(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 3 778 950 A1**

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
17.02.2021 Bulletin 2021/07

(21) Application number: **18912208.8**

(22) Date of filing: **29.03.2018**

(51) Int Cl.:
C22C 38/00 *(2006.01)* ***C22C 38/04*** *(2006.01)*
C21D 8/02 *(2006.01)*

(86) International application number:
PCT/JP2018/013289

(87) International publication number:
WO 2019/186911 (03.10.2019 Gazette 2019/40)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(71) Applicant: **NIPPON STEEL CORPORATION**
Chiyoda-ku
Tokyo 100-8071 (JP)

(72) Inventors:
- **FUJIOKA Masaaki**
  Tokyo 100-8071 (JP)
- **NAMEGAWA Tetsuya**
  Tokyo 100-8071 (JP)
- **YOSHIMURA Masahide**
  Tokyo 100-8071 (JP)
- **MINAGAWA Masanori**
  Tokyo 100-8071 (JP)

(74) Representative: **Vossius & Partner**
Patentanwälte Rechtsanwälte mbB
Siebertstrasse 3
81675 München (DE)

(54) **AUSTENITIC WEAR-RESISTANT STEEL SHEET**

(57) An austenitic wear-resistant steel plate according to an aspect of the present invention has a predetermined chemical composition, the amounts of C and Mn by mass% satisfy $-20 \times C + 30 < Mn \leq -20 \times C + 45$, a volume fraction of austenite in a metallographic structure is 90% to 100%, and an average grain size of the austenite is 40 to 300 μm.

EP 3 778 950 A1

Description

[Technical Field of the Invention]

[0001] The present invention relates to an austenitic wear-resistant steel plate used for a wear-resistant member.

[Related Art]

[0002] A steel plate for wear-resistant members in the related art is manufactured by hardening a steel containing about 0.1% to 0.3% of C as disclosed in Patent Document 1 or the like to cause the metallographic structure to contain martensite. Such a steel plate has a Vickers hardness as significantly high as about 400 to 600 Hv and is excellent in wear resistance. However, since the martensite structure is very hard, bending workability and toughness are poor. Moreover, although the steel plate for wear-resistant members in the related art contains C in a large amount in order to increase hardness, a C content of 0.2% or more causes a possibility of weld cracking.

[0003] On the other hand, high Mn cast steel has been used as a material having both wear resistance and ductility. The high Mn cast steel has good ductility and toughness because the matrix is austenite. However, the high Mn cast steel has a characteristic that, when the surface portion undergoes plastic deformation due to a collision with a rock or the like, deformation twinning or, under certain conditions, a strain-induced martensitic transformation occurs, and only the hardness of the surface portion significantly increases. Therefore, the high Mn cast steel remains austenitic in the central part even when the wear resistance of the impact surface (surface portion) is improved and thus can be maintained in a state of being excellent in ductility and toughness.

[0004] As the high Mn cast steel, steels defined in JIS G 5131 and austenitic wear-resistant steels in which the mechanical properties and wear resistance are improved by increasing the C content and the Mn content have been proposed. (refer to Patent Documents 2 to 8 and the like).

[0005] In many cases, these high Mn cast steels contain C in an amount as large as 1% or more in order to improve wear resistance. In a steel having a C content of 1% or more, even if austenite excellent in ductility and toughness is formed, there may be cases where the ductility and toughness decrease due to the precipitation of a large amount of carbides and the like.

[0006] For the purpose of securing ductility and toughness even in steels having a C content of 1% or more, it has been proposed to perform a solution heat treatment in an austenite region after casting, and thereafter perform a water cooling heat treatment (water toughening treatment) thereon for manufacturing. The water toughening treatment is a treatment performed to improve ductility and toughness by rapidly cooling the steel and thus suppressing the precipitation of carbides generated during normal air cooling. For the same purpose, it has been proposed to improve the ductility and toughness of a high Mn cast steel by refining grains or controlling the precipitation morphology of carbides (dispersing spheroidal carbides in grains) by including carbide-forming elements such as Ti, V, Nb, Zr, and Ta (for example, refer to Patent Documents 3, 4, and 6 to 8).

[0007] Although it is considered that the above-mentioned methods have an effect of improving the toughness to some extent, at present, innovative properties having both wear resistance and toughness have not been obtained. In particular, in a case of refining grains by including Ti, V, Nb, Zr, Ta, and the like, these elements have to act during solidification, and thus need to be contained in large amounts. Therefore, there are cases where precipitates such as carbides and nitrides precipitate in the steel coarsely in large amounts, and these precipitates act as the origin of fatigue fracture. Furthermore, Ti, V, Nb, Zr, Ta, and the like are expensive elements, and the addition of these elements causes an increase in cost.

[0008] Refinement of grains is effective not only for improving ductility and toughness as described above, but also for improving a strain hardening property. Therefore, in order to refine the grains of a high Mn cast steel, lowering the casting temperature of the high Mn cast steel is proposed in addition to adding Ti, V, Nb, Zr, Ta, and the like. However, there is a limit to lowering the casting temperature of the high Mn cast steel, and there is also a problem that casting defects are easily generated when the casting temperature of the high Mn cast steel is lowered.

[Prior Art Document]

[Patent Document]

[0009]

[Patent Document 1] Japanese Examined Patent Application, Second Publication No. 2014-194042
[Patent Document 2] Japanese Examined Patent Application, Second Publication No. S57-17937
[Patent Document 3] Japanese Examined Patent Application, Second Publication No. S63-8181

[Patent Document 4] Japanese Examined Patent Application, Second Publication No. H1-14303
[Patent Document 5] Japanese Examined Patent Application, Second Publication No. H2-15623
[Patent Document 6] Japanese Unexamined Patent Application, First Publication No. S60-56056
[Patent Document 7] Japanese Unexamined Patent Application, First Publication No. S62-139855
[Patent Document 8] Japanese Unexamined Patent Application, First Publication No. H1-142058

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0010] The present invention has been made in view of such circumstances, and an object thereof is to provide an austenitic wear-resistant steel plate which is excellent in wear resistance and strength and excellent in toughness and ductility which conflict therewith.

[Means for Solving the Problem]

[0011] In order to obtain the wear resistance, strength, toughness, and ductility of an austenitic wear-resistant steel plate, a structure primarily containing an austenite phase needs to be formed at a temperature at which the austenitic wear-resistant steel plate is used. Furthermore, it is necessary to improve the stability of austenite and cause a sufficient amount of austenite to be contained in steel so that a structure primarily containing a' martensite and ε martensite is not formed.

[0012] In order to further improve the wear resistance of the austenitic wear-resistant steel plate, it is necessary to significantly increase the hardness of the surface portion of the steel plate by causing significant strain-induced hardening to occur on the surface portion of the steel plate by causing twinning deformation by plastic deformation due to a collision with a rock or the like by increasing the C content to about 1%, or by generating hard martensite through strain-induced martensitic transformation. Since the hardness of martensite containing a large amount of carbon is high, causing the strain-induced martensitic transformation to occur on the surface portion of the steel plate significantly improves the wear resistance of the austenitic wear-resistant steel plate. From this viewpoint, it is necessary to control the stability of austenite so that strain-induced martensitic transformation occurs at the time of a collision with a rock or the like even when the structure of the austenitic wear-resistant steel plate is a structure that primarily contains austenite during manufacturing. For this purpose, the amount of C and Mn is controlled.

[0013] In order to improve the toughness of the steel plate, the refinement of austenite grains (hereinafter, sometimes simply referred to as "grains") is extremely effective, and this can be achieved by hot rolling. The refinement of grains has an effect of improving the toughness proportional to "the -1/2 power of grain size" as is known from the Hall-Petch relationship or the like. However, excessive refinement has a disadvantage of increasing the amount of carbides precipitated at grain boundaries by increasing the nucleation sites of carbides formed at austenite grain boundaries. The carbides at grain boundaries are very hard, and when the amount of the precipitated carbides increases, the toughness and ductility of the steel decrease. The present inventors found that the toughness and ductility of the steel plate can be improved by achieving the refinement of grains without excessively reducing the grains.

[0014] As described above, the present invention provides the following austenitic wear-resistant steel plate by appropriately controlling the chemical composition of the steel plate and achieving the refinement of grains of the steel plate through hot rolling.

[1] An austenitic wear-resistant steel plate according to an aspect of the present invention includes, as a chemical composition, by mass%:

C: more than 0.80% to 1.60%;
Si: 0.01% to 2.00%;
Mn: 5.0% to 30.0%;
P: 0.050% or less;
S: 0.0100% or less;
Cu: 0% to 3.0%;
Ni: 0% to 3.0%;
Co: 0% to 3.0%;
Cr: 0% to 5.0%;
Mo: 0% to 2.0%;
W: 0% to 2.0%;
Nb: 0% to 0.30%;

V: 0% to 0.30%;
Ti: 0% to 0.30%;
Zr: 0% to 0.30%;
Ta: 0% to 0.30%;
B: 0% to 0.300%;
Al: 0.001% to 0.300%;
N: 0% to 1.000%;
O: 0% to 0.0100%;
Mg: 0% to 0.0100%;
Ca: 0% to 0.0100%;
REM: 0% to 0.0100%; and
a remainder consisting of Fe and impurities,
in which, assuming that amounts of C and Mn by mass% are respectively referred to as C and Mn, $-20 \times C + 30 < Mn \leq -20 \times C + 45$ is satisfied,
a metallographic structure of the austenitic wear-resistant steel plate includes, by volume fraction, austenite: 90% to 100%, and
an average grain size of the austenite is 40 to 300 μm.

