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

(57) Provided is an abrasion resistant steel plate which possesses excellent abrasion resistance, excellent low-temperature toughness and excellent corrosive wear resistance.

An abrasion resistant steel plate includes the composition containing by mass%: 0.23% to 0.35% C, 0.05% to 1.00% Si, 0.1% to 2.0% Mn, 0.020% or less P, 0.005% or less S, 0.005% to 0.100% Al, 0.03% to 2.0% Cr, and 0.03% to 1.0% Mo in a state where DI* defined by the following formula (1) is satisfied 45 or more, and further containing remaining Fe and unavoidable impurities as a balance. The steel plate has 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 is 450 or more at Brinel hardness HBW10/3000.

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Description

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 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, abrasion 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. In this case, 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 zone 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 plate from a temperature of Ar_3 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 of the steel 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 Mo more than 0.50% to 0.80%, 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 of the steel plate 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 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 of the steel 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, further, 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 Ar_3 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, 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 technique described in patent literature 6 is related to 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 described in patent literature 6 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, regarding the abrasion resistant steel plate described in patent literature 6, it is considered that both abrasion resistance against abrasion caused by earth and sand and bending property 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] 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 sufficiently with respect to corrosive wear resistance.

[0012] Further, in the respective techniques described in patent literatures 1 to 4, tempering 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, there is a problem that 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, and it is an object of the present invention to provide an abrasion resistant steel plate which can be manufactured at a low cost, possesses excellent abrasion resistance, and has both of excellent low-temperature toughness and excellent corrosive wear resistance.

Solution to Problem

[0014] To achieve the above-mentioned object, 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 of the steel plate. 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 Mo as indispensable components. It is supposed that by allowing the steel plate to contain Cr and Mo, even when the steel plate is exposed to earth and sand in a wet state having pH in a various range, Cr and 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 of the steel plate at a high level provided that the steel plate has the above-mentioned composition.

[0016] The inventors also have found that the excellent low-temperature toughness of the steel plate can be surely acquired while the excellent abrasion resistance being assured by allowing the steel plate to contain proper amounts of Cr and Mo as indispensable components and to contain proper amounts of at least C, Si, Mn, P, S, Al, Cr, Mo in a state where DI* defined by the following formula (1) is satisfied 45 or more to enhance hardenability of the steel plate, then by making the structure where an as-quenched martensitic phase forms a main phase with ensuring surface hardness of 450 or more at Brinel hardness HBW 10/3000 and further by making the as-quenched martensitic phase finer so that a grain size of prior austenite (γ) grains is 30 μm or less.

$$DI^{*}=33.85\times(0.1\times C)^{0.5}\times(0.7\times Si+1)\times(3.33\times Mn+1)\times(0.35\times Cu+1)\times(0.36\times Ni+1)\times(2.16\times Cr+1)\times(3\times Mo+1)\times(1.75\times V+1)\ \ldots\ldots\ (1)$$

(where, C, Si, Mn, Cu, Ni, Cr, Mo and V denote the contents (mass%) of respective elements)

[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.

[0018]

(1) An abrasion resistant steel plate having excellent low temperature toughness and excellent corrosive wear resistance, the steel plate having the composition containing by mass%: 0.23% to 0.35% C, 0.05% to 1.00% Si, 0.1% to 2. 0% Mn, 0.020% or less P, 0.005% or less S, 0.005% to 0.100% Al, 0.03% to 2.0% Cr, and 0.03% to 1.0% Mo in a state where DI* defined by the following formula (1) is satisfied 45 or more, and further containing remaining Fe and unavoidable impurities as a balance, 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 450 or more at Brinel hardness HBW10/3000.
(Formula)

$$DI^{*}=33.85\times(0.1\times C)^{0.5}\times(0.7\times Si+1)\times(3.33\times Mn+1)\times(0.35\times Cu+1)\times(0.36\times Ni+1)\times(2.16\times Cr+1)\times(3\times Mo+1)\times(1.75\times V+1)\ \ldots\ldots\ (1)$$

(where, C, Si, Mn, Cu, Ni, Cr, Mo and V in the formula (1) refer to the contents (mass%) of respective elements.)

(2) In the abrasion resistant steel plate described in (1), the steel composition further 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 further 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 further 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 further 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.

(6) In the abrasion resistant steel plate described in any of (1) to (5), wherein the content of the as-quenched martensitic phase is 98% or more in terms of volume fraction. Advantageous Effects of Invention

[0019] According to the present invention, it is possible to manufacture, easily and in a stable manner, an abrasion resistant steel plate having especially 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

[0020] Firstly, the reasons for limiting the composition of the abrasion resistance steel plate of the present invention, which is also called "the steel plate" in this specification, are explained. In the explanation made hereinafter, mass% is simply expressed by % unless otherwise specified.

C: 0.23% to 0.35%

[0021] C is an element for increasing hardness of the steel plate and for enhancing abrasive resistance. When the content of C is less than 0.23%, the steel plate cannot acquire sufficient hardness. On the other hand, when the content of C exceeds 0.35%, weldability, low-temperature toughness and workability of the steel plate are lowered. Accordingly, the content of C is limited to a value which falls within a range from 0.23% to 0.35%. The content of C is preferably limited to a value which falls within a range from 0.25% to 0.30%.

Si: 0.05% to 1.00%

[0022] Si is an effective element acting as a deoxidizing agent for molten steel. Si is also an element which contributes to the enhancement of strength of the steel plate by increasing 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 1.00%, ductility and toughness of the steel plate 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 1.00%. The content of Si is preferably limited to a value which falls within a range from 0.15% to 0.45%.

Mn: 0.1% to 2. 0%

[0023] Mn is an 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%, temper embrittlement is occurred and weld heat-affected zone become hardened, weldability being 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 1.7%. It is more preferable that the content of Mn is limited to a value which falls within a range from 0.5% to 1.0%.

P: 0.020% or less

[0024] When the content of P in steel is large, lowering of low-temperature toughness of the steel plate 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%. The excessive reduction of the content of P induces the sharp rise in a refining cost. Accordingly, it is desirable to set the content of P to 0.005% or more.

