentioned formula (1). To sufficiently ensure the above-mentioned inhibitor effect, in the present invention, it is necessary to set (Cr_{sol}+2.5Mo_{sol}) to 0.05 or more. On the other hand, when (Cr_{sol}+2.5Mo_{sol}) exceeds 2.0, the inhibitor effect is

saturated and, at the same time, a manufacturing cost sharply rises. It is preferable that $(Cr_{sol} + 2.5Mo_{sol})$ is set to a value which falls within a range from 0.10 to 1.0.

[0031]

The content of solute Cr and the content of solute Mo can be calculated by the following method. Steel is extracted by electrolysis in electrolytic solution containing 10% acetylacetone, and an obtained extracted residue (precipitates) is analyzed by an inductively coupled plasma atomic emission spectrophotometry method. The content of Cr contained in the extracted residue and the content of Mo contained in the extracted residue are respectively determined as the content of precipitated Cr and the content of precipitated Mo. The content of solute Cr and the content of solute Mo are obtained by subtracting the determined values from the total content of Cr and the total content of Mo respectively.

[0032]

Further, to enable the content of solute Cr and the content of solute Mo to satisfy the formula (1), it is necessary to suppress the precipitation of carbide and the like as much as possible. For this end, it is necessary to adjust heat history or to control the content of Nb and the content of Ti. To be more specific, for example, it is desirable to make a time that steel is held in a temperature range (500°C to 800°C)

where carbide or the like of Cr or Mo precipitates as short as possible or to add Nb or Ti which is more liable to form carbide or the like than Cr and Mo.

[0033]

The above-mentioned components are the basic components of the steel according to the present invention. Further, the steel according to the present invention may optionally contain, in addition to the above-mentioned basic components, as an optional element or optional elements, one or two or more kinds of components selected from a group consisting of 0.005% to 0.1% Nb, 0.005% to 0.1% Ti, and 0.005% to 0.1% V, and/or one or two kinds of components selected from a group consisting of 0.005% to 0.2% Sn and 0.005% to 0.2% Sb, and/or one or two or more kinds of components selected from a group consisting of 0.03% to 1.0% Cu, 0.03% to 2.0% Ni, and 0.0003% to 0.0030% B, and/or one or two or more kinds of components selected from a group consisting of 0.0005% to 0.008% REM, 0.0005% to 0.005% Ca, and 0.0005% to 0.005% Mg.

[0034]

One or two or more kinds of components selected from a group consisting of 0.005% to 0.1% Nb, 0.005% to 0.1% Ti, and 0.005% to 0.1% V

All of Nb, Ti and V are elements which precipitate as precipitates such as carbonitride and the like, and enhance toughness of steel through refining of the structure. In the

present invention, when necessary, steel may contain one or two or more kinds of components selected from a group consisting of Nb, Ti and V.

[0035]

Nb is an element which precipitates as carbonitride and effectively contributes to the enhancement of toughness through refining of the structure. The content of Nb may preferably be set to 0.005% or more for ensuring such an effect. On the other hand, when the content of Nb exceeds 0.1%, weldability is lowered. Accordingly, when the steel contains Nb, the content of Nb is preferably limited to a value which falls within a range from 0.005% to 0.1%. The content of Nb is more preferably set to a value which falls within a range from 0.012% to 0.03% from a view point of refining of the structure.

[0036]

Ti is an element which precipitates as TiN and contributes to the enhancement of toughness through fixing solute N. The content of Ti is preferably set to 0.005% or more for acquiring such an effect. On the other hand, when the content of Ti exceeds 0.1%, coarse carbonitride precipitates so that toughness is lowered. Accordingly, when the steel contains Ti, the content of Ti is preferably limited to a value which falls within a range from 0.005% to 0.1%. The content of Ti is more preferably limited to a value which falls

within a range from 0.005% to 0.03% from a view point of the reduction of a manufacturing cost.

[0037]

V is an element which precipitates as carbonitride and contributes to the enhancement of toughness through an effect of refining the structure. The content of V is preferably set to 0.005% or more for acquiring such an effect. On the other hand, when the content of V exceeds 0.1%, weldability is lowered. Accordingly, when the steel contains V, the content of V is preferably limited to a value which falls within a range from 0.005% to 0.1%.

[0038]

One or two kinds of components selected from a group consisting of 0.005% to 0.2% Sn and 0.005% to 0.2% Sb

Both Sn and Sb are elements which enhance corrosive wear resistance. In the present invention, when necessary, steel may contain one or two kinds of elements selected from a group consisting of Sn and Sb.

[0039]

Sn is dissolved as Sn ion due to an anodic reaction, and suppresses corrosion by an inhibitor effect thus enhancing corrosive wear resistance of a steel plate. Further, Sn forms an oxide film containing Sn on a surface of the steel plate and hence, an anodic reaction and a cathodic reaction of the steel plate are suppressed whereby corrosive wear resistance

of the steel plate is enhanced. The content of Sn is preferably set to 0.005% or more for acquiring such an effect. On the other hand, when the content of Sn exceeds 0.2%, the deterioration of ductility and toughness of the steel plate are induced. Accordingly, when the steel contains Sn, the content of Sn is preferably limited to a value which falls within a range from 0.005% to 0.2%. The content of Sn is more preferably set to a value which falls within a range from 0.005% to 0.1% from a view point of reducing tramp elements.