[2] In the austenitic wear-resistant steel plate according to [1], the chemical composition may satisfy the following formula,

$$-C + 0.8 \times Si - 0.2 \times Mn - 90 \times (P + S) + 1.5 \times (Cu + Ni + Co) + 3.3 \times Cr + 9 \times Mo + 4.5 \times W + 0.8 \times Al + 6 \times N + 1.5 \geq 3.2$$

where a symbol for each of elements in the formula represents an amount of the corresponding element by mass%.
[3] In the austenitic wear-resistant steel plate according to [1] or [2], the metallographic structure may include, by volume fraction:

ε martensite: 0% to 10%; and
a' martensite: 0% to 10%, and

a sum of the ε martensite and the a' martensite may be 0% to 10%.
[4] In the austenitic wear-resistant steel plate according to any one of [1] to [3],
as the chemical composition, by mass%, 0.0001% to 0.0100% of O may be included, and
a sum of a Mg content, a Ca content, and a REM content may be 0.0001% to 0.0100%.
[5] In the austenitic wear-resistant steel plate according to [4],
as the chemical composition, by mass%, 0.0001% to 0.0050% of S may be included, and
amounts of O and S by mass% may satisfy $O/S \geq 1.0$.
[6] In the austenitic wear-resistant steel plate according to any one of [1] to [5],
as the chemical composition, by mass%, 0% to 0.2% of Cu may be included.

[Effects of the Invention]

[0015] According to the aspect of the present invention, it is possible to provide an austenitic wear-resistant steel plate (hereinafter, simply referred to as "steel plate") which is excellent in wear resistance and strength and excellent in toughness and ductility which conflict therewith. Specifically, according to the aspect of the present invention, it is possible to provide a steel plate excellent in wear resistance and strength and excellent in toughness and ductility by appropriately controlling the chemical composition, appropriately controlling the metallographic structure through hot rolling, and achieving the refinement of grains of the steel plate. The steel plate according to the present invention can be manufactured to a width of about 5 m and a length of about 50 m with various plate thicknesses ranging from about 3 mm to about 200 mm. Therefore, the steel plate according to the present invention is not limited to a relatively small wear-resistant member to which an impact is applied, such as a crusher liner, and can also be used as a very large member for a construction machine and a wear-resistant structural member. Moreover, according to the steel plate according to the present invention, steel pipes and shaped steels having similar characteristics to the steel plate according to the present invention can also be manufactured. Furthermore, according to a preferable aspect of the present invention, coarsening of grains in a welding can be suppressed using oxysulfides, so that it is possible to provide a steel plate

excellent also in the toughness of the weld.

[Embodiments of the Invention]

[0016] Hereinafter, an austenitic wear-resistant steel plate according to an embodiment will be described in detail. In the present embodiment, a steel plate having a structure primarily containing high hardness austenite as described above or utilizing martensitic transformation of the austenite structure is defined as austenitic wear-resistant steel. Specifically, a steel plate having an austenite volume fraction of 90% or more is defined as an austenitic wear-resistant steel plate.

[0017] First, the reason for limiting each of elements contained in the austenitic wear-resistant steel plate according to the present embodiment will be described. In addition, "%" regarding the amount of an element means "mass%" unless otherwise specified.

[C: More Than 0.80% to 1.60%]

[0018] C stabilizes austenite, improves the wear resistance of the steel plate, and further increases the hardness. In order to secure a desired hardness of the steel plate and to improve the wear resistance of the steel plate, the C content needs to be more than 0.80%. In a case where particularly high wear resistance is required, the C content is preferably 0.90% or more, or 1.00% or more. On the other hand, when the C content exceeds 1.60%, a large amount of coarse carbides are formed in the steel, and the steel plate cannot achieve high toughness. Therefore, the C content is set to 1.60% or less. The C content is preferably set to 1.50% or less or 1.40% or less.

[Si: 0.01% to 2.00%]

[0019] Si is typically a deoxidizing element and a solid solution strengthening element, but has an effect of suppressing the formation of carbides of Cr and Fe. The present inventors conducted various examinations on the elements that suppress the formation of carbides, and found that the formation of carbides is suppressed by including a predetermined amount of Si. Specifically, the present inventors found that the formation of carbide is suppressed by setting the Si content to 0.01 to 2.00%. When the Si content is less than 0.01%, the effect of suppressing the formation of carbides is not obtained. On the other hand, when the Si content exceeds 2.00%, there may be cases where coarse inclusions are formed in the steel and thus the ductility and toughness of the steel plate deteriorate. The Si content is preferably set to 0.20% or more, or 0.50% or more. The Si content is preferably set to 1.50% or less, 1.20% or less, or 1.00% or less.

[Mn: 5.0% to 30.0%, $-20 \times C + 30 < Mn \leq -20 \times C + 45$]

[0020] Mn is an element that stabilizes austenite together with C. The Mn content is set to 5.0% to 30.0%. In order to improve austenite stabilization, the Mn content is preferably set to 7.0% or more, 10.0% or more, 12.0% or more, or 15.0% or more. The Mn content is preferably set to 25.0% or less, 20.0% or less, or 18.0% or less.

[0021] From the viewpoint of austenite stabilization, the Mn content is set to, in relation to the C content, more than $-20 \times C + 30$ (%) and $-20 \times C + 45$ (%) or less (that is, $-20 \times C + 30 < Mn \leq -20 \times C + 45$). This is because when the Mn content is $-20 \times C + 30$ (%) or less, the stability of austenite decreases, hard a' martensite and ε martensite are generated in the steel plate after hot rolling and cooling, and thus the ductility, toughness, and workability of the steel plate decrease. On the other hand, when the Mn content is $-20 \times C + 45$ (%), the stability of austenite is sufficiently secured, and there is no need to include Mn, which is more expensive than C, in an amount of more than this value. Since the influence of C on austenite stabilization is very large, in the steel plate according to the present embodiment, the relationship between the Mn content and C content mentioned above is particularly important.

[P: 0.050% or Less]

[0022] P segregates at grain boundaries and reduces the ductility and toughness of the steel plate, so that it is preferable to reduce the amount of P as much as possible. Therefore, the P content is set to 0.050% or less. The P content is preferably set to 0.030% or less or 0.020% or less. P is generally incorporated as impurities from scraps or the like during molten steel production, but the lower limit thereof is not particularly limited and is 0%. However, when the P content is excessively reduced, there may be cases where the manufacturing cost increases. Therefore, the lower limit of the P content may be set to 0.001% or more, or 0.002% or more.

[S: 0.0100% or Less]

[0023] S is an impurity, and when S is contained excessively, S segregates at grain boundaries or forms coarse MnS, thereby reducing the ductility and toughness of the steel plate. Therefore, the S content is set to 0.0100% or less. The S content is preferably set to 0.0060% or less, 0.0040% or less, or 0.0020% or less. The lower limit of the S content is 0%. As will be described later, S has an effect of improving the toughness of the steel plate, particularly the toughness of a heat-affected zone (HAZ) by forming fine oxysulfides in the steel with O and Mg, Ca, and/or rare-earth metals (REM) and thus suppressing the growth of austenite grains. In order to obtain the effect, the S content may be set to 0.0001% or more, 0.0005% or more, or 0.0010% or more. In the present embodiment, "oxysulfides" include not only a compound containing both O and S but also oxides and sulfides.

[0024] The steel plate according to the present embodiment further includes, in addition to the essential elements mentioned above, one or two or more of Cu, Ni, Co, Cr, Mo, W, Nb, V, Ti, Zr, Ta, B, N, O, Mg, Ca, and REM. These elements are not necessarily contained, and the lower limits of the amounts of all the elements are 0%. In addition, Al, which will be mentioned later, is not an optional element but an essential element.

[Cu: 0% to 3.0%, Ni: 0% to 3.0%, and Co: 0% to 3.0%]

[0025] Cu, Ni, and Co improve the toughness of the steel plate and stabilize austenite. However, when the amount of at least one of Cu, Ni, and Co exceeds 3.0%, the effect of improving the toughness of the steel plate is saturated, and the cost also increases. Therefore, in a case where these elements are contained, the amount of each of the elements is set to 3.0% or less. Each of the Cu content, the Ni content, and the Co content is preferably set to 2.0% or less, 1.0% or less, 0.5% or less, or 0.3% or less. In particular, the Cu content is more preferably set to 0.2% or less. For austenite stabilization, the Cu content may be set to 0.02% or more, 0.05% or more, or 0.1% or more, and each of the Ni content and the Co content may be set to 0.02% or more, 0.05% or more, 0.1% or more, or 0.2% or more.

[Cr: 0% to 5.0%]

[0026] Cr improves the strain hardening property of the steel. When the Cr content exceeds 5.0%, precipitation of intergranular carbides is promoted, and the toughness of the steel plate is reduced. Therefore, the Cr content is set to 5.0% or less. The Cr content is preferably set to 2.5% or less, or 1.5% or less. In order to improve the strain hardening property, the Cr content may be set to 0.05% or more, or 0.1% or more.

[Mo: 0% to 2.0%, and W: 0% to 2.0%]

[0027] Mo and W strengthen the steel, reduce the activity of C in the austenite phase, and thus suppress the precipitation of carbides of Cr and Fe precipitated at austenite grain boundaries, thereby improving the toughness and ductility of the steel plate. However, even though Mo and W are contained excessively, the above effect is saturated, but the cost increases. Therefore, each of the Mo content and the W content is set to 2.0% or less. Each of the Mo content and the W content is preferably set to 1.0% or less, 0.5% or less, or 0.1% or less. In order to reliably obtain the effects, each of the Mo content and the W content may be set to 0.01% or more, 0.05% or more, or 0.1% or more.