S: 0.005% or less

[0025] 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 of the steel plate and hence, 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. Accordingly, it is desirable to set the content of S to 0.0005% or more.

Al: 0.005% to 0.100%

[0026] Al is an 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 of the steel plate 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%.

Cr: 0.03% to 2.0%

[0027] Cr has an effect of increasing hardenability. Cr has also an effect of enhancing low-temperature toughness due to refining of a martensitic phase. 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 of the steel plate. To acquire such an effect, the content of Cr is set to 0.03% or more. When the content of Cr is less than 0.03%, 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 0.03% to 2.0%. The content of Cr is preferably limited to a value which falls within a range from 0.07% to 1.0%. It is more preferable that the content of Cr is limited to a value which falls within a range from 0.2% to 0.9%.

Mo: 0.03% to 1.0%

[0028] Mo has an effect of increasing hardenability. Mo has also an effect of enhancing low-temperature toughness due to refining of a martensitic phase. 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 0.03% or more. When the content of Mo is less than 0.03%, the steel plate cannot exhibit such an effect sufficiently. On the other hand, when the content of Mo exceeds 1.0%, weldability of the steel plate 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 0.03% to 1.0%. The content of Mo is preferably limited to a value which falls within a range from 0.10% to 0.50%. It is more preferable that the content of Mo is limited to a value which falls within a range from 0.20% to 0.40%.

[0029] By containing Cr and Mo in a combined manner in the steel plate, it is expected that corrosive wear resistance can be enhanced remarkably. It is based on the estimation that Cr and Mo have different pH regions where Cr or Mo can exist as an oxygen acid and hence, corrosive wear caused by earth and sand or the like in a wet state having pH in a wide range can be suppressed.

[0030] The above-mentioned components are the basic components of the steel. The abrasion resistant steel plate according to the present invention further 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.

[0031] 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

[0032] All of Nb, Ti and V are elements which precipitate as precipitates, and enhance toughness of steel through refining of the structure. The abrasion resistant steel plate according to the present invention, when necessary, contains one or two or more kinds of components selected from a group consisting of Nb, Ti and V.

[0033] Nb is an element which precipitates as carbonitride and contributes to the enhancement of toughness through refining of the structure. The content of Nb may be set to 0.005% or more for obtaining such an effect. On the other hand, when the content of Nb exceeds 0.1%, weldability may be lowered. 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.

[0034] Ti is an element which precipitates as TiN and contributes to the enhancement of toughness through fixing solid solute N. The content of Ti is 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 in some cases. 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 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.

[0035] 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 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 in some cases. 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%.

[0036] 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

[0037] Both Sn and Sb are elements which enhance corrosive wear resistance. The abrasion resistant steel plate according to the present invention, when necessary, contains one or two kinds of elements selected from a group consisting of Sn and Sb.

[0038] Sn is dissolved as Sn ion due to an anodic reaction, and suppresses corrosion by an inhibiter 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 cathode reaction of the steel plate are suppressed whereby corrosive wear resistance of the steel plate is enhanced. The content of Sn is 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 may be 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.

[0039] 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 cathode reaction thus enhancing corrosive wear resistance of the steel plate. The content of Sb is 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 may be 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%.

[0040] 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

[0041] All of Cu, Ni and B are elements which enhance hardenability. The abrasion resistant steel plate according to the present invention, when necessary, 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 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 also to the enhancement of hardenability and the enhancement of low-temperature toughness of the steel plate. The content of Ni may 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 may rise. 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 in steel. The content of B may be 0.0003% or more for acquiring such an effect. On the other hand, when the content of B exceeds 0.0030%, toughness of the steel plate may be 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 low-heat input welding such as CO_2 welding or the like 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

[0046] 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. The abrasion resistant steel plate according to the present invention, when necessary, contains one or two or more kinds of components selected from a group consisting of REM, Ca and Mg.

[0047] REM fixes S thus suppressing the formation of MnS which causes lowering of toughness of the steel plate. The content of REM may be 0.0005% or more for acquiring such an effect. On the other hand, when the content of REM exceeds 0.008%, the contents of inclusions in the steel plate are increased so that toughness is lowered in some cases. 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%.

[0048] Ca fixes S thus suppressing the formation of MnS which causes lowering of toughness. The content of Ca may 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 and toughness may be lowered to the contrary. 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%.

[0049] Mg fixes S thus suppressing the formation of MnS which causes lowering of toughness of the steel plate. The content of Mg 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 plate is increased and toughness may be lowered to the contrary. 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%.

[0050] The abrasion resistant steel plate according to the present invention has the above-mentioned components within the above-mentioned rages and in a state where DI* is satisfied 45 or more. DI* is defined by the following formula (1). In the calculation for DI*, regarding the elements described in the formula (1), elements not contained in the steel are calculated as Zero.

$$DI^* = 33.85\times(0.1\times C)^{0.5}\times(0.7\times Si+1)\times(3.33\times Mn+1)\times(0.35\times Cu+1)\times(0.36\times Ni+1)\times(2.16\times Cr+1)\times(3\times Mo+1)\times(1.75\times V+1) \ldots\ldots \quad (1)$$

(where, C, Si, Mn, Cu, Ni, Cr, Mo and V are the contents (mass%) of respective elements.)

[0051] When DI* is set to less than 45, a quenching depth from a surface of the steel plate becomes less than 10 mm and hence, a lifetime of the steel plate as the abrasion resistant steel plate is shortened. Accordingly, DI* is limited 45 or more. The range of DI* is preferably set to 75 or more.

[0052] Remaining other than the above-mentioned compositions are Fe and unavoidable impurities as a balance.

[0053] Next, the structure and the property of the abrasion resistant steel plate of the present invention are explained.

[0054] The abrasion resistant steel plate according to the present invention has the above-mentioned composition and the structure wherein an as-quenched martensitic phase forms a main phase and a grain size of prior austenite (γ) grains is 30 μm or less. Further, the abrasion resistant steel plate according to the present invention has surface hardness of 450 or more at Brinel hardness HBW 10/3000. Here, a phase which occupies 90% or more in an area ratio is defined as "main phase".