[0040]

Sb suppresses corrosion of a steel plate by suppressing an anodic reaction of the steel plate and also by suppressing a hydrogen generation reaction which is a cathodic reaction thus enhancing corrosive wear resistance. The content of Sb is preferably set to 0.005% or more for sufficiently acquiring such an effect. On the other hand, when the content of Sb exceeds 0.2%, the deterioration of toughness of the steel plate is induced. Accordingly, when the steel contains Sb, the content of Sb is preferably set to a value which falls within a range from 0.005% to 0.2%. It is more preferable that the content of Sb is set to a value which falls within a range from 0.005% to 0.1%.

[0041]

One or two or more kinds of components selected from a group consisting of 0.03% to 1.0% Cu, 0.03% to 2.0% Ni, and 0.0003%

to 0.0030% B

All of Cu, Ni and B are elements which enhance hardenability. In the present invention, when necessary, steel may contain one or two or more kinds of elements selected from a group consisting of Cu, Ni and B.

[0042]

Cu is an element which contributes to the enhancement of hardenability. The content of Cu may preferably be 0.03% or more for acquiring such an effect. On the other hand, when the content of Cu exceeds 1.0%, hot workability is lowered, and a manufacturing cost also sharply rises. Accordingly, when the steel contains Cu, the content of Cu is preferably limited to a value which falls within a range from 0.03% to 1.0%. The content of Cu is more preferably limited to a value which falls within a range from 0.03% to 0.5% from a view point of further reduction of a manufacturing cost.

[0043]

Ni is an element which contributes to the enhancement of hardenability and also the enhancement of low-temperature toughness. The content of Ni may preferably be 0.03% or more for acquiring such an effect. On the other hand, when the content of Ni exceeds 2.0%, a manufacturing cost rises. Accordingly, when the steel contains Ni, the content of Ni is preferably limited to a value which falls within a range from 0.03% to 2.0%. The content of Ni is more preferably limited

to a value which falls within a range from 0.03% to 0.5% from a viewpoint of further reduction of a manufacturing cost.

[0044]

B is an element which contributes to the enhancement of hardenability with a small amount contained in steel. The content of B may preferably be 0.0003% or more for acquiring such an effect. On the other hand, when the content of B exceeds 0.0030%, toughness is lowered. Accordingly, when the steel contains B, the content of B is preferably limited to a value which falls within a range from 0.0003% to 0.0030%. The content of B more preferably falls within a range from 0.0003% to 0.0015% from a viewpoint of suppressing cold cracking at a welded part formed by a low-heat input welding such as CO₂ welding used in general in welding of an abrasion resistant steel plate.

[0045]

One or two or more kinds of components selected from a group consisting of 0.0005% to 0.008% REM, 0.0005% to 0.005% Ca, and 0.0005% to 0.005% Mg

All of REM, Ca and Mg are elements which form sulfide inclusions by combining with S and hence, these elements are elements which suppress the formation of MnS. In the present invention, when necessary, steel may contain one or two or more kinds of components selected from a group consisting of REM, Ca and Mg.

[0046]

REM fixes S thus suppressing the formation of MnS which causes lowering of toughness. The content of REM may preferably be 0.0005% or more for acquiring such an effect. On the other hand, when the content of REM exceeds 0.008%, the content of inclusions in the steel is increased so that toughness is lowered to the contrary. Accordingly, when the steel contains REM, the content of REM is preferably limited to a value which falls within a range from 0.0005% to 0.008%. The content of REM is more preferably set to a value which falls within a range from 0.0005% to 0.0020%.

[0047]

Ca fixes S thus suppressing the formation of MnS which causes lowering of toughness. The content of Ca may preferably be 0.0005% or more for acquiring such an effect. On the other hand, when the content of Ca exceeds 0.005%, the content of inclusions in the steel is increased so that toughness is lowered to the contrary. Accordingly, when the steel contains Ca, the content of Ca is preferably limited to a value which falls within a range from 0.0005% to 0.005%. The content of Ca is more preferably set to a value which falls within a range from 0.0005% to 0.0030%.

[0048]

Mg fixes S thus suppressing the formation of MnS which causes lowering of toughness. The content of Mn may preferably

be 0.0005% or more for acquiring such an effect. On the other hand, when the content of Mg exceeds 0.005%, the content of inclusions in the steel is increased so that toughness is lowered to the contrary. Accordingly, when the steel contains Mg, the content of Mg is preferably limited to a value which falls within a range from 0.0005% to 0.005%. It is more preferable that the content of Mg is set to a value which falls within a range from 0.0005% to 0.0040%.

[0049]

The abrasion resistant steel plate according to the present invention has the above-mentioned composition, and further has a microstructure comprising an as-quenched martensitic phase forming a main phase and prior austenite (γ) grains with grain size of 30 μm or less. Here, a phase which occupies 90% or more in an area ratio is defined as "main phase".

[0050]

As-quenched martensitic phase: 90% or more in area ratio

When the phase fraction of the as-quenched martensitic phase is less than 90% in an area ratio, steel cannot ensure desired hardness, and wear resistance is lowered so that desired wear resistance cannot be ensured. Further, steel cannot ensure the sufficient low-temperature toughness. Further, in case of tempered martensite, Cr and Mo form carbide together with Fe when cementite is formed by tempering and hence, solute Cr and solute Mo, which are effective to ensure corrosion

resistance, are decreased. Accordingly, the martensitic phase is held in as-quenched martensitic phase where the martensitic phase is not tempered. An area ratio of the as-quenched martensitic phase is preferably set to 95% or more.