[Nb: 0% to 0.30%, V: 0% to 0.30%, Ti: 0% to 0.30%, Zr: 0% to 0.30%, and Ta: 0% to 0.30%]

[0028] Nb, V, Ti, Zr, and Ta form precipitates such as carbonitrides in the steel. These precipitates improve the toughness of the steel by suppressing the coarsening of grains during solidification of the steel. Moreover, the elements reduce the activity of C and N in austenite, and thus suppresses the formation of carbides, such as cementite and graphite. Furthermore, the above elements strengthen the steel by solid solution strengthening or precipitation hardening.

[0029] When at least one of the Nb content, the V content, the Ti content, the Zr content, and the Ta content exceeds 0.30%, there may be cases where the precipitates become significantly coarsened and the ductility and toughness of the steel plate decrease. Therefore, each of the Nb content, the V content, the Ti content, the Zr content, and the Ta content is set to 0.30% or less, and more preferably 0.20% or less, 0.10% or less, or 0.01 % or less. Furthermore, it is more preferable to set the sum of the Nb content, the V content, the Ti content, the Zr content, and the Ta content to 0.30% or less, or 0.20% or less. For the improvement in the toughness of the steel and high-strengthening, each of the Nb content and the V content may be set to 0.005% or more, 0.01% or more, or 0.02% or more. For the same reason, each of the Ti content, the Zr content, and the Ta content may be set to 0.001% or more or 0.01% or more.

[B: 0% to 0.300%]

[0030] B segregates at austenite grain boundaries and thus suppresses intergranular fracture, thereby improving the proof stress and ductility of the steel plate. However, when the B content exceeds 0.300%, there may be cases where the toughness of the steel plate deteriorates. Therefore, the B content is set to 0.300% or less. The B content is preferably set to 0.250% or less. In order to suppress intergranular fracture, the B content may be set to 0.0002% or more, or 0.001% or more.

[Al: 0.001% to 0.300%]

[0031] Al is a deoxidizing element and is a solid solution strengthening element, but similarly to Si, suppresses the formation of carbides of Cr and Fe. The present inventors conducted various examinations on the elements that suppress the formation of carbides, and as a result, found that the formation of carbides is suppressed when the Al content is equal to or more than a predetermined amount. Specifically, the present inventors found that the formation of carbides is suppressed by setting the Al content to 0.001 to 0.300%. When the Al content is less than 0.001%, the effect of suppressing the formation of carbides is not obtained. On the other hand, when the Al content exceeds 0.300%, there may be cases where coarse inclusions are formed and thus the ductility and toughness of the steel plate deteriorate. The Al content is preferably set to 0.003% or more, or 0.005% or more. In addition, the Al content is preferably set to 0.250% or less or 0.200% or less.

[N: 0% to 1.000%]

[0032] N is an element effective for stabilizing austenite and improving the proof stress of the steel plate. N has the same effect as C as an element for austenite stabilization. N does not have an adverse effect such as toughness deterioration due to grain boundary precipitation, and the effect of N increasing the strength at extremely low temperatures is greater than C. N also has an effect of dispersing fine nitrides in the steel by coexistence with nitride forming elements. When the N content exceeds 1.000%, there may be cases where the toughness of the steel plate significantly deteriorates. Therefore, the N content is set to 1.000% or less. The N content is more preferably set to 0.300% or less, 0.100% or less, or 0.030% or less. N is incorporated as an impurity in a certain amount in some cases, but the N content may be set to 0.003% or more for the high-strengthening described above and the like. The N content is more preferably set to 0.005% or more, 0.007% or more, or 0.010% or more.

[O: 0% to 0.0100%]

[0033] O is incorporated into the steel as an impurity in a certain amount, but O has an effect of increasing the toughness by refining the grains in the HAZ. On the other hand, when the O content exceeds 0.0100%, there may be cases where the ductility and toughness in the HAZ decrease due to the coarsening of oxides and the segregation to grain boundaries. Therefore, the O content is set to 0.0100% or less. The O content is more preferably set to 0.0070% or less or 0.0050% or less. In order to increase the toughness, the O content may be set to 0.0001% or more, or 0.0010% or more.

[Mg: 0% to 0.0100%, Ca: 0% to 0.0100%, and REM: 0% to 0.0100%]

[0034] Mg, Ca, and REM supress the formation of MnS which is abundantly generated in high Mn steel and deteriorate the ductility and toughness of the steel plate. On the other hand, when the amounts of these elements are excessive, a large amount of coarse inclusions are formed in the steel, which causes deterioration of the ductility and toughness of the steel plate. Therefore, each of the Mg content, the Ca content, and the REM content is set to 0.0100% or less. Each of the Mg content, the Ca content, and the REM content is more preferably 0.0070% or less or 0.0050% or less. In order to suppress the formation of MnS, each of the Mg content, the Ca content, and the REM content may be set to 0.0001% or more. Each of the Mg content, the Ca content, and the REM content may be set to 0.0010% or more, or 0.0020% or more.

[0035] In addition, rare-earth metals (REM) mean a total of 17 elements including Sc, Y, and lanthanides. The amount of REM means the sum of the amounts of these 17 elements.

[O: 0.0001% to 0.0100%, and Sum of Mg Content, Ca Content, and REM Content: 0.0001% to 0.0100%]

[0036] For the reasons described below, in addition to the O content being set to 0.0001% to 0.0100%, it is preferable to set the sum of the Mg content, the Ca content, and the REM content to 0.0001% to 0.0100%. That is, the amount of at least one element of Mg, Ca, and REM is preferably set to 0.0001% to 0.0100%. At this time, the O content may be

set to 0.0002% or more, and set to 0.0050% or less. The sum of the Mg content, the Ca content, and the REM content may be set to 0.0003% or more, 0.0005% or more, or 0.0010% or more, and may be set to 0.0050% or less, or 0.0040% or less.

[0037] The reason why the O content is set to 0.0001% or more and the sum of the Mg content, the Ca content, and the REM content is set to 0.0001% to 0.0100% is that coarsening of grains in the HAZ of the steel plate is prevented by forming oxides of Mg, Ca, and/or REM. Under standard welding conditions, the austenite grain size of the HAZ obtained by the austenite pinning effect of grain growth by the oxides is several tens μm to 300 μm and does not exceed 300 μm (However, a case where the austenite grain size of the steel plate (base metal) exceeds 300 μm is excluded). As described above, in order to control the austenite grain size of the steel plate including the HAZ to 300 μm or less, it is preferable that the above elements (O, Mg, Ca, and REM) are included.

[S: 0.0001 % to 0.0050%, $O/S \geq 1.0$]

[0038] S forms oxysulfides with O and Mg, Ca, and/or REM and is thus an element effective for grain refinement. Therefore, in a case where S is contained in the steel together with O and Mg, Ca, and/or REM, in order to obtain the effect of increasing the toughness through refinement of grains in the HAZ, the S content preferably set to 0.0001% or more. In a case where S is contained in the steel together with O and Mg, Ca, and/or REM, in order to obtain better ductility and toughness for the steel plate, the S content is preferably set to 0.0050% or less.

[0039] In a case where S is contained together with O and Mg, Ca, and/or REM in the steel, by causing the S content and the O content to satisfy a relationship of $O/S \geq 1.0$, the effect of increasing the toughness through refinement of grains in the HAZ can be significantly exhibited. Since sulfides are thermally unstable compared to oxides, when the proportion of S in precipitated particles increases, there may be cases where pinning particles which are stable at high temperatures cannot be secured. Therefore, in a case where the O content is set to 0.0001% to 0.0100%, the sum of the Mg content, the Ca content, and the REM content is set to 0.0001% to 0.0100%, and S is contained in the steel, it is preferable that the S content is set to 0.0001% to 0.0050% and the O content and the S content are set to $O/S \geq 1.0$. Preferably, $O/S \geq 1.5$ or $O/S \geq 2.0$ is satisfied. By causing the O content and the S content to satisfy the above conditions, the precipitation state of the oxysulfides in the steel becomes more preferable, and the grain refinement effect can be significantly exhibited. When the average grain size of austenite of the steel plate is less than 150 μm due to the above effect, the average grain size of austenite in the HAZ can be set to 150 μm or less under standard welding conditions. The upper limit of O/S does not need to be particularly determined, but may be set to 200.0 or less, 100.0 or less, or 10.0 or less.

[0040] In the steel plate according to the present embodiment, the remainder other than the above-mentioned elements consists of Fe and impurities. In the present embodiment, the impurities are elements that are incorporated due to various factors of the manufacturing process, including raw materials such as ore and scrap, when the steel plate is industrially manufactured, and are acceptable without adversely affecting the properties of the steel plate according to the present embodiment.

$[-C + 0.8 \times Si - 0.2 \times Mn - 90 \times (P + S) + 1.5 \times (Cu + Ni + Co) + 3.3 \times Cr + 9 \times Mo + 4.5 \times W + 0.8 \times Al + 6 \times N + 1.5 \geq 3.2]$

[0041] The present inventors obtained the knowledge that the corrosion resistance of the steel plate can be improved when a CIP value expressed by $-C + 0.8 \times Si - 0.2 \times Mn - 90 \times (P + S) + 1.5 \times (Cu + Ni + Co) + 3.3 \times Cr + 9 \times Mo + 4.5 \times W + 0.8 \times Al + 6 \times N + 1.5$ is 3.2 or more. In addition, the present inventors obtained the knowledge that the corrosion wear properties due to a material in which a slurry such as sand and gravel is mixed in salt water which is a corrosive environment can be improved by the improvement of the corrosion resistance. The upper limit of the CIP value is not particularly limited, but may be set to, for example, 64.0 or less, 50.0 or less, 40.0 or less, 30.0 or less, or 20.0 or less.