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

[0055] When the phase fraction of the as-quenched martensitic phase is less than 90% in an area ratio, the steel plate cannot ensure desired hardness. Accordingly, when the area ratio is less than 90%, wear resistance of the steel plate is lowered so that desired wear resistance cannot be ensured. Further, the steel plate cannot ensure the sufficient low-temperature toughness. Further, in tempered martensite phase, Cr and Mo form carbide together with Fe when cementite is formed in tempering. Due to the formation of carbide, solute Cr and solute Mo, which are effective to ensure corrosion resistance, are decreased. Accordingly, the martensitic phase is held in the as-quenched martensitic phase where the martensitic phase is not tempered. A phase fraction of the as-quenched martensitic phase is preferably set to 95% or more in area ratio, and it is more preferable that the phase fraction of the as-quenched martensitic phase is set to 98% or more in area ratio.

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

[0056] Even when the phase fraction of the as-quenched martensitic phase can ensure 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 of the steel plate 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.

[0057] The abrasion resistant steel plate according to the present invention having the above-mentioned composition and structure has surface hardness of 450 or more at Brinel hardness HBW 10/3000.

Surface hardness: 450 or more at Brinel hardness HBW 10/3000

[0058] When the surface hardness of steel is less than 450 at Brinel hardness HBW 10/3000, the lifetime of the abrasion resistant steel plate becomes short. Accordingly, the surface hardness is set to 450 or more at Brinel hardness HBW 10/3000. Brinel hardness is measured in accordance with the stipulation described in JIS Z 2243.

[0059] Next, the preferred method of manufacturing the abrasion resistant steel plate of the present invention is explained.

[0060] The steel material having the above-mentioned composition is produced by casting and then subjected to hot rolling without cooling when the steel material holds a predetermined temperature or subjected to hot rolling after cooling and reheating, thus manufacturing a steel plate having a desired size and a desired shape.

[0061] 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.

Reheating temperature: 950 to 1250°C

[0062] 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 may not ensure desired high toughness. Accordingly, the reheating temperature is preferably limited to a value which falls within a range from 950 to 1250°C.

[0063] 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 where the steel plate is immediately quenched 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 to the Ar3 transformation point or higher, it is preferable that the hot rolling finish temperature is set to 800°C or more not below the Ar3 transformation point. When the hot rolling finish temperature is excessively high, there may be a case where crystal grains become coarse. Accordingly, it is preferable that the hot rolling finish temperature is set to 950°C or below. 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. It is desirable that the quenching cooling rate is as high as possible to prevent a martensitic phase from being self-tempered. The solute Cr and the solute Mo, which are effective for corrosion resistance, form carbide along with Fe when cementite is formed in the self-tempering, so that the amount of solute Cr and solute Mo is reduced. The self-tempering also reduces a volume fraction of martensite. It is desirable that the quenching cooling rate is set to 65 to 75°C/s when a plate thickness is 5 to 15 mm, the quenching cooling rate is set to 40 to 55°C/s when the plate thickness is 16 to 22 mm, the quenching cooling rate is set to 30 to 40°C/s when the plate thickness is 22 to 28 mm, and the quenching cooling rate is set to 20 to 30°C/s when the plate thickness is 29 to 35 mm. Further, it is preferable that the cooling stop temperature is set to 300°C or below. It is more preferable that the cooling stop temperature is 200°C or below. In this specification, "cooling rate" is a cooling rate obtained by calculating a temperature of a center portion of a steel plate by heat transfer-heat conduction calculation.

[0064] After hot rolling is finished, in place of the direct quenching treatment where a steel plate is immediately quenched, treatment may be performed where the steel plate is gradually cooled by air after the hot rolling is finished (air cooling) and, thereafter, the steel plate is reheated to a predetermined heating temperature and, thereafter, the steel plate is quenched. It is desirable that the reheating 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. It is desirable that the quenching cooling rate is as high as possible to prevent a martensitic phase from being self-tempered. The solute Cr and the solute Mo, which are effective for corrosion resistance, form carbide along with Fe when cementite is formed in the self-tempering, so that the amount of solute Cr and solute Mo is reduced. The self-tempering also reduces a volume fraction of martensite. It is desirable that the quenching cooling rate is set to 65 to 75°C/s when a plate thickness is 5 to 15 mm, the quenching cooling rate is set to 40 to 55°C/s when the plate thickness is 16 to 22 mm, the quenching cooling rate is set to 30 to 40°C/s when the plate thickness is 22 to 28 mm, and the quenching cooling rate is set to 20 to 30°C/s when the plate thickness is 29 to 35 mm. Further, to prevent a martensitic phase from being self-tempered, it is preferable that the cooling stop temperature is set to 300°C or below. It is more preferable that the cooling stop temperature is set to 200°C or below.

[0065] To acquire the as-quenched martensite structure, tempering treatment is not performed after performing the above-mentioned treatment.

[0066] Hereinafter, the present invention is further explained based on examples.

Example

[0067] 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 reheated at heating temperatures described in Tables 2 (Table 2-1, Table 2-2, and Table 2-3) and, thereafter, the steel materials were subjected to hot rolling under conditions described in Table 2. Then, with respect to some steel plates, direct quenching treatment (DQ) where quenching (direct quenching) is immediately performed after hot rolling is finished was performed under conditions described in Tables 2. With respect to other steel plates, reheating quenching treatment (RQ) where a steel plate is cooled by air after hot rolling is finished on the respective conditions described in Table 2 and the steel plate is reheated at a temperature described in Tables 2 and, thereafter, is quenched was performed. In the examples described in Table 2-3, cooling rates from 800°C to 500°C at DQ or RQ were also indicated. In general, with respect to an ordinary C-Mn steel, the transformation during cooling is started at a temperature of approximately 800°C and is completed at a temperature around 500°C. Therefore, a cooling rate from 800°C to 500°C largely influences the transformation behavior of steel. Accordingly, the cooling rate from 800°C to 500°C has been generally used as a representative cooling rate for estimating the transformation behavior of steel.