[0051]

Grain size of prior austenite (γ) grains: 30 μm or less

Even when the as-quenched martensitic phase is ensured the area ratio of 90% or more, when a grain size of prior austenite (γ) grains becomes coarse exceeding 30 μm , the low-temperature toughness is lowered. As the grain size of prior austenite (γ) grains, values which are obtained in accordance with JIS G 0551 after microscopically observing the structure etched by a picric acid using an optical microscope (magnification: 400 times) are used.

[0052]

The abrasion resistant steel plate according to the present invention having the above-mentioned composition and structure has surface hardness of 360 or more at Brinell hardness HBW 10/3000.

[0053]

Surface hardness: 360 or more at Brinell hardness HBW 10/3000

When the surface hardness of steel is less than 360 at Brinell hardness HBW 10/3000, the lifetime of the abrasion resistant steel plate becomes short. Brinell hardness is measured in accordance with the stipulation described in JIS

Z 2243 (2008).

[0054]

Next, the preferred method of manufacturing the abrasion resistant steel plate of the present invention is explained.

[0055]

Steel material having the above-mentioned composition is subjected to hot rolling as it is without cooling when the steel material holds a predetermined temperature or after cooling and reheating, thus manufacturing a steel plate having a desired size and a desired shape.

The method of manufacturing the steel material is not particularly limited. It is desirable that molten steel having the above-mentioned composition is produced using a known refining method such as using a converter, and a steel material such as a slab having a predetermined size is manufactured by a known casting method such as a continuous casting method. It goes without saying that a steel material can be manufactured by an ingot casting-blooming method.

[0056]

Reheating temperature: 950 to 1250°C

When the reheating temperature is below 950°C, the deformation resistance becomes excessively high so that a rolling load becomes excessively large whereby hot rolling may not be performed. On the other hand, when the reheating temperature becomes high exceeding 1250°C, the crystal grains

become excessively coarse so that steel cannot ensure desired high toughness. Accordingly, the reheating temperature is preferably limited to a value which falls within a range from 950 to 1250°C.

[0057]

The reheated steel material or the steel material which holds a predetermined temperature without being reheated is, then, subjected to hot rolling so that a steel plate having a desired size and a desired shape is manufactured. The hot rolling condition is not particularly limited. After the hot rolling is finished, it is preferable that direct quenching treatment (DQ), where the steel plate is quenched immediately after the hot rolling finish, is applied to the steel plate. It is preferable that a quenching start temperature is set to a temperature not below an Ar3 transformation point. To set the quenching start temperature equal to or higher than the Ar3 transformation point, it is preferable to set the hot rolling finish temperature to a value which falls within a range from 800 to 950°C, being equal to or higher than the Ar3 transformation point. A quenching cooling rate is not particularly limited provided that the quenching cooling rate is equal to or higher than a cooling rate at which a martensitic phase is formed.

[0058]

A cooling stop temperature is preferably set to a

temperature equal to or below an Ms point. It is more preferable that the cooling stop temperature is set to 300°C or below for preventing an as-quenched martensitic phase from being self-tempered. It is further preferable that the cooling stop temperature is set to 200°C or below.

[0059]

After the hot rolling is finished, in place of the direct quenching treatment where a steel plate is immediately quenched, reheating quenching treatment (RQ) may be performed where the steel plate is cooled by air after the hot rolling is finished, thereafter, the steel plate is reheated to a predetermined heating temperature and, then, the steel plate is quenched. It is desirable that the reheating quenching temperature is set to a value which falls within a range from 850 to 950°C. A quenching cooling rate after reheating is not particularly limited provided that the quenching cooling rate after reheating is equal to or higher than a cooling rate at which a martensitic phase is formed. A cooling stop temperature is preferably set to a temperature equal to or below an Ms point. The cooling stop temperature is more preferably set to 300°C or below for preventing an as-quenched martensitic phase from being self-tempered. The cooling stop temperature is further preferably set to 200°C or below.

Example 1

[0060]

Hereinafter, the present invention is further explained based on examples.

[0061]

Molten steel having the composition described in Table 1 was produced by a vacuum melting furnace, and was cast into a mold so that ingots (steel material) having a weight of 150 kgf respectively were manufactured. These steel materials were heated at reheating temperatures described in Tables 2 and 3 and, thereafter, the steel materials were subjected to hot rolling under conditions described in Table 2 and Table 3, and direct quenching treatment (DQ) was performed where quenching is immediately performed after the hot rolling is finished (direct quenching). Reheating quenching treatment (RQ) was applied to some steel plates where the steel plates were cooled by air after the hot rolling was finished, the steel plates were reheated at heating temperatures described in Tables 2, 3 and, thereafter, quenching was performed.