[0042] The larger the CIP value is, the more the corrosion resistance and the corrosion wear properties of the steel plate can be improved. However, in a case where the CIP value is less than 3.2, the corrosion resistance and the corrosion wear properties of the steel plate are not significantly improved.

[0043] In the above formula, C, Si, Mn, P, S, Cu, Ni, Co, Cr, Mo, W, Al, and N represent the amounts of the corresponding elements in mass%. In a case where the corresponding elements are not contained, 0 is substituted.

[Volume Fraction of Austenite: 90% to 100%]

[0044] In the steel plate according to the present embodiment, in order to obtain a desired toughness, the volume fraction of austenite in a metallographic structure is set to 90% to 100%. When the volume fraction of austenite in the steel plate is less than 90%, the toughness of the steel plate decreases. The volume fraction of austenite is preferably set to 95% or more, 97% or more, or 100% or more.

[Volume Fraction of ε Martensite and α' Martensite: 0% to 10% in Total, Volume Fraction of ε Martensite: 0% to 10%, Volume Fraction of α' Martensite: 0% to 10%]

[0045] As described above, the steel plate according to the present embodiment obtains a desired toughness by including a predetermined amount of austenite. When the total volume fraction of ε martensite and α' martensite exceeds 10%, a sufficient amount of austenite is not obtained, and the toughness of the steel plate decreases. Therefore, the total volume fraction of ε martensite and α' martensite is preferably set to 10% or less, 5% or less, 3% or less, or 0% or less.

[0046] The metallographic structure of the steel plate according to the present embodiment is preferably made of austenite and a residual structure consisting of ε martensite and a' martensite. In the steel plate according to the present embodiment, the residual structure in the metallographic structure may be 0%. In addition, there may be cases where when the structure analysis is performed by X-ray diffraction, measurement results that indicate the presence of trace amounts (for example, less than 1%) of precipitates and inclusions such as iron-based carbonitrides such as cementite, carbonitrides of metal elements other than iron, and oxysulfides of Ti, Mg, Ca, REM, and the like, and other inclusions in an actual metallographic structure (including the boundary between the metallographic structures) are obtained. However, these are rarely observed when observed with a typical optical microscope, or even though these are observed, these are finely dispersed in each of austenite, ε martensite, and α' martensite or at the boundaries between the structures. Therefore, these are not regarded as the metallographic structure of a so-called matrix of the steel plate.

[0047] The volume fractions of austenite, ε martensite, and a' martensite are determined by the following method.

[0048] A sample is cut out from the plate thickness center portion of the steel plate (1/2T depth (T is the plate thickness) from the surface of the steel plate). A surface of the sample parallel to the plate thickness direction and the rolling direction of the sample is used as an observed section, and after the observed section is finished to a mirror surface by buffing or the like, strain is removed by electrolytic polishing or chemical polishing.

[0049] Regarding the observed section, using an X-ray diffractometer, the volume fractions of austenite, ε martensite, and a' martensite are obtained from the average value of the integrated intensities of the (311), (200), and (220) planes of austenite having a face-centered cubic structure (fcc structure), the average value of the integrated intensities of the (010), (011), and (012) planes of ε martensite having a dense hexagonal close-packed structure (hcp structure), and the average value of the integrated intensities of the (220), (200), and (211) planes of α' martensite having a body-centered cubic structure (bcc structure).

[0050] However, since the steel plate according to the present embodiment has a C content of more than 0.80%, a' martensite has a body-centered tetragonal structure (bct structure), and the diffraction peaks obtained by X-ray diffraction measurement have double peaks due to the anisotropy of the crystal structure. Therefore, the volume fraction of α' martensite is obtained from the sum of the integrated intensities of the respective peaks.

[Average Grain Size of Austenite: 40 to 300 μm]

[0051] First, the mechanism of reducing the toughness of the high C and high Mn austenitic steel will be described. In the steel plate according to the present embodiment, since the C content and the Mn content are high, a large number of iron carbides are formed not only at austenite grain boundaries but also in the grains. Since these carbides are harder than the iron primary phase, stress concentration around the carbides is increased when an external force is applied. Accordingly, cracking occurs between the carbides or around the carbides, which causes fracture. When an external force is applied, the stress concentration that causes the steel to fracture decreases as the grain size of austenite decreases. However, excessive refinement increases the nucleation sites of carbides formed at austenite grain boundaries and has a disadvantage of increasing the amount of carbonitrides precipitated. The carbides at grain boundaries are very hard, and when the amount of the precipitated carbides increases, the toughness and ductility of the steel decrease. The present inventors found that by optimizing the grain size, the toughness and ductility of the steel plate can be improved.

[0052] In the present embodiment, the toughness of the steel plate is improved basically by refining austenite while suppressing the formation of carbides. As described above, the steel plate according to the present embodiment includes austenite in a volume fraction of 90% to 100%. Furthermore, since the steel plate according to the present embodiment is manufactured by hot rolling, as will be described later in detail, austenite in the steel plate is refined by the hot rolling, and has excellent toughness.

[0053] Since austenite grain boundaries are also nucleation sites of carbides, excessive austenite refinement promotes the formation of carbides. When carbides are excessively formed, there may be cases where the toughness of the steel plate deteriorates. From this viewpoint, the average grain size of austenite in the steel plate is set to 40 μm or more. The average grain size of austenite in the steel plate is preferably set to 50 μm or more, 75 μm or more, or 100 μm or more. On the other hand, when the average grain size of austenite exceeds 300 μm, sufficient toughness cannot be secured at a low temperature of about -40°C. Therefore, the average grain size of austenite in the steel plate is set to 300 μm or less. The average grain size of austenite in the steel plate is preferably set to 250 μm or less, or 200 μm or

less. In addition, the upper and lower limits of the average grain size of the austenite are values which can be achieved by hot rolling as well as by the austenite pinning effect by the oxysulfides and the like according to the present invention.

[0054] According to the steel plate according to the present embodiment, for example, even when exposed to a high temperature by welding, the average grain size of austenite in the HAZ can be reduced. For example, in a case of a steel plate having a plate thickness of 20 mm or more, even in a case where shielded metal arc welding (SMAW) is performed on the steel plate with a weld heat input amount of 1.7 kJ/mm, the average grain size of austenite in a HAZ in the vicinity of a fusion line (FL) at a plate thickness center portion can be maintained in a range of 40 to 300 μm. Furthermore, depending on the average grain size of austenite of the steel plate (base metal), as described above, by including Mg, Ca, and/or REM and furthermore causing the mass ratio of O to S in the steel plate to satisfy $O/S \geq 1.0$, the average grain size of austenite in the HAZ in the vicinity of FL after the welding can be maintained in a range of 150 or less, or in a range of 40 to 150 μm. As a result, the toughness of the welded joint obtained by welding the steel plate according to the present embodiment can be enhanced. Moreover, when the steel plate according to the present embodiment is welded, a highly efficient welding method such as increasing a weld heat input can be used.

[0055] Hereinafter, a method of measuring the average grain size of austenite in the present embodiment will be described. First, a sample is cut out from the plate thickness center portion of the steel plate (1/2T depth (T is the plate thickness) from the surface of the steel plate). A cross section parallel to the rolling direction and the plate thickness direction of the steel plate is used as an observed section, and after the observed section is finished to a mirror surface by alumina polishing or the like, the observed section is corroded with a nital solution or picral solution. The metallographic structure of the observed section after the corrosion is enlarged and observed by an optical microscope, an electron microscope, or the like to obtain the average grain size of austenite. More specifically, in the observed section, a visual field of 1 mm × 1 mm or more is enlarged at a magnification of about 100-fold, the mean lineal intercept length per austenite grain observed in the observed visual field is obtained by the linear intercept segment method in Annex C.2 of JIS Z 0551: 2013, and this is used as the average grain size, whereby the average grain size of austenite is obtained.

[0056] Means for achieving the average grain size of austenite described above will be described below. Since the present embodiment relates to the steel plate, for refinement of the grain size of austenite in the steel plate (base metal), recrystallization by hot rolling can be used. The average grain size of austenite after recrystallization is expressed, for example, by Formula (1). In Formula (1), D_{rex} is the average grain size of austenite after recrystallization, Do is the average grain size of austenite before recrystallization, ε is the plastic strain by hot rolling, p and q are positive constants, and r is a negative constant.

$$D_{rex} = p \times D_0^{q} \times \varepsilon^{r} \ldots (1)$$

[0057] According to Formula (1), it is possible to obtain austenite having a predetermined grain size by performing a plurality of rolling processes while making the plastic strain at the time of hot rolling as large as possible. For example, in a case where p = 5, q = 0.3, r = -0.75, and the initial grain size, that is, the average grain size of austenite before recrystallization is 600 μm, in order to cause the average grain size of austenite after recrystallization to be 300 or less, the plastic strain at the time of hot rolling needs to be 0.056 or more. Under the same conditions, in order to cause the average grain size of austenite after recrystallization to be 100 μm or less, the plastic strain at the time of hot rolling needs to be 0.25 or more. In addition, under the same conditions, in order to maintain the average grain size of austenite after recrystallization at 20 μm or more, the plastic strain at the time of hot rolling may be 2.1 or less. The plastic strain at the time of hot rolling calculated by Formula (1) for obtaining austenite having a predetermined grain size as described above is a standard, and in practice, needs to be finely adjusted in consideration of the grain growth of austenite after recrystallization and the effect of multi-pass rolling.

[0058] The present inventors confirmed that the steel plate according to the present embodiment can be manufactured by the manufacturing method described below by the research to date including the above.

(1) Melting and Slab Manufacturing Processes

[0059] Melting and slab manufacturing processes need not be particularly limited. That is, subsequent to melting by a converter, an electric furnace, or the like, various secondary refining processes are performed to achieve the above-described chemical composition. Thereafter, a slab may be manufactured by a method such as typical continuous casting.