[0068] Specimens were sampled from the manufactured steel plates, and the specimens were subject to an observation of the structure, a surface hardness test, a Charpy impact test, and a corrosive wear resistance test. The following test methods were adopted. The results of the observation of the structure, the surface hardness test, the Charpy impact test, and the corrosive wear resistance test are shown in Table 3 (Table 3-1, Table 3-2, and Table 3-3).

(1) Structure observation

[0069] 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 parallel to the rolling direction. The observation surface of the specimens for structure observation was polished and was etched by a picric acid thus exposing prior γ grains. Thereafter, the observation surfaces were observed by an optical microscope (magnification: 400 times). Equivalent circle diameters of respective 100 views 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.

[0070] Thin film specimens (specimens for observation of structure by transmission electron microscope) were sampled from the manufactured steel plates at a position of 1/4 plate thickness of the steel plate in the same way. Next, the thin film specimen was grinded and polished (mechanical polishing, electrolytic polishing) thus forming a thin film. Next, each 20 fields of vision of the thin film were observed by a transmission electron microscope (magnification: 20000 times), a region where cementite does not precipitate was recognized as a martensitic phase region, and the area of the region was measured. The area of the martensitic phase region was indicated by a ratio (%) with respect to the whole structure, and this ratio was set as a martensitic fraction (area ratio). Also, a kind of a phase where cementite precipitates was determined.

(2) Surface hardness test

[0071] 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 (1998). In the hardness measurement, a tungsten hard ball having a diameter of 10 mm was used, and a weight was set to 3000 kgf.

(3) Charpy impact test

[0072] V-notched specimens were sampled from manufactured steel plates at a position of 1/4 plate thickness of the steel plate, in the direction (C direction) perpendicular to the rolling direction, and a Charpy impact test was performed in accordance with the stipulation of JIS Z 2242 (1998). Absorbed energy vE_{-40} (J) was obtained under the condition of a test temperature at -40°C. The number of specimens was three for each of the steel plates, and an arithmetic mean of the obtained vales of three specimens is respectively 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 toughness.

(4) corrosive wear resistance test

[0073] 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.

[0074] 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 mm x 75 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 grain 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.

[0075] 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 the steel plate SS400 stipulated in Rolled steels for general structure, Tensile strength 400 MPa class (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".

[Table 1]

Steel Number	Chemical Composition (mass%)												DI*	Ar3 (°C)	Remarks
	C	Si	Mn	P	S	sol.Al	Cr	Mo	Nb,Ti,V	Sn,Sb	Cu,Ni,B	Ca,REM,Mg			
A	0.26	0.33	1.64	0.007	0.0017	0.032	0.05	0.05	-	-	-	-	55.3	693	within scope of present invention
B	0.23	0.25	1.22	0.008	0.0024	0.027	0.20	0.10	-	-	-	-	56.8	730	within scope of present invention
C	0.24	0.41	0.62	0.007	0.0019	0.025	1.10	0.10	-	-	Cu:0.1, Ni:0.12, B:0.0021	-	98.0	753	within scope of present invention
D	0.27	0.25	0.75	0.007	0.0015	0.025	0.38	0.16	Nb:0.022, Ti:0.014	-	B:0.0009	-	61.6	748	within scope of present invention
E	0.26	0.26	0.65	0.008	0.0013	0.022	0.45	0.11	Nb:0.025, Ti:0.017	-	B:0.0013	-	53.5	762	within scope of present invention
F	0.28	0.30	0.85	0.008	0.0015	0.027	0.25	0.25	Nb:0.017, Ti:0.010	-	B:0.0006	-	70.8	731	within scope of present invention
G	0.26	0.27	0.76	0.008	0.0015	0.027	0.40	0.15	Nb:0.015, Ti:0.015	-	B:0.0020	Ca:0.0022	61.9	751	within scope of present invention
H	0.29	0.32	1.23	0.008	0.0018	0.023	0.10	0.06	Ti:0.022	-	-	REM:0.0015	51.6	715	within scope of present invention
I	0.27	0.32	1.34	0.008	0.0018	0.023	0.15	0.15	Nb:0.013, Ti:0.015	-	-	-	71.4	705	within scope of present invention
J	0.30	0.35	0.50	0.006	0.0022	0.024	0.30	0.65	V:0.035	-	-	Ca:0.0021	100.4	721	within scope of present invention

(continued)

Steel Number	Chemical Composition (mass%)												DI*	Ar3 (°C)	Remarks
	C	Si	Mn	P	S	sol.Al	Cr	Mo	Nb,Ti,V	Sn,Sb	Cu,Ni,B	Ca,REM,Mg			
K	0.24	0.32	1.05	0.007	0.0027	0.021	0.12	0.32	Ti:0.013	-	B:0.0009	Mg:0.0016	71.2	724	within scope of present invention
L	0.31	0.27	0.57	0.007	0.0015	0.023	0.76	0.11	Nb:0.019, V:0.016	-	B:0.0025	-	74.2	748	within scope of present invention
M	0.28	0.30	1.21	0.008	0.0016	0.025	0.13	0.16	Nb:0.021, Ti:0.015	-	B:0.0013	-	65.3	712	within scope of present invention
N	0.26	0.29	1.02	0.007	0.0014	0.019	0.53	0.25	Nb:0.029, Ti:0.021, V:0.034	Sb:0.066	Cu:0.24,Ni:0.31	Ca:0.0012	138.3	698	within scope of present invention
O	0.26	0.36	1.52	0.008	0.0016	0.024	0.02	-	Ti:0.016	-	-	Ca:0.0018	43.2	708	outside scope of present invention
P	0.29	0.35	1.42	0.007	0.0019	0.025	-	0.02	V:0.021	-	-	Mg:0.0032	45.2	705	outside scope of present invention
Q	0.30	0.38	1.36	0.006	0.0021	0.029	0.01	0.02	-	-	Cu:0.08	-	45.7	705	outside scope of present invention
R	0.18	0.24	0.88	0.008	0.0016	0.024	0.28	0.15	Nb:0.015	Sn:0.015	B:0.0022	-	48.5	768	outside scope of present invention