[0062]

Specimens were sampled from the manufactured steel plates, and specimens were subject to an observation of the structure, a surface hardness test, a Charpy impact test, and a corrosive wear resistance test. Specimens for electrolytic extraction were sampled from the manufactured steel plates, and the specimens were subjected to electrolysis in a 10% AA electrolytic solution (10% acetylacetone-1%

tetramethylammonium chloride-methyl alcohol electrolytic solution), and residues were extracted. With respect to each of the obtained extracted residues, the content of Cr contained in the extracted residue and the content of Mo contained in the extracted residue were analyzed using an inductively coupled plasma atomic emission spectrophotometry method, and the content of Cr in the form of precipitates and the content of Mo in the form of precipitates were calculated. The content of solute Cr (Cr_{sol}) and the content of solute Mo (Mo_{sol}) were obtained by subtracting the content of Cr in the form of precipitates and the content of Mo in the form of precipitates from the total content of Cr and the total content of Mo respectively.

[0063]

The following test methods were adopted.

[0064]

(1) Observation of structure

Specimens for structure observation were sampled from manufactured steel plates at a position of 1/2 plate thickness of the steel plate such that an observation surface becomes a cross section perpendicular to the rolling direction. The specimens were polished and were etched by a picric acid to expose prior γ grains and, thereafter, subjected to observation by an optical microscope (magnification: 400 times). Equivalent circle diameters of respective 100 grains of prior

γ grains were measured, an arithmetic mean was calculated based on obtained equivalent circle diameters, and the arithmetic mean was set as the prior γ grain size of the steel plate.

[0065]

Thin film specimens (specimens for observation of structure by transmission electron microscope) were sampled from the manufactured steel plates at a position of 1/2 plate thickness of the steel plate being parallel to a surface of the plate. The specimen was grinded and polished (mechanical polishing, electrolytic polishing) thus forming a thin film. Next, 20 fields of vision for each were observed by a transmission electron microscope (magnification: 20000 times). A region where cementite does not precipitate was set as an as-quenched martensitic phase region, and the area of the region was measured. The area of the as-quenched martensitic phase region was indicated by a ratio (%) with respect to the whole structure, and this ratio was set as an as-quenched martensitic fraction (area ratio).

[0066]

(2) Surface hardness test

Specimens for surface hardness measurement were sampled from the manufactured steel plates, and surface hardness HBW 10/3000 was measured in accordance with JIS Z 2243 (2008). In the hardness measurement, a tungsten hard ball having a diameter of 10 mm was used, and a load was set to 3000 kgf.

[0067]

(3) Charpy impact test

V-notched specimens were sampled from manufactured steel plates at a position of 1/2 plate thickness of the steel plate away from a surface of the steel plate in the direction (C direction) perpendicular to the rolling direction in accordance with the stipulation of JIS Z 2242(2005), and a Charpy impact test was performed. A test temperature was set to -40°C and absorbed energy vE_{-40} (J) was obtained. The number of specimens was three for each of steel plates, and an arithmetic mean of the three specimens is set as the absorbed energy vE_{-40} of the steel plate. The steel plate having the absorbed energy vE_{-40} of 30 J or more was evaluated as the steel plate having excellent "base material low-temperature toughness". With respect to the steel plates having a plate thickness of less than 10 mm, 1/2 t sub-size Charpy specimens were used (t: plate thickness). In the case of the 1/2 t sub-size Charpy specimens, the steel plate having the absorbed energy vE_{-40} of 15 J or more was evaluated as the steel plate having excellent "base material toughness".

[0068]

(4) Corrosive wear resistance test

Wear specimens (size: thickness of 10 mm, width of 25 mm and length of 75 mm) were sampled from manufactured steel plates at a position 1 mm away from a surface of the manufactured

steel plate. These wear specimens were mounted on a wear tester, and a wear test was carried out.

The wear specimen was mounted on the wear tester such that the wear specimen was perpendicular to an axis of rotation of a rotor of the tester and a surface of 25 mmx75 mm was parallel to the circumferential tangential direction of a rotating circle, the specimen and the rotor were covered with an outer vessel, and a wear material was introduced into the inside of the outer vessel. As the wear material, a mixture is used where silica sand having an average particle size of 0.65 mm and an NaCl aqueous solution which was prepared such that the concentration becomes 15000 mass ppm were mixed together such that a weight ratio between silica sand and the NaCl aqueous solution becomes 3:2.

[0069]

Test conditions were set such that the rotor was rotated at 600 rpm and the outer vessel was rotated at 45 rpm. The test was finished at the revolutions of the rotor became 10800 times in total. After the test was finished, weights of the respective specimens were measured. The difference between the weight after test and the initial weight (=an amount of reduction of weight) was calculated, and a wear resistance ratio (= (reference value)/(amount of reduction of weight of specimen)) was calculated using an amount of reduction of weight of steel stipulated in Rolled steels for general

structure, Tensile strength 400 MPa class SS400 (JIS G3101) (conventional example) as a reference value. When the wear resistance ratio was 1.5 or more, the steel plate was evaluated as the steel plate "having excellent corrosive wear resistance".

[0070]

The measured results are shown in Table 4 and Table 5.