(2) Hot Rolling Process

[0060] The slab manufactured by the above-described method is subjected to hot rolling after being heated. The slab heating temperature is preferably higher than 1250°C to 1300°C. When the slab is heated to higher than 1300°C, there

may be cases where the surface of the steel plate is oxidized and the yield decreases, and cases where austenite becomes coarse and cannot be easily refined even by hot rolling after heating the slab. Therefore, the slab heating temperature is set to 1300°C or less.

[0061] The cumulative rolling reduction in the temperature range of 900°C to 1000°C is set to 10% to 80%. It has been confirmed that this can cause the average grain size of austenite to be 40 to 300 μm.

[0062] However, it has been confirmed that even if the slab heating temperature is 1200°C to 1250°C, the steel plate according to the present embodiment can be obtained by setteing the cumulative rolling reduction to 10% to lower than 30% in the temperature range of 900°C to 1000°C and satisfying the conditions described later.

[0063] In the present embodiment, it has been confirmed that in addition to the above conditions, it is also important to control the finish temperature during hot rolling (hereinafter, sometimes referred to as a rolling finish temperature). When the rolling finish temperature is lower than 900°C, there may be cases where austenite is not completely recrystallized and cases where austenite is excessively refined even if the austenite is recrystallized and the average grain size thereof becomes less than 40 μm. If austenite is not completely recrystallized, there may be cases where many dislocations and deformation twins are introduced into the metallographic structure, and a large amount of carbides are formed in subsequent cooling. When a large amount of carbides are formed in the steel, the ductility and toughness of the steel plate decrease. By setting the rolling finish temperature to 900°C or higher, the above-mentioned problems can be prevented. Therefore, in the present embodiment, the rolling finish temperature is set to 900°C or higher.

[0064] In cooling after hot rolling, accelerated cooling is performed except for a case where a heat treatment described later is performed. The purpose of the accelerated cooling is to increase the ductility and toughness of the steel plate by suppressing the formation of carbides after hot rolling. In order to suppress the formation of carbides, from the viewpoint of thermodynamics and whether diffusion is possible or not, it is necessary to set the retention time as short as possible at 850°C to 550°C, which is a temperature range at which carbides precipitate in the steel.

[0065] The average cooling rate during accelerated cooling is set to 1 °C/s or more. This is because, when the average cooling rate during accelerated cooling is less than 1 °C/s, the effect of accelerated cooling (the effect of suppressing the formation of carbides) is not sufficiently obtained in some cases. On the other hand, when the cooling rate during accelerated cooling exceeds 200 °C/s, there may be cases where the amount of austenite in the steel decreases, and the toughness and ductility of the steel plate decrease. Therefore, the average cooling rate during accelerated cooling is set to 200 °C/s or less.

[0066] Accelerated cooling after hot rolling starts from the high temperature side as much as possible. Since the temperature at which carbides actually start to precipitate is lower than 850°C, the cooling start temperature is set to 850°C or higher. The cooling finishing temperature is set to 550°C or lower. The accelerated cooling has not only the effect of suppressing the formation of carbides as described above, but also the effect of suppressing austenite grain growth. Therefore, also from the viewpoint of suppressing the austenite grain growth, the hot rolling and the accelerated cooling described above performed in combination.

(3) Heat Treatment Process

[0067] In a case where the accelerated cooling described above is not performed, for example, in a case where cooling is performed by air cooling after hot rolling, it is necessary to perform a heat treatment on the steel plate after the hot rolling in order to decompose precipitated carbides. As such a heat treatment, there is a solutionizing treatment. In the present embodiment, as the solutionizing treatment, for example, the steel plate is reheated to a temperature of 1100°C or higher, subjected to accelerated cooling from a temperature of 1000°C or higher at an average cooling rate of 1 to 200 °C/s, and cooled to a temperature of 500°C or lower.

[0068] The plate thickness of the steel plate according to the present embodiment need not be particularly limited, but may be set to 3 to 100 mm. As necessary, the plate thickness may be set to 6 mm or more, or 12 mm or more, and may be set to 75 mm or less, or 50 mm or less. The mechanical properties of the steel plate according to the present embodiment need not be particularly defined, but according to JIS Z 2241: 2011, the yield stress (YS) may be set to 300 N/mm^2 or more, the tensile strength (TS) is 800 N/mm^2 or more, and the elongation (EL) may be set to 40% or more. As necessary, the tensile strength may be set to 900 N/mm^2 or more or 950 N/mm^2 or more, and may be set to 2000 N/mm^2 or less or 1500 N/mm^2 or less. The toughness of the steel plate may be set such that the absorbed energy at -40°C according to JIS Z 2242: 2005 is 100 J or more, 200 J or more, or 300 J or more.

[0069] By satisfying the chemical composition and manufacturing conditions described above, an austenitic wear-resistant steel plate excellent in wear resistance and strength, and toughness and ductility can be obtained. The austenitic wear-resistant steel plate according to the present embodiment can be suitably used for small members such as a rail crossing, a caterpillar liner, an impeller blade, a crusher blade, a rock hammer, and large members that require wear resistance in the fields of construction machinery, industrial machinery, civil engineering, and architecture, such as columns, steel pipes, and outer plates.

[Examples]

[0070] Slabs having the chemical compositions shown in Tables 1-1 and 1-2 are hot-rolled under the rolling conditions shown in Tables 2-1 and 2-2 into steel plates having the product thicknesses shown in Tables 2-1 and 2-2. In Example 2 of Table 2-1, air cooling was performed after hot rolling, and a heat treatment (solutionizing treatment) was performed under the conditions shown in Table 2-1. For each of test pieces collected from the obtained steel plates, the volume fractions of austenite (γ), ε martensite (ε), and α' martensite (α'), and the average grain size, yield stress (YS) tensile strength (TS), elongation (EL), wear resistance, corrosion wear properties, and toughness of austenite (γ) were evaluated. The results are shown in Tables 2-1 and 2-2.

[0071] In addition, the specific evaluation method and pass/fail criteria of each characteristic value of Tables 2-1 and 2-2 are as follows.

Volume Fractions of Austenite, ε Martensite, and a' Martensite

[0072] Three samples were cut out from the plate thickness center portion of the steel plate (1/2T depth (T is the plate thickness) from the surface of the steel plate), surfaces of the samples parallel to the plate thickness direction and the rolling direction of the samples were used as observed sections, and after the observed sections were finished to mirror surfaces by buffing or the like, strain was removed by electrolytic polishing or chemical polishing.

[0073] Regarding the observed sections, using an X-ray diffractometer (XRD: RINT 2500 manufactured by Rigaku Corporation), the volume fractions of austenite, ε martensite, and α' martensite were obtained from the average value of the integrated intensities of the (311), (200), and (220) planes of austenite having a face-centered cubic structure (fcc structure), the average value of the integrated intensities of the (010), (011), and (012) planes of ε martensite having a dense hexagonal close-packed structure (hcp structure), and the average value of the integrated intensities of the (220), (200), and (211) planes of a' martensite having a body-centered cubic structure (bcc structure).

[0074] However, since a' martensite had a body-centered tetragonal structure (bct structure) and the diffraction peaks obtained by X-ray diffraction measurement had double peaks due to the anisotropy of the crystal structure, the volume fraction of α' martensite was obtained from the sum of the integrated intensities of the respective peaks.

[0075] A case where the volume fraction of austenite was 90% or more was determined to be within the range of the present invention and thus passed. A case where the volume fraction of austenite was less than 90% was determined to be outside of the range of the present invention and thus failed.

Average Grain Size of Austenite:

[0076] Three samples were cut out from the plate thickness center portion of the steel plate (1/2T depth (T is the plate thickness) from the surface of the steel plate), cross sections parallel to the rolling direction and the plate thickness direction of the steel plate were used as observed sections, and after the observed sections were finished to mirror surfaces by alumina polishing or the like, the observed sections were corroded with a nital solution. In the observed sections, a visual field of 1 mm × 1 mm or more was enlarged at a magnification of about 100-fold, the mean lineal intercept length per austenite grain observed in the observed visual field was obtained by the linear intercept segment method in Annex C.2 of JIS Z 0551: 2013, and this was used as the average grain size.

[0077] Furthermore, under shielded metal arc welding (SMAW) with a weld heat input amount of 1.7 kJ/mm, for a HAZ in the vicinity of a fusion line (FL) at the plate thickness center portion, the average grain size of austenite in the HAZ was measured.

[0078] A case where the average grain size of austenite in the steel plate (base metal) was 40 to 300 was determined to be within the range of the present invention and thus passed. On the other hand, a case where the average grain size of austenite in the steel plate (base metal) was out of the range of 40 to 300 μm was determined to be outside of the range of the present invention and thus failed.

Yield Stress (YS), Tensile Strength (TS), and Elongation (EL):

[0079] A tension test piece collected so that the length direction of the test piece and the width direction of the steel plate were parallel to each other was used and evaluated according to JIS Z 2241: 2011. However, the tension test piece having a plate thickness of 20 mm or less was No. 13B of JIS Z 2241: 2011, and the tension test piece having a plate thickness of more than 20 mm was No. 4 of JIS Z 2241: 2011.

[0080] A case where the yield stress (YS) was 300 N/mm^2 or more, the tensile strength (TS) was 800 N/mm^2 or more, and the elongation (EL) was 40% or more was determined to be excellent in strength and ductility and thus passed. A case where any one of the above conditions was not satisfied was determined to be failed.