(continued)

Steel Number	Chemical Composition (mass%)												DI*	Ar3 (°C)	Remarks
	C	Si	Mn	P	S	sol.Al	Cr	Mo	Nb,Ti,V	Sn,Sb	Cu,Ni,B	Ca,REM,Mg			
S	0.25	0.31	0.76	0.007	0.0017	0.021	0.09	0.10	Nb:0.013	Sb:0.033	Cu:0.1, Ni:0.09	REM:0.0012	38.2	755	outside scope of present invention
T	0.28	0.26	1.09	0.007	0.0025	0.024	0.05	0.27	-	-	-	-	62.2	714	within scope of present invention
U	0.27	0.30	0.93	0.007	0.0019	0.028	0.43	0.19	-	-	-	-	83.5	730	within scope of present invention
V	0.28	0.25	1.13	0.009	0.0029	0.022	0.52	0.13	-	Sn:0.021	-	-	93.6	715	within scope of present invention
W	0.29	0.36	0.85	0.008	0.0021	0.031	0.75	0.11	Nb:0.014	Sn:0.067	-	-	96.3	732	within scope of present invention

[Table 2-1]

Steel Plate Number	Steel Number	Plate Thickness (mm)	Type of Treatment*	Hot Rolling		DQ			RQ		
				Reheating Temperature (°C)	Rolling Finish Temperature (°C)	Cooling Start Temperature (°C)	Cooling After Rolling	Cooling Stop Temperature (°C)	Heating Temperature (°C)	Cooling Method	Cooling Stop Temperature (°C)
1	A	12	RQ	1120	900	-	cooled by air	-	900	cooled by water	150
2	A	19	RQ	1120	920	-	cooled by air	-	910	cooled by water	170
3	A	25	DQ	1120	880	830	cooled by water	150	-	-	-
4	A	25	DQ	1250	950	870	cooled by water	310	-	-	-
5	A	25	DQ	1120	980	900	cooled by water	310	-	-	-
6	B	12	RQ	1120	890	-	cooled by air	-	900	cooled by water	150
7	B	19	DQ	1120	870	850	cooled by water	150	-	-	-
8	B	32	DQ	1120	890	840	cooled by water	150	-	-	-
9	B	32	DQ	1200	970	900	cooled by water	250	-	-	-
10	B	32	DQ	1230	960	900	cooled by water	250	-	-	-
11	C	19	DQ	1050	840	810	cooled by water	150	-	-	-
12	C	25	DQ	1050	850	800	cooled by water	130	-	-	-
13	C	35	DQ	1050	880	820	cooled by water	100	-	-	-

(continued)

Steel Plate Number	Steel Number	Plate Thickness (mm)	Type of Treatment*	Hot Rolling		DQ			RQ		
				Reheating Temperature (°C)	Rolling Finish Temperature (°C)	Cooling Start Temperature (°C)	Cooling After Rolling	Cooling Stop Temperature (°C)	Heating Temperature (°C)	Cooling Method	Cooling Stop Temperature (°C)
14	D	19	RQ	1100	870	-	cooled by air	-	910	cooled by water	170
15	D	25	RQ	1100	890	-	cooled by air	-	910	cooled by water	170
16	D	35	DQ	1100	890	870	cooled by water	100	-	-	-
17	E	19	RQ	1100	870	-	cooled by air	-	910	cooled by water	260
18	E	25	RQ	1100	890	-	cooled by air	-	910	cooled by water	160
19	F	35	DQ	1100	890	870	cooled by water	150	-	-	-
20	F	19	RQ	1100	870	-	cooled by air	-	910	cooled by water	160
21	F	25	RQ	1100	890	-	cooled by air	-	910	cooled by water	160
22	G	35	DQ	1100	890	870	cooled by water	150	-	-	-
23	G	19	RQ	1100	870	-	cooled by air	-	910	cooled by water	280
24	G	25	RQ	1100	890	-	cooled by air	-	910	cooled by water	180
25	G	35	DQ	1100	890	870	cooled by water	150	-	-	-
26	H	6	RQ	1120	910	-	cooled by air	-	880	cooled by water	150

(continued)

Steel Plate Number	Steel Number	Plate Thickness (mm)	Type of Treatment*	Hot Rolling		DQ			RQ		
				Reheating Temperature (°C)	Rolling Finish Temperature (°C)	Cooling Start Temperature (°C)	Cooling After Rolling	Cooling Stop Temperature (°C)	Heating Temperature (°C)	Cooling Method	Cooling Stop Temperature (°C)
27	H	19	RQ	1120	930	-	cooled by air	-	900	cooled by water	150
28	H	32	DQ	1120	870	800	cooled by water	170	-	-	-
29	I	6	RQ	1120	850	-	cooled by air	-	950	cooled by water	150
30	I	12	RQ	1120	860	-	cooled by air	-	870	cooled by water	150
31	I	19	DQ	1120	890	830	cooled by water	150	-	-	-
32	J	12	RQ	1110	860	-	cooled by air	-	870	cooled by water	150
33	J	19	DQ	1110	870	840	cooled by water	170	-	-	-
34	J	35	DQ	1110	880	850	cooled by water	170	-	-	-
35	K	6	RQ	1120	840	-	cooled by air	-	930	cooled by water	150
36	K	12	RQ	1120	870	-	cooled by air	-	900	cooled by water	150
37	K	20	DQ	1120	890	830	cooled by water	180	-	-	-

*DQ: direct quenching, RQ: reheating quenching

[Table 2-2]