[0071]

[Table 1]

Steel Number	Chemical Composition (mass%)											Ar3 Transformation Point (°C)	Remarks
	C	Si	Mn	P	S	sol.Al	Cr	Mo	Nb, Ti, V	Sn, Sb	Cu, Ni, B	REM, Ca, Mg	
A	0.15	0.36	1.38	0.007	0.0017	0.032	0.11						within scope of present invention
B	0.13	0.29	0.42	0.009	0.0026	0.028	1.37				Cu:0.07, Ni:0.15		within scope of present invention
C	0.15	0.33	1.05	0.009	0.0019	0.021	0.40		Nb:0.02, Ti:0.016		B:0.0015		within scope of present invention
D	0.19	0.31	1.15	0.008	0.0026	0.021		0.12					within scope of present invention
E	0.20	0.25	1.64	0.008	0.0018	0.023		0.21	Ti:0.014			REM:0.0015	within scope of present invention
F	0.12	0.35	0.52	0.007	0.0017	0.030		0.56	V:0.041			Ca:0.0019	within scope of present invention
G	0.14	0.29	1.12	0.007	0.0026	0.029	0.06	0.07	Ti:0.014, V:0.016		B:0.0009	Mg:0.0011	within scope of present invention
H	0.17	0.31	1.01	0.008	0.0021	0.024	0.41	0.09					within scope of present invention
I	0.16	0.25	0.49	0.011	0.0016	0.027	0.81	0.21	Nb:0.018		B:0.0025		within scope of present invention
J	0.15	0.34	1.21	0.010	0.0023	0.023	0.09	0.14	Nb:0.02, Ti:0.014		B:0.0013		within scope of present invention
K	0.16	0.32	0.99	0.008	0.0025	0.026	1.01	0.22	Nb:0.02, Ti:0.014		B:0.0011		within scope of present invention
L	0.15	0.33	0.93	0.009	0.0021	0.028	0.76	0.36	Nb:0.019, Ti:0.015, V:0.045		B:0.0013		within scope of present invention
M	0.15	0.36	1.01	0.008	0.0022	0.022	0.10	0.25	Nb:0.019, Ti:0.013		B:0.0012		within scope of present invention
N	0.16	0.29	0.95	0.007	0.0019	0.026	0.31		Nb:0.019, Ti:0.014	Sn:0.035	B:0.0013		within scope of present invention
O	0.14	0.21	1.35	0.007	0.0023	0.025	0.08	0.21	Nb:0.020, Ti:0.012	Sn:0.067	B:0.0014		within scope of present invention
P	0.15	0.26	1.09	0.007	0.0029	0.030	0.80	0.33	Nb:0.017, Ti:0.014	Sn:0.045, Sb:0.044	B:0.0009		within scope of present invention
Q	0.18	0.29	0.87	0.007	0.0014	0.019	1.10	0.34	Nb:0.029, Ti:0.021, V:0.034		Cu:0.24, Ni:0.31	Ca:0.0012	within scope of present invention

(Continued)

Steel Number	Chemical Composition (mass%)												Ar3 Transformation Point (°C)	Remarks
	C	Si	Mn	P	S	sol.Al	Cr	Mo	Nb, Ti, V	Sn, Sb	Cu, Ni, B	REM, Ca, Mg		
<u>R</u>	0.17	0.38	1.43	0.008	0.0016	0.023	<u>0.02</u>		Ti:0.016, V:0.019			Ca:0.0013	743	outside scope of present invention
<u>S</u>	0.12	0.37	1.51	0.012	0.0023	0.030		<u>0.02</u>			B:0.0031		750	outside scope of present invention
<u>I</u>	0.16	0.34	1.23	0.011	0.0019	0.021	<u>0.04</u>		Ti:0.014, V:0.025		Cu:0.12		759	outside scope of present invention
<u>U</u>	0.14	0.28	1.36	0.007	0.0019	0.025	<u>0.03</u>	<u>0.02</u>			Ni:0.14	Mg:0.0021	748	outside scope of present invention
<u>V</u>	<u>0.08</u>	0.35	0.98	0.008	0.0023	0.028	0.19	0.15	Nb:0.022				792	outside scope of present invention

Underlined values fall outside the scope of present invention.

[0072]

[Table 2]

Steel Plate Number	Steel Number	Plate Thickness (mm)	Type of Treatment*	Hot Rolling				Heat Treatment			
				Reheating Temperature (°C)	Rolling Finish Temperature (°C)	Cooling Start Temperature (°C)	Cooling Method	Cooling Stop Temperature (°C)	Heating Temperature (°C)	Cooling Method	Cooling Stop Temperature (°C)
1	A	12	RQ	1110	860	-	cooled by air	-	870	cooled by water	250
2	A	19	DQ	1110	870	840	cooled by water	200	-	-	-
3	A	35	DQ	1110	880	850	cooled by water	230	-	-	-
4	B	6	RQ	1120	910	-	cooled by air	-	880	cooled by water	150
5	B	19	RQ	1120	930	-	cooled by air	-	900	cooled by water	150
6	B	32	DQ	1120	870	800	cooled by water	150	-	-	-
7	C	6	RQ	1120	850	-	cooled by air	-	950	cooled by water	200
8	C	12	RQ	1120	860	-	cooled by air	-	870	cooled by water	200
9	C	19	DQ	1120	890	830	cooled by water	150	-	-	-
10	D	19	DQ	1050	840	810	cooled by water	150	-	-	-
11	D	25	DQ	1050	850	800	cooled by water	150	-	-	-
12	D	35	DQ	1050	880	820	cooled by water	130	-	-	-
13	E	6	RQ	1120	840	-	cooled by air	-	930	cooled by water	150
14	E	12	RQ	1120	870	-	cooled by air	-	900	cooled by water	150
15	E	20	DQ	1120	890	830	cooled by water	150	-	-	-
16	F	12	RQ	1120	890	-	cooled by air	-	900	cooled by water	150
17	F	19	DQ	1120	870	850	cooled by water	150	-	-	-
18	F	32	DQ	1120	890	840	cooled by water	170	-	-	-
19	G	20	DQ	1150	920	880	cooled by water	160	-	-	-
20	G	25	RQ	1150	930	-	cooled by air	-	900	cooled by water	150