Wear Resistance:

[0081] In a scratching wear test (peripheral velocity: 3.7 m/sec, 50 hours) in a case where a mixture of silica sand (No. 5 of JIS G 5901: 2016) and water (mixing ratio is silica sand 2: water 1) was used as a wear material, the wear loss was evaluated on the basis of plain steel (SS400 of JIS G 3101: 2015). The wear amount ratio to the plain steel in Tables 2-1 and 2-2 was obtained by dividing the wear loss of each steel by the wear loss of the plain steel. In a case where the plate thickness exceeded 15 mm, a test piece reduced in plate thickness to 15 mm was used.

[0082] A case where the wear amount ratio to the plain steel was less than 0.10 was determined to be excellent in wear resistance and thus passed. On the other hand, a case where the wear amount ratio to the plain steel was 0.10 or more was determined to be inferior in wear resistance and thus failed.

Corrosion Wear Properties:

[0083] For evaluation of corrosion wear properties, in a scratching wear test (peripheral velocity: 3.7 m/sec, 100 hours) using a mixture of silica sand (average grain size 12 μm) and sea water (mixing ratio: 30% silica sand, 70% sea water) as a wear material, the wear loss was evaluated on the basis of plain steel (SS400 of JIS G 3101: 2015). The corrosion wear amount ratio to the plain steel in Tables 2-1 and 2-2 was obtained by dividing the corrosion wear loss of each steel by the corrosion wear loss of the plain steel. In a case where the plate thickness exceeded 15 mm, a test piece reduced in plate thickness to 15 mm was used.

[0084] In a preferable embodiment of the present invention, the target value of the corrosion wear amount ratio to the plain steel was set to 0.80 or less.

Toughness:

[0085] For the toughness of the steel plate (base metal), a test piece parallel to the rolling direction was taken from the position of 1/4T (T is the plate thickness) of the steel plate, using a V-notch test piece of JIS Z 2242: 2005 in which a notch was inserted in a direction in which cracks propagate in the width direction, the absorbed energy ($vE_{-40°C}$ (J)) at -40°C was evaluated according to JIS Z 2242: 2005.

[0086] In addition, under shielded metal arc welding (SMAW) with a weld heat input amount of 1.7 kJ/mm (however, a plate thickness of 9 mm was set to 0.6 kJ/mm, and a plate thickness of 15 mm was set to 1.2 kJ/mm), using a Charpy test piece in which a HAZ in the vicinity of a fusion line (FL) at the plate thickness center portion became a notch position, the absorbed energy ($vE_{-40°C}$ (J)) at -40°C was evaluated under the same conditions as above.

[0087] A case where the absorbed energy at -40°C of the steel plate (base metal) was 300 J or more was determined to be excellent in toughness and thus passed. A case where the absorbed energy at -40°C of the steel plate (base metal) was less than 300 J was determined to be inferior in toughness and thus failed.

[Table 1-1]

Classification	No.	Chemical composition (mass%) remainder consisting of Fe and impurities																												
		C	Si	Mn	-20x C+30	-20x C+45	-20xC+30 <Mn≤ -20xC+45	P	S	Cu	Ni	Co	Cr	Mo	W	Nb	V	Ti	Zr	Ta	B	Al	N	O	Mg	Ca	REM	O/S	CIP value	CIP≥ 3.2
Example	1	0.9	0.50	25.0	12	27	OK	0.005	0.0020									0.01				0.010	0.003	0.0020	0.0025			1.0	-4.6	-
Example	2	0.9	0.50	25.0	12	27	OK	0.005	0.0020									0.01				0.001	0.003	0.0020	0.0025			1.0	-4.6	-
Example	3	0.9	2.00	25.0	12	27	OK	0.005	0.0020								0.05	0.01				0.005	0.030	0.0020	0.0025			1.0	-3.2	-
Example	4	0.83	0.80	22.0	13	28	OK	0.010	0.0020									0.01				0.010	0.003	0.0020	0.0030	0.0020	0.0020	1.0	-4.1	-
Example	5	1.1	0.80	22.0	8	23	OK	0.010	0.0020									0.01		0.03		0.010	0.003	0.0020	0.0030			1.0	-4.4	-
Example	6	0.83	0.60	18.0	13	28	OK	0.001	0.0020							0.03						0.030	0.003	0.0020	0.0030			1.0	-2.7	-
Example	7	1.0	0.60	18.0	10	25	OK	0.001	0.0020									0.01				0.030	0.003	0.0020	0.0030			1.0	-2.8	-
Example	8	1.0	0.60	18.0	10	25	OK	0.001	0.0020									0.02				0.300	0.003	0.0020	0.0030			1.0	-2.6	-
Example	9	1.0	0.60	18.0	10	25	OK	0.001	0.0020							0.30	0.30					0.030	0.003	0.0020	0.0030			1.0	-2.8	-
Example	10	1.0	0.60	15.0	10	25	OK	0.001	0.0015									0.01	0.02	0.01		0.010	0.003	0.0020			0.0030	1.3	-2.2	-
Example	11	1.0	0.60	15.0	10	25	OK	0.001	0.0015	3.0		1.0						0.01				0.010	0.003	0.0020			0.0030	1.3	3.8	OK
Example	12	1.22	0.60	15.0	6	21	OK	0.001	0.0020				1.0	1.0				0.01				0.010	0.003	0.0020	0.0030			1.0	-2.5	-
Example	13	0.83	0.60	15.0	13	28	OK	0.002	0.0010									0.01				0.010	0.003	0.0020	0.0030			2.0	10.2	OK
Example	14	1.0	0.60	13.0	10	25	OK	0.002	0.0010									0.01				0.010	0.003	0.0020	0.0030			2.0	-1.9	-
Example	15	1.0	0.60	13.0	10	25	OK	0.002	0.0001									0.01				0.010	0.003	0.0020	0.0030			20.0	-1.8	-
Example	16	1.0	0.60	13.0	10	25	OK	0.002	0.0010													0.010	0.003	0.0015	0.0030			1.5	-1.9	-
Example	17	1.0	0.60	13.0	10	25	OK	0.002	0.0030													0.010	0.003	0.0015	0.0030			0.5	-2.0	-
Example	18	1.0	0.60	13.0	10	25	OK	0.002	0.0030									0.01				0.010	0.020	0.0070	0.0030			2.3	-1.9	-
Example	19	1.0	0.60	13.0	10	25	OK	0.002	0.0080	1.0	1.0											0.010	0.003					0.0	0.5	-
Example	20	1.0	0.60	13.0	10	25	OK	0.002	0.0010									0.01				0.010	0.003	0.0020	0.0030			2.0	-1.9	-
Example	21	1.0	0.60	13.0	10	25	OK	0.002	0.0010									0.01				0.010	0.003	0.0007	0.0030			0.7	-1.9	-
Example	22	1.0	0.60	13.0	10	25	OK	0.002	0.0010									0.01				0.010	0.003	0.0020				2.0	-1.9	-
Example	23	1.0	0.60	13.0	10	25	OK	0.002	0.0010				5.0	0.2				0.01				0.010	0.003	0.0020	0.0030			2.0	16.4	OK
Example	24	1.0	0.60	13.0	10	25	OK	0.002	0.0010				5.0	0.2				0.01				0.010	0.003	0.0020				2.0	16.4	OK
Example	25	1.0	0.60	13.0	10	25	OK	0.002	0.0010				5.0	0.2				0.01				0.010	0.003	0.0020	0.0030			2.0	16.4	OK
Example	26	1.0	0.60	13.0	10	25	OK	0.002	0.0010									0.01				0.010	0.003					0.0	-1.9	-
Example	27	1.0	0.60	13.0	10	25	OK	0.002	0.0010													0.010	0.003					0.0	-1.9	-
Example	28	1.0	0.60	13.0	10	25	OK	0.002	0.0010													0.010	0.003	0.0007	0.0030			0.7	-1.9	-
Example	29	1.0	0.60	13.0	10	25	OK	0.002	0.0010													0.010	0.003	0.0020	0.0030			2.0	-1.9	-
Example	30	1.2	0.60	13.0	6	21	OK	0.002	0.0010					0.8				0.01				0.010	0.003	0.0020	0.0030			2.0	5.1	OK
Example	31	1.2	1.00	10.0	6	21	OK	0.001	0.0015	1.0	1.0											0.030	0.003	0.0020	0.0030			1.3	1.9	-
Example	32	1.2	1.00	10.0	6	21	OK	0.001	0.0015		0.5							0.01				0.040	0.003	0.0020	0.0030			1.3	-0.3	-
Example	33	1.6	1.00	10.0	-2	13	OK	0.001	0.0010			0.5						0.01				0.005	0.003	0.0020	0.0030			2.0	-0.7	-
Example	34	1.0	1.00	11.0	10	25	OK	0.001	0.0010			0.5						0.01				0.004	1.000	0.0020	0.0030			2.0	5.7	OK
Example	35	1.2	0.80	7.0	6	21	OK	0.002	0.0010					0.5	0.5						0.001	0.010	0.003	0.0020	0.0050			2.0	6.0	OK
Example	36	1.2	0.80	7.0	6	21	OK	0.002	0.0010				2.0	0.5	0.5						0.001	0.010	0.003	0.0020	0.0050			2.0	12.6	OK
Example	37	1.2	0.80	7.0	6	21	OK	0.002	0.0010				2.0	0.5	0.5						0.001	0.010	0.003	0.0020	0.0050			2.0	12.6	OK
Example	38	1.2	0.80	7.0	6	21	OK	0.002	0.0010		3.0			0.5	0.5						0.001	0.010	0.003	0.0020	0.0050			2.0	10.5	OK
Example	39	1.2	0.80	7.0	6	21	OK	0.002	0.0010		1.0			0.5	0.5						0.300	0.020	0.003	0.0020	0.0050			2.0	7.6	OK
Example	40	1.6	0.60	7.0	-2	13	OK	0.002	0.0010				0.5			0.05		0.02				0.030	0.003	0.0020	0.0050			2.0	0.4	-

Blank means that the element is not intentionally contained.