Steel Plate Number	Steel Number	Plate Thickness (mm)	Type of Treatment*	Hot Rolling		DQ			RQ		
				Reheating Temperature (°C)	Rolling Finish Temperature (°C)	Cooling Start Temperature (°C)	Cooling After Rolling	Cooling Stop Temperature (°C)	Heating Temperature (°C)	Cooling Method	Cooling Stop Temperature (°C)
38	L	20	DQ	1150	920	880	cooled by water	180	-	-	-
39	L	25	RQ	1150	930	-	cooled by air	-	900	cooled by water	150
40	L	35	DQ	1150	910	870	cooled by water	180	-	-	-
41	M	12	DQ	1170	900	860	cooled by water	160	-	-	-
42	M	25	DQ	1170	920	880	cooled by water	140	-	-	-
43	M	35	RQ	1170	880	-	cooled by air	-	900	cooled by water	250
44	N	12	RQ	1080	890	-	cooled by air	-	930	cooled by water	160
45	N	19	DQ	1080	870	830	cooled by water	100	-	-	-
46	N	25	DQ	1080	850	810	cooled by water	120	-	-	-
47	O	12	RQ	1180	840	-	cooled by air	-	900	cooled by water	280
48	O	19	RQ	1180	930	-	cooled by air	-	930	cooled by water	280
49	O	30	DQ	1180	900	850	cooled by water	250	-	-	-
50	P	6	DQ	1150	880	840	cooled by water	250	-	-	-

(continued)

Steel Plate Number	Steel Number	Plate Thickness (mm)	Type of Treatment*	Hot Rolling		DQ			RQ		
				Reheating Temperature (°C)	Rolling Finish Temperature (°C)	Cooling Start Temperature (°C)	Cooling After Rolling	Cooling Stop Temperature (°C)	Heating Temperature (°C)	Cooling Method	Cooling Stop Temperature (°C)
51	P	19	DQ	1150	840	820	cooled by water	250	-	-	-
52	P	35	DQ	1150	820	800	cooled by water	250	-	-	-
53	Q	19	RQ	1130	930	-	cooled by air	-	900	cooled by water	320
54	Q	25	DQ	1130	920	890	cooled by water	280	-	-	-
55	Q	35	DQ	1130	850	830	cooled by water	280	-	-	-
56	R	12	RQ	1200	860	-	cooled by air	-	900	cooled by water	310
57	R	25	RQ	1200	890	-	cooled by air	-	900	cooled by water	290
58	R	35	DQ	1200	880	840	cooled by water	300	-	-	-
59	S	6	RQ	1120	850	-	cooled by air	-	880	cooled by water	210
60	S	19	DQ	1120	870	830	cooled by water	300	-	-	-
61	S	35	RQ	1120	900	-	cooled by air	-	850	cooled by water	210
62	T	12	RQ	1120	920	-	cooled by air	-	920	cooled by water	150
63	T	25	RQ	1120	900	-	cooled by air	-	900	cooled by water	150

(continued)

Steel Plate Number	Steel Number	Plate Thickness (mm)	Type of Treatment*	Hot Rolling		DQ			RQ		
				Reheating Temperature (°C)	Rolling Finish Temperature (°C)	Cooling Start Temperature (°C)	Cooling After Rolling	Cooling Stop Temperature (°C)	Heating Temperature (°C)	Cooling Method	Cooling Stop Temperature (°C)
64	T	32	RQ	1120	880	-	cooled by air	-	870	cooled by water	150
65	U	12	RQ	1180	900	-	cooled by air	-	890	cooled by water	150
66	U	19	DQ	1180	880	850	cooled by water	150	-	-	-
67	U	32	RQ	1180	890	-	cooled by air	-	870	cooled by water	180
68	V	12	RQ	1120	870	-	cooled by air	-	920	cooled by water	180
69	V	25	RQ	1120	930	-	cooled by air	-	910	cooled by water	180
70	V	32	RQ	1120	900	-	cooled by air	-	920	cooled by water	180
71	W	12	DQ	1180	860	830	cooled by water	150	-	-	-
72	W	19	RQ	1180	900	-	cooled by air	-	900	cooled by water	190
73	W	32	RQ	1180	910	-	cooled by air	-	870	cooled by water	190

*DQ: direct quenching, RQ: reheating quenching

[Table 2-3]

Steel Plate Number	Steel Number	Plate Thickness (mm)	Type of Treatment*	Hot Rolling		DQ			RQ			Cooling Rate in Cooling by Water 800°C-→ 500°C (°C/s)	Remarks
				Reheating Temperature (°C)	Rolling Finish Temperature (°C)	Cooling Start Temperature (°C)	Cooling After Rolling	Cooling Stop Temperature (°C)	Heating Temperature (°C)	Cooling Method	Cooling Stop Temp. (°C)		
74	A	12	RQ	1120	900	-	cooled by air	-	900	cooled by water	150	32	present invention example
75	A	12	RQ	1120	900	-	cooled by air	-	910	cooled by water	150	28	present invention example
76	A	12	RQ	1120	900	-	cooled by air	-	900	cooled by water	150	62	present invention example
77	A	12	DQ	1120	880	860	cooled by water	145	-	-	-	65	present invention example
78	A	12	DQ	1120	870	850	cooled by water	150	-	-	-	71	present invention example
79	A	19	RQ	1120	920	-	cooled by air	-	910	cooled by water	170	19	present invention example
80	A	19	RQ	1120	920	-	cooled by air	-	900	cooled by water	150	19	present invention example
81	A	19	DQ	1120	890	840	cooled by water	150	-	-	-	41	present invention example
82	A	25	DQ	1120	880	830	cooled by water	150	-	-	-	15	present invention example

(continued)

Steel Plate Number	Steel Number	Plate Thickness (mm)	Type of Treatment*	Hot Rolling		DQ			RQ			Cooling Rate in Cooling by Water 800°C-→ 500°C (°C/s)	Remarks
				Reheating Temperature (°C)	Rolling Finish Temperature (°C)	Cooling Start Temperature (°C)	Cooling After Rolling	Cooling Stop Temperature (°C)	Heating Temperature (°C)	Cooling Method	Cooling Stop Temp. (°C)		
83	A	25	RQ	1120	890	-	cooled by air	-	900	cooled by water	150	32	present invention example
84	B	12	RQ	1120	890	-	cooled by air	-	900	cooled by water	150	32	present invention example
85	B	12	RQ	1120	890	-	cooled by air	-	900	cooled by water	160	65	present invention example
86	B	12	DQ	1120	950	890	cooled by water	150	-	-	-	71	present invention example
87	B	19	DQ	1120	870	850	cooled by water	150	-	-	-	19	present invention example
88	B	19	DQ	1120	950	890	cooled by water	150	-	-	-	40	present invention example
89	B	32	DQ	1120	890	840	cooled by water	150	-	-	-	12	present invention example