(Continued)

Steel Plate Number	Steel Number	Plate Thickness (mm)	Type of Treatment*	Hot Rolling				Heat Treatment			
				Reheating Temperature (°C)	Rolling Finish Temperature (°C)	Cooling Start Temperature (°C)	Cooling Method	Cooling Stop Temperature (°C)	Heating Temperature (°C)	Cooling Method	Cooling Stop Temperature (°C)
21	G	35	DQ	1150	910	870	cooled by water	200	-	-	-
22	H	6	RQ	1120	910	-	cooled by air	-	880	cooled by water	150
23	H	19	RQ	1120	930	-	cooled by air	-	900	cooled by water	150
24	H	32	RQ	1120	870	-	cooled by air	-	900	cooled by water	150
25	I	12	RQ	1120	900	-	cooled by air	-	900	cooled by water	170
26	I	19	RQ	1120	920	-	cooled by air	-	910	cooled by water	170
27	I	25	DQ	1120	880	830	cooled by water	210	-	-	-
28	I	12	DQ	1170	900	860	cooled by water	210	-	-	-
29	J	25	DQ	1170	920	880	cooled by water	220	-	-	-
30	J	35	RQ	1170	880	-	cooled by air	-	900	cooled by water	160
37	K	6	RQ	1070	900	-	cooled by air	-	900	cooled by water	170
38	K	19	RQ	1170	920	-	cooled by air	-	900	cooled by water	170
39	K	25	RQ	1120	860	-	cooled by air	-	900	cooled by water	170
40	L	6	RQ	1120	880	-	cooled by air	-	870	cooled by water	170
41	L	19	RQ	1120	900	-	cooled by air	-	920	cooled by water	170
42	L	25	RQ	1120	890	-	cooled by air	-	900	cooled by water	170

Underlined values fall outside the scope of present invention.

*DQ: direct quenching, RQ: reheating quenching

[0073]

[Table 3]

Steel Plate Number	Steel Number	Plate Thickness (mm)	Type of Treatment*	Hot Rolling					Heat Treatment		
				Reheating Temperature (°C)	Rolling Finish Temperature (°C)	Cooling Start Temperature (°C)	Cooling Method	Cooling Stop Temperature (°C)	Heating Temperature (°C)	Cooling Method	Cooling Stop Temperature (°C)
43	M	12	RQ	1120	900	-	cooled by air	-	910	cooled by water	170
44	M	19	DQ	1120	870	840	cooled by water	220	-	-	-
45	M	32	DQ	1120	890	830	cooled by water	220	-	-	-
46	N	12	RQ	1120	900	-	cooled by air	-	900	cooled by water	150
47	N	25	RQ	1120	920	-	cooled by air	-	870	cooled by water	150
48	N	32	RQ	1120	900	-	cooled by air	-	880	cooled by water	150
49	O	6	RQ	1070	880	-	cooled by air	-	920	cooled by water	150
50	O	12	RQ	1070	900	-	cooled by air	-	910	cooled by water	150
51	O	19	RQ	1070	920	-	cooled by air	-	900	cooled by water	150
52	P	6	RQ	1120	920	-	cooled by air	-	880	cooled by water	150
53	P	25	RQ	1120	920	-	cooled by air	-	900	cooled by water	150
54	P	32	RQ	1120	860	-	cooled by air	-	910	cooled by water	150
55	Q	12	RQ	1080	900	-	cooled by air	-	910	cooled by water	150
56	Q	19	DQ	1080	880	840	cooled by water	150	-	-	-
57	Q	25	DQ	1080	860	820	cooled by water	150	-	-	-
58	R	6	RQ	1120	850	-	cooled by air	-	880	cooled by water	310
59	R	19	DQ	1120	870	830	cooled by water	320	-	-	-
60	R	35	RQ	1120	900	-	cooled by air	-	850	cooled by water	310
61	S	6	DQ	1150	880	840	cooled by water	310	-	-	-
62	S	19	DQ	1150	840	820	cooled by water	310	-	-	-

(Continued)

Steel Plate Number	Steel Number	Plate Thickness (mm)	Type of Treatment*	Hot Rolling				Heat Treatment			
				Reheating Temperature (°C)	Rolling Finish Temperature (°C)	Cooling Start Temperature (°C)	Cooling Method	Cooling Stop Temperature (°C)	Heating Temperature (°C)	Cooling Method	Cooling Stop Temperature (°C)
63	S	35	DQ	1150	820	810	cooled by water	310	-	-	
64	I	19	RQ	1130	930	-	cooled by air	-	900	cooled by water	310
65	I	25	DQ	1130	920	890	cooled by water	310	-	-	
66	I	35	DQ	1130	850	830	cooled by water	310	-	-	
67	U	12	RQ	1200	860	-	cooled by air	-	900	cooled by water	320
68	U	25	RQ	1200	890	-	cooled by air	-	900	cooled by water	310
69	U	35	DQ	1200	880	840	cooled by water	310	-	-	
70	V	12	RQ	1180	840	-	cooled by air	-	900	cooled by water	210
71	V	19	RQ	1180	930	-	cooled by air	-	930	cooled by water	210
72	V	30	DQ	1180	900	850	cooled by water	210	-	-	

Undefined values fall outside the scope of present invention.