[Table 1-2]

Classification	No.	Chemical composition (mass%) remainder consisting of Fe and impurities																										
		C	Si	Mn	-20xC+30	-20xC+45	-20xC+30<Mn≤-20xC+45	P	S	Cu	Ni	Co	Cr	Mo	W	Nb	V	Ti	Zr	Ta	B	Al	N	O	Mg	Ca	REM	O/S	CIP value	CIP≥3.2
Comparative Example	41	0.3	0.60	2.0	24	39	NO	0.001	0.0010									0.01			0.001	0.030	0.003	0.0020	0.0050			2.0	1.1	-
Comparative Example	42	1.2	0.60	2.0	6	21	NO	0.001	0.0010									0.01				0.010	0.003	0.0020	0.0050			2.0	0.2	-
Comparative Example	43	0.83	0.60	7.0	13	28	NO	0.001	0.0015									0.01				0.010	0.003	0.0020	0.0050			1.3	-0.4	-
Comparative Example	44	0.3	0.60	12.0	24	39	NO	0.001	0.0030									0.01				0.030	0.003	0.0020			0.0005	0.7	-1.0	-
Comparative Example	45	0.6	0.60	12.0	18	33	NO	0.001	0.0020													0.010	0.003	0.0020	0.0050			1.0	-1.3	-
Comparative Example	46	1.8	0.60	12.0	-6	9	NO	0.001	0.0020									0.01				0.005	0.003	0.0020	0.0050	0.0010		1.0	-2.5	-
Comparative Example	47	0.3	0.60	18.0	24	39	NO	0.001	0.0025													0.010	0.003	0.0020	0.0050			0.8	-2.2	-
Comparative Example	48	0.1	0.60	25.0	28	43	NO	0.001	0.0030													0.030	0.003	0.0020	0.0050			0.7	-3.4	-
Comparative Example	49	1.4	0.60	20.0	2	17	NO	0.001	0.0020													0.010	0.003	0.0020	0.0050			1.0	-3.7	-
Comparative Example	50	1.0	0.60	13.0	10	25	OK	0.002	0.0010									0.01				0.002	0.003	0.0020	0.0200			2.0	-1.9	-
Comparative Example	51	1.0	0.60	13.0	10	25	OK	0.002	0.0010									0.01				0.003	0.003	0.0150	0.0030			15.0	-1.9	-
Comparative Example	52	1.0	0.60	13.0	10	25	OK	0.002	0.0010									0.03				0.005	0.003	0.0150	0.0030			15.0	-1.9	-
Comparative Example	53	1.0	0.60	13.0	10	25	OK	0.002	0.0600													0.010	0.003	0.0020	0.0030			0.03	-7.2	-
Comparative Example	54	1.0	0.60	13.0	10	25	OK	0.060	0.0010									0.01				0.005	0.003	0.0020	0.0030			2.0	-7.1	-
Comparative Example	55	1.0	0.60	13.0	10	25	OK	0.002	0.0010									0.01				0.010	0.003	0.0020				2.0	-1.9	-
Comparative Example	56	1.0	0.60	13.0	10	25	OK	0.002	0.0010									0.01				0.010	0.003	0.0020	0.0030			2.0	-1.9	-
Comparative Example	57	0.35	0.50	25.0	23	38	OK	0.005	0.0030				1.5	0.5			0.10					0.030	0.010	0.0030	0.0025			1.0	5.4	OK
Comparative Example	58	0.5	0.50	25.0	20	35	OK	0.005	0.0030				1.0									0.020	0.003	0.0030	0.0025			1.0	-1.0	-
Comparative Example	59	0.4	0.60	22.0	22	37	OK	0.020	0.0020									0.01				0.005	0.100	0.0020	0.0040			1.0	-4.2	-

Blank means that the element is not intentionally contained. The underlined mean outside of the range of the present invention.

[Table 2-1]

Classification	No	Rolling conditions								Heat treatment conditions				Metallographic structure state								Mechanical properties							
		Slab thickness (mm)	Product thickness (mm)	Heating temperature (°C)	Rolling start temperature (°C)	Rolling finish temperature (°C)	Cumulative rolling reduction at 900°C to 1000°C (%)	Cooling start temperature (°C)	Cooling rate (°C/s)	Cooling finish temperature (°C)	Reheating temperature (°C)	Cooling start temperature (°C)	Cooling rate (°C/s)	Cooling finish temperature (°C)	Base metal						HAZ	Base metal							HAZ
															γ volume fraction (%)	ε+α' volume fraction (%)	ε volume fraction (%)	α' volume fraction (%)	γ average grain size (μm)	γ average grain size (μm)	YS (N/mm²)	TS (N/mm²)	EL (%)	Wear amount ratio to plain steel	Corrosion wear amount ratio to plain steel	vE-40°C (J)	vE-80°C (J)	vE-40°C (J)
Example	1	250	35	1260	1135	980	67	960	21	80					100	0	0	0	65	110	389	964	59	0.06	127	343	284	284
Example	2	250	35	1260	1135	980	67	-	-	-	1250	1200	20	100	100	0	0	0	65	110	389	964	54	0.06	127	343	284	284
Example	3	250	50	1260	1120	1010	65	1000	15	350					100	0	0	0	60	110	400	1018	53	0.03	1.19	340	283	283
Example	4	250	25	1260	1130	900	78	870	30	80					100	0	0	0	51	72	376	951	55	0.07	124	337	349	349
Example	5	250	75	1260	1150	1010	50	1000	10	350					100	0	0	0	82	104	424	1022	51	0.03	126	369	272	272
Example	6	250	50	1260	1150	1040	44	1030	15	400					100	0	0	0	84	110	382	952	54	0.07	1.15	394	291	291
Example	7	250	50	1260	1150	1040	44	1030	15	90					100	0	0	0	84	104	406	993	52	0.05	1.16	375	284	284
Example	8	250	25	1260	1150	930	72	910	30	80					100	0	0	0	52	98	411	998	52	0.05	1.15	329	292	292
Example	9	250	25	1260	1150	930	72	910	30	90					100	0	0	0	52	110	507	1094	50	<0.01	1.16	326	265	265
Example	10	250	25	1260	1150	930	72	910	30	80					100	0	0	0	52	104	406	993	52	0.05	1.12	329	286	286
Example	11	250	35	1300	1135	980	67	960	21	80					100	0	0	0	90	104	406	993	52	0.05	0.75	375	284	284
Example	12	250	35	1300	1135	980	67	960	21	90					100	0	0	0	90	104	445	1047	49	0.02	1.14	362	253	253
Example	13	250	25	1260	1150	920	55	900	30	80					100	0	0	0	65	104	426	969	53	0.06	0.36	343	296	296
Example	14	250	25	1260	1150	920	55	900	30	90					100	0	0	0	65	104	406	993	52	0.05	1.10	338	284	284
Example	15	250	25	1260	1150	920	55	890	30	90					100	0	0	0	65	80	406	993	52	0.05	1.10	338	325	325
Example	16	250	25	1260	1150	920	55	900	30	80					100	0	0	0	65	110	405	991	52	0.05	1.10	338	254	254
Example	17	250	25	1260	1150	920	55	890	30	80					100	0	0	0	65	159	405	991	52	0.05	1.11	338	202	202
Example	18	250	25	1260	1150	920	55	900	30	90					100	0	0	0	65	104	410	1003	52	0.04	1.11	338	284	284
Example	19	250	25	1260	1150	920	55	900	30	70					100	0	0	0	65	252	405	991	52	0.05	0.95	338	117	117
Example	20	250	25	1260	1150	990	56	910	30	80					100	0	0	0	115	125	392	978	53	0.05	1.10	315	253	253
Example	21	250	25	1260	1100	920	50	860	30	80					100	0	0	0	150	155	392	978	53	0.05	1.10	315	189	189
Example	22	250	25	1260	1135	910	76	895	30	90					100	0	0	0	52	207	437	1024	50	0.03	1.10	326	167	167
Example	23	250	25	1260	1135	910	76	890	30	80					100	0	0	0	52	134	541	1089	45	0.03	0.10	317	265	265
Example	24	250	25	1260	1135	910	76	895	30	70					100	0	0	0	52	207	541	1089	45	0.03	0.10	317	165	165
Example	25	250	25	1200	1150	900	25	910	30	90					100	0	0	0	74	144	523	1071	46	0.03	0.10	345	267	267

Example	26	250	25	1260	1150	1030	53	910	30	80				100	0	0	0	68	217	419	1006	51	0.04	1.10	341	166
Example	27	250	25	1300	1180	1090	70	940	30	80				100	0	0	0	82	293	418	1004	52	0.06	1.10	385	132
Example	28	250	25	1360	1180	1090	70	940	30	90				100	0	0	0	82	151	416	1003	52	0.06	1.10	382	213
Example	29	250	25	1300	1180	1090	70	930	30	80				100	0	0	0	82	110	414	1000	52	0.07	1.10	375	273
Example	30	250	25	1200	1080	920	28	900	30	70				100	0	0	0	65	104	465	1050	48	0.02	0.67	324	258
Example	31	250	20	1260	1150	920	72	900	38	80				100	0	0	0	56	110	440	1049	50	0.04	0.87	335	279
Example	32	250	20	1260	1150	900	74	850	38	90				100	0	0	0	61	104	441	1051	50	0.02	1.01	336	289
Example	33	250	25	1260	1200	900	60	860	30	80				99	1	1	0	71	104	511	1138	45	<0.01	1.03	324	236
Example	34	250	9	1275	1150	900	77	850	83	90				90	10	10	0	54	104	626	1604	40	<0.01	0.64	347	292
Example	35	250	15	1260	1140	900	78	850	50	80				90	10	5	5	54	89	459	1051	50	0.02	0.61	361	323
Example	36	250	15	1260	1140	900	78	860	50	60				90	10	5	5	54	89	499	1077	48	0.02	0.20	358	320
Example	37	250	15	1220	1140	900	28	850	50	80				90	10	5	5	68	92	499	1077	48	0.02	0.20	368	320
Example	38	250	25	1260	1150	930	72	910	30	90				90	10	5	5	52	89	459	1051	50	0.02	0.33	359	323
Example	39	250	25	1260	1150	930	72	910	30	70				90	10	5	5	52	89	460	1051	50	0.02	0.52	359	323
Example	40	250	50	1260	1150	1040	44	1030	15	80				100	0	0	0	75	83	533	1148	46	<0.01	0.96	358	324

The underlined mean outside of the range of the present invention or outside of a preferable range.