*DQ: direct quenching, RQ: reheating quenching

[Table 3-1]

Steel Plate Number	Steel Number	Structure		Surface Hardness	Low-temperature Toughness	Corrosive Wear Resistance	Remarks
		Grain Size of Prior Austenite Grains (μm)	Martensitic Fraction (area%)	HBW 10/3000	vE-40 (°C)	Wear Resistance Ratio (Reference:1.0 (conventional example))	
1	A	25	93	486	33	1.5	present invention example
2	A	27	92	491	32	1.5	present invention example
3	A	27	91	493	31	1.5	present invention example
4	A	28	85	432	30	1.3	comparison example
5	A	32	83	430	17	1.2	comparison example
6	B	22	96	469	38	1.9	present invention example
7	B	25	93	468	34	1.9	present invention example
8	B	26	92	459	33	1.9	present invention example
9	B	36	92	466	17	1.9	comparison example
10	B	35	94	471	14	2.0	comparison example

(continued)

Steel Plate Number	Steel Number	Structure		Surface Hardness	Low-temperature Toughness	Corrosive Wear Resistance	Remarks
		Grain Size of Prior Austenite Grains (μm)	Martensitic Fraction (area%)	HBW 10/3000	vE-40 (°C)	Wear Resistance Ratio (Reference:1.0 (conventional example))	
11	C	16	97	465	39	1.9	present invention example
12	C	18	95	469	36	2.0	present invention example
13	C	19	93	472	34	2.1	present invention example
14	D	15	95	455	45	2.0	present invention example
15	D	12	96	460	46	2.1	present invention example
16	D	10	94	465	50	2.3	present invention example
17	E	15	95	470	45	2.0	present invention example
18	E	14	96	475	46	2.1	present invention example
19	F	12	94	490	52	2.4	present invention example

(continued)

Steel Plate Number	Steel Number	Structure		Surface Hardness	Low-temperature Toughness	Corrosive Wear Resistance	Remarks
		Grain Size of Prior Austenite Grains (μm)	Martensitic Fraction (area%)	HBW 10/3000	vE-40 (°C)	Wear Resistance Ratio (Reference:1.0 (conventional example))	
20	F	16	95	470	42	2.0	present invention example
21	F	13	95	489	46	2.1	present invention example
22	G	12	94	498	47	2.0	present invention example
23	G	18	94	470	46	2.0	present invention example
24	G	17	93	478	45	2.1	present invention example
25	G	15	95	498	48	2.1	present invention example
26	H	25	95	515	35	1.5	present invention example
27	H	27	93	519	33	1.5	present invention example
28	H	28	91	521	32	1.5	present invention example

(continued)

Steel Plate Number	Steel Number	Structure		Surface Hardness	Low-temperature Toughness	Corrosive Wear Resistance	Remarks
		Grain Size of Prior Austenite Grains (μm)	Martensitic Fraction (area%)	HBW 10/3000	vE-40 (°C)	Wear Resistance Ratio (Reference:1.0 (conventional example))	
29	I	22	96	493	33	1.6	present invention example
30	I	24	94	503	36	1.6	present invention example
31	I	25	92	505	32	1.6	present invention example
32	J	21	97	521	38	2.0	present invention example
33	J	17	95	534	40	2.1	present invention example
34	J	16	93	539	42	2.0	present invention example
35	K	23	96	465	36	2.1	present invention example
36	K	20	93	470	37	2.1	present invention example
37	K	24	92	481	34	2.1	present invention example

[Table 3-2]

Steel Plate Number	Steel Number	Structure		Surface Hardness	Low-temperature Toughness	Corrosive Wear Resistance	Remarks
		Grain Size of Prior Austenite Grains (μm)	Martensitic Fraction (area%)	HBW 10/3000	vE-40 (°C)	Wear Resistance Ratio (Reference:1.0 (conventional example))	
38	L	12	97	557	49	2.4	present invention example
39	L	13	95	545	57	2.4	present invention example
40	L	13	93	550	52	2.4	present invention example
41	M	11	93	508	45	1.6	present invention example
42	M	12	94	512	42	1.6	present invention example
43	M	10	92	505	45	1.5	present invention example
44	N	13	99	490	73	2.5	present invention example
45	N	10	98	493	62	2.5	present invention example
46	N	8	97	488	66	2.5	present invention example

(continued)

Steel Plate Number	Steel Number	Structure		Surface Hardness	Low-temperature Toughness	Corrosive Wear Resistance	Remarks
		Grain Size of Prior Austenite Grains (μm)	Martensitic Fraction (area%)	HBW 10/3000	vE-40 (°C)	Wear Resistance Ratio (Reference:1.0 (conventional example))	
47	O	32	92	482	27	0.8	comparison example
48	O	34	91	491	25	0.8	comparison example
49	O	31	93	493	24	0.8	comparison example
50	P	38	95	531	17	0.9	comparison example
51	P	36	92	524	22	0.9	comparison example
52	P	32	93	519	24	0.9	comparison example
53	Q	33	94	521	28	1.2	comparison example
54	Q	32	92	532	25	1.2	comparison example
55	Q	34	92	530	27	1.2	comparison example
56	R	15	96	413	51	1.4	comparison example
57	R	16	93	410	48	1.4	comparison example
58	R	16	91	409	44	1.4	comparison example
59	S	22	52	420	15	1.2	comparison example

(continued)

Steel Plate Number	Steel Number	Structure		Surface Hardness	Low-temperature Toughness	Corrosive Wear Resistance	Remarks
		Grain Size of Prior Austenite Grains (μm)	Martensitic Fraction (area%)	HBW 10/3000	vE-40 (°C)	Wear Resistance Ratio (Reference:1.0 (conventional example))	
60	S	21	55	425	20	1.2	comparison example
61	S	25	47	413	12	1.2	comparison example
62	T	27	94	507	34	1.6	present invention example
63	T	26	94	509	36	1.6	present invention example
64	T	25	93	506	37	1.6	present invention example
65	U	23	96	511	37	2.1	present invention example
66	U	26	95	510	35	2.1	present invention example
67	U	22	96	507	40	2.1	present invention example
68	V	20	97	520	40	2.4	present invention example