*DQ: direct quenching, RQ: reheating quenching

[0074]

[Table 4]

Steel Plate Number	Steel Number	Solute Content	Structure		Surface Hardness	Low-temperature Toughness	Corrosive Wear Resistance		Remarks
			Grain Size of Prior Austenite Grain (μm)	Martensite F-ratio (area%)			HBW 10/3000	vE_{-40} (J)	
1	A	0.07	26	93	405	40	405	40	present invention example
2	A	0.08	21	91	413	36	413	36	present invention example
3	A	0.07	19	90	418	33	418	33	present invention example
4	B	1.21	19	95	382	60	382	60	present invention example
5	B	1.18	21	93	386	83	386	83	present invention example
6	B	1.20	23	91	390	80	390	80	present invention example
7	C	0.36	20	94	427	47	427	47	present invention example
8	C	0.35	22	93	430	72	430	72	present invention example
9	C	0.35	24	91	431	60	431	60	present invention example
10	D	0.23	27	93	469	50	469	50	present invention example
11	D	0.25	28	92	472	47	472	47	present invention example
12	D	0.26	29	90	474	42	474	42	present invention example
13	E	0.44	23	96	479	40	479	40	present invention example
14	E	0.45	21	94	482	61	482	61	present invention example
15	E	0.44	24	92	486	57	486	57	present invention example
16	F	1.03	19	94	365	75	365	75	present invention example
17	F	1.05	21	93	364	72	364	72	present invention example
18	F	1.04	24	91	362	69	362	69	present invention example
19	G	0.21	22	93	406	65	406	65	present invention example
20	G	0.22	24	91	397	70	397	70	present invention example

(Continued)

Steel Plate Number	Steel Number	Solute Content	Structure		Surface Hardness	Low-temperature Toughness	Corrosive Wear Resistance		Remarks
			Grain Size of Prior Austenite Grain (μm)	Martensite Fraction (area%)			HBW 10/3000	Wear Resistance Ratio (Reference: 1.0 (conventional example))	
21	G	0.22	23	91	401	66	401	1.66	present invention example
22	H	1.21	23	95	433	40	433	2.22	present invention example
23	H	1.18	25	93	436	55	436	2.24	present invention example
24	H	1.20	24	91	430	59	430	2.21	present invention example
25	I	1.13	10	96	435	101	435	2.29	present invention example
26	I	1.14	14	94	438	97	438	2.22	present invention example
27	I	1.12	13	93	440	93	440	2.20	present invention example
28	I	0.29	17	94	410	85	410	2.00	present invention example
29	J	0.30	18	95	413	80	413	2.01	present invention example
30	J	0.29	14	91	406	84	406	2.02	present invention example
37	K	1.33	9	96	436	73	436	2.44	present invention example
38	K	1.35	13	93	430	100	430	2.47	present invention example
39	K	1.31	11	95	433	105	433	2.45	present invention example
40	L	1.23	10	97	420	72	420	2.27	present invention example
41	L	1.25	11	95	419	103	419	2.28	present invention example
42	L	1.26	10	95	416	104	416	2.22	present invention example

Underlined values fall outside the scope of present invention.

[0075]

[Table 5]

Steel Plate Number	Steel Number	Solute Content	Structure		Surface Hardness	Low-temperature Toughness	Corrosive Wear Resistance		Remarks
			Grain Size of Prior Austenite Grain (μm)	Martensite Fraction (area%)			HBW 10/3000	Wear Resistance Ratio (Reference: 1.0 (conventional example))	
43	M	0.36	13	95	415	83	415	1.97	present invention example
44	M	0.35	17	93	413	79	413	1.99	present invention example
45	M	0.37	19	91	409	77	409	1.95	present invention example
46	N	0.22	16	94	440	81	440	2.09	present invention example
47	N	0.22	13	92	432	89	432	2.03	present invention example
48	N	0.21	15	91	425	83	425	2.00	present invention example
49	O	0.35	15	95	405	55	405	2.10	present invention example
50	O	0.36	14	94	409	86	409	2.06	present invention example
51	O	0.35	13	93	403	92	403	2.10	present invention example
52	P	1.21	15	98	425	55	425	2.40	present invention example
53	P	1.19	14	96	419	81	419	2.42	present invention example
54	P	1.18	15	96	423	80	423	2.42	present invention example
55	Q	1.51	9	99	462	110	462	2.44	present invention example
56	Q	1.50	7	98	466	99	466	2.47	present invention example
57	Q	1.50	6	97	460	103	460	2.42	present invention example
58	R	0.01	36	91	436	11	436	0.78	comparative example
59	R	0.01	34	93	441	24	441	0.73	comparative example
60	R	0.01	38	90	433	14	433	0.76	comparative example
61	S	0.01	35	88	355	13	355	0.80	comparative example
62	S	0.02	33	87	352	25	352	0.70	comparative example

(Continued)