[Table 2-2]

Classification	No.	Rolling conditions								Heat treatment conditions				Metallographic structure state						Mechanical properties						
														Base metal				HAZ	Base metal							
		Slab thickness (mm)	Product thickness (mm)	Heating temperature (°C)	Rolling start temperature (°C)	Rolling finish temperature (°C)	Cumulative rolling reduction at 900°C to 1000°C (%)	Cooling start temperature (°C)	Cooling rate (°C/s)	Cooling finish temperature (°C)	Reheating temperature (°C)	Cooling start temperature (°C)	Cooling rate (°C/s)	Cooling finish temperature (°C)	γ volume fraction (%)	ε+α' volume fraction (%)	ε volume fraction (%)	α' volume fraction (%)	γ average grain size (μm)	γ average grain size (μm)	YS (N/mm²)	TS (N/mm²)	EL (%)	Wear amount ratio to plain steel	Corrosion wear amount ratio to plain steel	vE-40°C (J)	HAZ vE-40°C (J)
Comparative Example	41	250	25	1260	1150	930	72	910	30	90					0	100	0	100	84	52	628	1604	3	<0.01	0.92	15	10
Comparative Example	42	250	25	1260	1150	940	71	920	30	80					69	31	0	31	84	52	491	1269	36	<0.01	0.97	258	218
Comparative Example	43	250	25	1260	1150	930	72	910	30	80					51	49	0	49	84	52	447	1274	32	<0.01	1.01	238	169
Comparative Example	44	250	25	1260	1150	940	71	920	30	70					25	75	15	60	156	52	399	1369	17	<0.01	1.05	154	15
Comparative Example	45	250	25	1260	1150	930	72	910	30	80					53	47	18	29	89	52	490	1284	38	<0.01	1.06	251	193
Comparative Example	46	250	25	1260	1150	930	72	900	30	90					99	1	1	0	78	52	559	1180	35	<0.01	1.14	94	15
Comparative Example	47	250	25	1260	1150	930	72	910	30	80					67	33	16	17	159	52	311	1025	38	0.17	1.12	264	226
Comparative Example	48	250	25	1260	1150	930	72	900	30	80					85	15	5	10	164	52	261	800	51	0.23	1.20	340	279
Comparative Example	49	250	25	1260	1150	930	72	910	30	90					99	1	1	0	89	52	475	1086	46	<0.01	1.21	91	75
Comparative Example	50	250	25	1260	950	900	90	800	30	80					100	0	0	0	19	15	530	1117	29	<0.01	1.10	5	91
Comparative Example	51	250	25	1260	1150	930	72	910	30	70					100	0	0	0	104	52	406	993	37	0.05	1.10	79	64
Comparative Example	52	250	25	1260	1150	930	72	900	30	80					100	0	0	0	93	52	409	996	29	0.05	1.10	79	96
Comparative Example	53	250	25	1260	1150	930	72	900	30	90					100	0	0	0	160	52.	405	991	37	0.05	1.43	79	52
Comparative Example	54	250	25	1260	1150	930	72	910	30	70					100	0	0	0	104	52	406	994	42	0.05	1.42	49	34
Comparative Example	55	250	10	1300	1100	830	96	500	75	80					100	0	0	0	220	35	376	963	52	0.07	1.10	146	117
Comparative Example	56	250	25	1300	1190	1090	9	950	30	80					100	0	0	0	451	347	376	963	52	0.07	1.10	148	5
Comparative Example	57	250	25	1260	1110	940	78	920	30	90					100	0	0	0	118	45	348	816	56	0.13	0.65	332	302
Comparative Example	58	250	25	1260	1150	940	73	920	30	80					100	0	0	0	118	55	337	850	57	0.12	1.05	353	297
Comparative Example	59	250	25	1200	1090	900	78	850	30	70					100	0	0	0	92	45	323	861	60	0.11	1.25	334	333

The underlined mean outside of the range of the present invention or outside of a preferable range.

Claims

1. An austenitic wear-resistant steel plate comprising, as a chemical composition, by mass%:

C: more than 0.80% to 1.60%;
Si: 0.01% to 2.00%;
Mn: 5.0% to 30.0%;
P: 0.050% or less;
S: 0.0100% or less;
Cu: 0% to 3.0%;
Ni: 0% to 3.0%;
Co: 0% to 3.0%;
Cr: 0% to 5.0%;
Mo: 0% to 2.0%;
W: 0% to 2.0%;
Nb: 0% to 0.30%;
V: 0% to 0.30%;
Ti: 0% to 0.30%;
Zr: 0% to 0.30%;
Ta: 0% to 0.30%;
B: 0% to 0.300%;
Al: 0.001% to 0.300%;
N: 0% to 1.000%;
O: 0% to 0.0100%;
Mg: 0% to 0.0100%;
Ca: 0% to 0.0100%;
REM: 0% to 0.0100%; and
a remainder consisting of Fe and impurities,
wherein, assuming that amounts of C and Mn by mass% are respectively referred to as C and Mn, $-20 \times C + 30 < Mn \leq -20 \times C + 45$ is satisfied,
a metallographic structure of the austenitic wear-resistant steel plate includes, by volume fraction, austenite: 90% to 100%, and
an average grain size of the austenite is 40 to 300 μm.

2. The austenitic wear-resistant steel plate according to claim 1,
wherein the chemical composition satisfies the following formula,

$$-C + 0.8 \times Si - 0.2 \times Mn - 90 \times (P + S) + 1.5 \times (Cu + Ni + Co) + 3.3 \times Cr + 9 \times Mo + 4.5 \times W + 0.8 \times Al + 6 \times N + 1.5 \geq 3.2$$

where a symbol for each of elements in the formula represents an amount of the corresponding element by mass%.

3. The austenitic wear-resistant steel plate according to claim 1 or 2, wherein the metallographic structure includes, by volume fraction:

ε martensite: 0% to 10%; and
α' martensite: 0% to 10%, and

a sum of the ε martensite and the a' martensite is 0% to 10%.

4. The austenitic wear-resistant steel plate according to any one of claims 1 to 3,
wherein, as the chemical composition, by mass%, 0.0001 % to 0.0100% of O is included, and
a sum of a Mg content, a Ca content, and a REM content is 0.0001% to 0.0100%.

5. The austenitic wear-resistant steel plate according to claim 4,
wherein, as the chemical composition, by mass%, 0.0001% to 0.0050% of S is included, and

amounts of O and S by mass% satisfy $O/S \geq 1.0$.

6. The austenitic wear-resistant steel plate according to any one of claims 1 to 5, wherein, as the chemical composition, by mass%, 0% to 0.2% of Cu is included.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/013289

A. CLASSIFICATION OF SUBJECT MATTER
Int. Cl. C22C38/00(2006.01)i, C22C38/04(2006.01)i, C21D8/02(2006.01)n

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int. Cl. C22C38/00, C22C38/04, C21D8/02

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

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2018
Registered utility model specifications of Japan	1996-2018
Published registered utility model applications of Japan	1994-2018

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	JP 2012-107325 A (KOBE STEEL, LTD.) 07 June 2012, claim 1, paragraphs [0001], [0030], [0031], [0035]-[0042], table 1, (C-3, C-7, C-10), table 2 (experiment no. 14, 18, 21) (Family: none)	1, 3, 6 4-5 2
Y	JP 2016-196703 A (NIPPON STEEL & SUMITOMO METAL CORP.) 24 November 2016, claim 1, paragraphs [0013], [0020], [0021], [0024] (Family: none)	4-5
A	JP 2016-507648 A (POSCO) 10 March 2016, claims 1-4, paragraphs [0023]-[0025], [0038], tables 3, 4 & EP 2940173 A1, claims 1-4, [0023]-[0025], [0036], table 3, 4 & US 2015/0354037 A1 & WO 2014/104706 A1 & CA 2896534 A1 & CN 104884661 A	1-6

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13.06.2018	26.06.2018
Name and mailing address of the ISA/ Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/013289

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2011-219809 A (HONDA MOTOR CO., LTD.) 04 November 2011, claim 1, paragraphs [0028], [0029], [0034], table 1, (embodiment 12), table 2 (Family: none)	1-6
A	WO 2015/147166 A1 (NISSHIN STEEL CO., LTD.) 01 October 2015, paragraph [0014] & US 2017/0114425 A1, paragraph [0017] & CN 106414784 A	1-6

Form PCT/ISA/210 (continuation of second sheet) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 2014194042 A **[0009]**
- JP S5717937 B **[0009]**
- JP S638181 B **[0009]**
- JP H114303 B **[0009]**
- JP H215623 B **[0009]**
- JP S6056056 B **[0009]**
- JP S62139855 B **[0009]**
- JP H1142058 B **[0009]**