(continued)

Steel Plate Number	Steel Number	Structure		Surface Hardness	Low-temperature Toughness	Corrosive Wear Resistance	Remarks
		Grain Size of Prior Austenite Grains (μm)	Martensitic Fraction (area%)	HBW 10/3000	vE-40 (°C)	Wear Resistance Ratio (Reference:1.0 (conventional example))	
69	V	19	96	523	43	2.4	present invention example
70	V	21	97	519	38	2.5	present invention example
71	W	21	97	528	45	2.4	present invention example
72	W	17	97	531	48	2.4	present invention example
73	W	15	96	521	51	2.4	present invention example

[Table 3-3]

Steel Plate Number	Steel Number	Structure		Surface Hardness	Low-temperature Toughness	Corrosive Wear Resistance	Remarks
		Grain Size of Prior Austenite Grains (μm)	Martensitic Fraction (area%)	HBW 10/3000	vE-40 (°C)	Wear Resistance Ratio (Reference:1.0 (conventional example))	
74	A	25	93	486	33	1.5	present invention example
75	A	27	94	493	34	1.5	present invention example
76	A	26	97	500	32	1.6	present invention example
77	A	25	98	501	31	1.7	present invention example
78	A	26	99	504	32	1.8	present invention example
79	A	27	92	491	32	1.5	present invention example
80	A	27	92	492	33	1.5	present invention example
81	A	26	96	498	34	1.6	present invention example
82	A	27	91	493	31	1.5	present invention example
83	A	26	95	496	30	1.7	present invention example
84	B	22	96	469	38	1.9	present invention example
85	B	21	98	473	39	2.0	present invention example
86	B	20	99	477	38	2.1	present invention example

(continued)

Steel Plate Number	Steel Number	Structure		Surface Hardness	Low-temperature Toughness	Corrosive Wear Resistance	Remarks
		Grain Size of Prior Austenite Grains (μm)	Martensitic Fraction (area%)	HBW 10/3000	vE-40 (°C)	Wear Resistance Ratio (Reference:1.0 (conventional example))	
87	B	25	93	468	34	1.9	present invention example
88	B	25	96	472	36	2.0	present invention example
89	B	26	92	459	33	1.9	present invention example

[0076] All of the present invention examples exhibit high surface hardness of 450 or more in HBW 10/3000, excellent low-temperature toughness of vE_{-40} of 30 J or more, and excellent corrosive wear resistance of the wear resistance ratio of 1.5 or more. Moreover, the steel plate cooled with higher cooling rate has a higher martensitic fraction. Particularly, the steel plate having martensitic fraction of 98% or more exhibits excellent corrosive wear resistance in particular, as compared with the steel plate having martensitic fraction of less than 98% and having same composition. 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.

Claims

1. An abrasion resistant steel plate having excellent low temperature toughness and excellent corrosive wear resistance, the steel plate having the composition containing by mass%: 0.23% to 0.35% C, 0.05% to 1.00% Si, 0.1% to 2. 0% Mn, 0.020% or less P, 0.005% or less S, 0.005% to 0.100% Al, 0.03% to 2.0% Cr, and 0.03% to 1.0% Mo in a state where DI* defined by the following formula (1) is satisfied 45 or more, and further containing remaining Fe and unavoidable impurities as a balance, 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 450 or more at Brinel hardness HBW10/3000.
   (Formula)

   $$DI^{*}=33.85\times(0.1\times C)^{0.5}\times(0.7\times Si+1)\times(3.33\times Mn+1)\times(0.35\times Cu+1)\times(0.36\times Ni+1)\times(2.16\times Cr+1)\times(3\times Mo+1)\times(1.75\times V+1)\ldots\ldots\ (1)$$

   (where, C, Si, Mn, Cu, Ni, Cr, Mo and V in the formula (1) refer to the contents (mass%) of respective elements.)

2. The abrasion resistant steel plate according to claim 1, wherein the steel composition further 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. The abrasion resistant steel plate according to claim 1 or 2, wherein the steel composition further 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. The abrasion resistant steel plate according to any of claims 1 to 3, wherein the steel composition further 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. The abrasion resistant steel plate according to any of claims 1 to 4, wherein the steel composition further 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.

6. The abrasion resistant steel plate according to any of claims 1 to 5, wherein the content of the as-quenched martensitic phase is 98% or more in terms of volume fraction.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2013/005433

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/38(2006.01)i, *C22C38/60*(2006.01)i, *C21D8/02*(2006.01)n

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00-38/60, C21D8/02

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2013
Kokai Jitsuyo Shinan Koho	1971-2013	Toroku Jitsuyo Shinan Koho	1994-2013

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.
X A	JP 2011-214120 A (JFE Steel Corp.), 27 October 2011 (27.10.2011), claims; paragraphs [0043] to [0045]; tables 1 to 3 (Family: none)	4-6 1-3
X A	JP 2009-30093 A (JFE Steel Corp.), 12 February 2009 (12.02.2009), claims; paragraphs [0034], [0035]; tables 1, 2 (Family: none)	4,5 1-3,6
X A	JP 2009-30094 A (JFE Steel Corp.), 12 February 2009 (12.02.2009), claims; paragraphs [0034], [0035]; tables 1, 2 (Family: none)	4,5 1-3,6

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

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Date of the actual completion of the international search 05 December, 2013 (05.12.13)	Date of mailing of the international search report 17 December, 2013 (17.12.13)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2013/005433

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	JP 2005-256169 A (JFE Steel Corp.), 22 September 2005 (22.09.2005), claims (Family: none)	1-6
A	JP 2012-31510 A (JFE Steel Corp.), 16 February 2012 (16.02.2012), claims & US 2013/0216422 A1 & EP 2589676 A1 & WO 2012/002567 A1	1-6

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