Steel Plate Number	Steel Number	Solute Content	Structure		Surface Hardness	Low-temperature Toughness	Corrosive Wear Resistance		Remarks
			Grain Size of Prior Austenite Grain (μm)	Martensite Fraction (area%)			Wear Resistance Ratio (Reference: 1.0 (conventional example))		
<u>63</u>	<u>S</u>	<u>0.01</u>	<u>31</u>	<u>86</u>	<u>348</u>	<u>27</u>		<u>0.74</u>	comparative example
<u>64</u>	<u>I</u>	<u>0.04</u>	<u>29</u>	<u>90</u>	<u>435</u>	<u>25</u>		<u>0.92</u>	comparative example
<u>65</u>	<u>I</u>	<u>0.03</u>	<u>28</u>	<u>88</u>	<u>441</u>	<u>21</u>		<u>0.95</u>	comparative example
<u>66</u>	<u>I</u>	<u>0.03</u>	<u>29</u>	<u>88</u>	<u>440</u>	<u>23</u>		<u>1.00</u>	comparative example
<u>67</u>	<u>U</u>	<u>0.04</u>	<u>31</u>	<u>89</u>	<u>401</u>	<u>25</u>		<u>1.14</u>	comparative example
<u>68</u>	<u>U</u>	<u>0.04</u>	<u>32</u>	<u>87</u>	<u>396</u>	<u>22</u>		<u>1.07</u>	comparative example
<u>69</u>	<u>U</u>	<u>0.04</u>	<u>32</u>	<u>86</u>	<u>394</u>	<u>20</u>		<u>1.11</u>	comparative example
<u>70</u>	<u>V</u>	<u>0.29</u>	<u>24</u>	<u>91</u>	<u>290</u>	<u>60</u>		<u>0.64</u>	comparative example
<u>71</u>	<u>V</u>	<u>0.31</u>	<u>26</u>	<u>90</u>	<u>295</u>	<u>55</u>		<u>0.65</u>	comparative example
<u>72</u>	<u>V</u>	<u>0.30</u>	<u>23</u>	<u>92</u>	<u>299</u>	<u>53</u>		<u>0.66</u>	comparative example

Underlined values fall outside the scope of present invention.

[0076]

All of the present invention examples exhibit surface hardness of 360 or more in HBW 10/3000, excellent low-temperature toughness of vE_{-40} of 30 J or more (15 J or more in a case of the 1/2 t specimen), and excellent corrosive wear resistance of the wear resistance ratio of 1.5 or more. On the other hand, the comparative examples which fall outside the scope of the present invention exhibit lowering of surface hardness, lowering of low-temperature toughness, lowering of corrosive wear resistance or lowering of two or more of these properties.

[0077]

It is to be understood that, if any prior art publication is referred to herein, such reference does not constitute an admission that the publication forms a part of the common general knowledge in the art, in Australia or any other country.

CLAIMS

[Claim 1]

An abrasion resistant steel plate having excellent low-temperature toughness and excellent corrosive wear resistance, the steel plate having a composition consisting of by mass%:

0.10% to 0.20% C;

0.05% to 1.00% Si;

0.1% to 2.0% Mn;

0.005% to 0.020% P;

0.0005% to 0.005% S;

0.005% to 0.100% Al;

one or two kinds of components selected from a group consisting of 0.05% to 2.0% Cr and 0.05% to 1.0% Mo;

optionally one or two or more kinds of components selected from a group consisting of 0.005% to 0.1% Nb, 0.005% to 0.1% Ti, 0.005% to 0.1% V, 0.005% to 0.2% Sn, 0.005% to 0.2% Sb, 0.03% to 1.0% Cu, 0.03% to 2.0% Ni, 0.0003% to 0.0030% B, 0.0005% to 0.008% REM, 0.0005% to 0.005% Ca, and 0.0005% to 0.005% Mg;

and remaining Fe and unavoidable impurities as a balance;

wherein the content of solute Cr in steel and the content of solute Mo in steel satisfy a following formula (1), the steel plate having a structure where an as-quenched martensitic phase forms a main phase and a grain size of prior austenite grains is 30 μm or less, and surface hardness of the steel plate

being 360 or more at Brinel hardness HBW10/3000.

$$0.05 \leq (\text{Cr}_{\text{sol}} + 2.5\text{Mo}_{\text{sol}}) \leq 2.0 \quad \dots \quad (1)$$

where, Cr_{sol} : the content of solute Cr in steel (mass%),
and Mo_{sol} : the content of solute Mo in steel (mass%)

[Claim 2]

The abrasion resistant steel plate according to claim 1, wherein the steel composition contains by mass% one or two or more kinds of components selected from a group consisting of 0.005% to 0.1% Nb, 0.005% to 0.1% Ti, and 0.005% to 0.1% V.

[Claim 3]

The abrasion resistant steel plate according to claim 1 or 2, wherein the steel composition contains by mass% one or two kinds of components selected from a group consisting of 0.005% to 0.2% Sn and 0.005% to 0.2% Sb.

[Claim 4]

The abrasion resistant steel plate according to any of claims 1 to 3, wherein the steel composition contains by mass% one or two or more kinds of components selected from a group consisting of 0.03% to 1.0% Cu, 0.03% to 2.0% Ni, and 0.0003% to 0.0030% B.

[Claim 5]

The abrasion resistant steel plate according to any of claims 1 to 4, wherein the steel composition contains by mass% one or two or more kinds of components selected from a group

consisting of 0.0005% to 0.008% REM, 0.0005% to 0.005% Ca, and
0.0005% to 0.005% Mg.