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(54) STEEL MATERIAL AND PRODUCTION METHOD THEREFOR

(57) Provided are a steel material and a method of producing the same. The steel material has a chemical composition containing, in mass%, C: 0.10-2.50 %, Mn: 8.0-45.0 %, P: ≤ 0.300 %, S: ≤ 0.1000 %, Ti: 0.10-5.00 %, Al: 0.001-5.000 %, N: ≤ 0.5000 %, and O: ≤ 0.1000 %, where C, Ti, and Mn satisfy 25([C] - 12.01[Ti]/47.87) + [Mn] ≥ 25 ([C], [Ti] and [Mn] are a content of each element in mass%), with the balance being Fe and inevitable impurities, and a microstructure containing ≥ 90 % of an austenite phase and ≥ 0.2 % of Ti carbides in area ratio. Such a microstructure can be obtained by heating the steel material having the chemical composition to a temperature of ≥ 950 °C, and then cooling the steel material at a cooling rate of > 1 °C/s in a temperature range between 900-500 °C. A steel material excellent in wear resistance is thus obtained. By adjusting the hardness of the austenite phase to ≥ 200 HV, the impact wear resistance is remarkably improved.

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Description

TECHNICAL FIELD

[0001] This disclosure relates to a steel material and a method of producing the same, and particularly to an improvement in wear resistance of an austenitic steel material.

BACKGROUND

[0002] Industrial machinery and transportation equipment, such as power shovels, bulldozers, hoppers, bucket conveyors, and rock crushers, used in fields of construction, civil engineering, mining and the like are exposed to wear such as sliding wear and impact wear caused by rocks, sand, ores, and the like. Therefore, members of industrial machinery, transportation equipment and the like are required to have excellent wear resistance from the viewpoint of extending the life of the machines, equipment and the like.

[0003] It is known that the wear resistance of a steel material improves as the hardness of the steel material increases. In a steel microstructure, an austenite phase has a high degree of hardening, that is, high hardenability when it is applied with strain. Therefore, an austenitic steel material exhibits extremely excellent wear resistance because the steel is hardened in the vicinity of a wearing surface when it is used in an environment of impact wear where the steel is applied with an impact force such as a collision of rocks. Further, an austenite phase has better ductility and toughness than microstructures such as a ferrite phase and a martensite phase. Therefore, for example, austenitic steel materials such as Hadfield steel, which can obtain an austenite microstructure by containing a large amount of manganese, have been widely used as inexpensive wear-resistant steel materials.

[0004] For example, PTL 1 (JP 5879448 B) describes "a wear-resistant austenitic steel material and a method of producing the same". The technique described in PTL 1 is a wear-resistant austenitic steel material containing, in weight%, manganese (Mn): 15 % to 25 %, carbon (C): 0.8 % to 1.8 %, and copper (Cu) satisfying 0.7 C - 0.56 (%) $\leq$ Cu $\leq$ 5 %, with the balance consisting of Fe and inevitable impurities, where the wear-resistant austenitic steel material has excellent toughness in a heat-affected zone where a Charpy impact value at -40 °C is 100 J or more. According to the technique described in PTL 1, an austenite microstructure can be stably obtained by containing a large amount of manganese, the formation of carbides in the heat-affected zone after welding can be suppressed, and deterioration of the toughness of the heat-affected zone can be prevented.

[0005] In addition, PTL 2 (JP 6014682 B) describes "a wear-resistant austenitic steel material and a method of producing the same". The wear-resistant austenitic steel material described in PTL 2 is a wear-resistant austenitic steel material containing, in weight%, 8 % to 15 % of manganese (Mn), carbon (C) satisfying a relation of 23 % < 33.5 C - Mn $\leq$ 37 %, and copper (Cu) satisfying 1.6 C - 1.4 (%) $\leq$ Cu $\leq$ 5 %, with the balance consisting of Fe and inevitable impurities, where carbides are 10 % or less in area fraction, and the wear-resistant austenitic steel material has excellent ductility. According to the technique described in PTL 2, an austenite microstructure can be stably obtained by containing a large amount of manganese, the formation of carbides inside the steel material can be suppressed, and deterioration of the toughness of the steel material can be prevented.

CITATION LIST

Patent Literature

[0006]

PTL 1: JP 5879448 B
PTL 2: JP 6014682 B

SUMMARY

(Technical Problem)

[0007] However, for the austenitic steel materials described in PTLS 1 and 2, a large and hardened layer is not formed on the steel material surface in a case of wear where no impact force is applied to the steel material, for example, a case of wear where sand rubs against the steel material surface, that is, sliding wear. Therefore, the wear resistance cannot be remarkably improved.

[0008] It could thus be helpful to provide an austenitic steel material excellent in wear resistance and a method of producing the same. As used herein, "excellent in wear resistance" means having both excellent sliding wear resistance

and excellent impact wear resistance, and the "steel material" includes a plate-shaped steel sheet (plate material), a rod-shaped steel bar (bar material), a linear wire rod, and shaped steel having various cross-sectional shapes.

(Solution to Problem)

[0009] We first diligently investigated various factors affecting the sliding wear resistance of an austenitic steel material. As a result, we discovered that, in order to improve the sliding wear resistance of an austenitic steel material, it is effective to contain hard particles in the matrix phase (austenite phase), and Ti carbides having extremely high hardness are particularly effective among the particles that can be contained in the matrix phase (austenite phase). The sliding wear develops when an outermost layer of the steel material is continuously scraped. Therefore, by containing hard particles in the matrix phase (austenite phase), hard particles appear on the outermost layer of the steel material as the wear develops, and the hard particles are a resistance to the development of wear. As a result, the wear resistance is improved, and the life against wear is extended.

[0010] On the other hand, it is important to maintain a stable austenite microstructure for improving the impact wear resistance of an austenitic steel material. In addition, it is necessary to increase the amounts of dissolved C and Mn, which are austenite stabilizing elements, for obtaining a stable austenite microstructure at low cost even at normal temperature. However, as described above, when a large amount of Ti carbide is contained in the matrix phase to improve the sliding wear resistance, the amount of dissolved C that is effective for maintaining a stable austenite microstructure is reduced. We newly discovered that it is effective to adjust the amounts of C and Mn in consideration of the difference between the amounts of dissolved C and Mn, which are austenite stabilizing elements, and the austenite stabilizing ability of C and Mn so as to satisfy a relation of the following expression (1) to have both excellent sliding wear resistance and excellent impact wear resistance.

$$25([\mathrm{C}] - 12.01[\mathrm{Ti}]/47.87) + [\mathrm{Mn}] \geq 25 \qquad (1)$$

where [C], [Ti] and [Mn] are a content of each element in mass%.

[0011] The present disclosure is based on the above discoveries and further studies. The primary features of the present disclosure are described below.

(1) A steel material comprising
a chemical composition containing (consisting of), in mass%,

C: 0.10 % or more and 2.50 % or less,
Mn: 8.0 % or more and 45.0 % or less,
P: 0.300 % or less,
S: 0.1000 % or less,
Ti: 0.10 % or more and 5.00 % or less,
Al: 0.001 % or more and 5.000 % or less,
N: 0.5000 % or less, and
O (oxygen): 0.1000 % or less, where
C, Ti, and Mn are contained in ranges satisfying the following expression (1),

$$25([\mathrm{C}] - 12.01[\mathrm{Ti}]/47.87) + [\mathrm{Mn}] \geq 25 \qquad (1)$$

where [C], [Ti] and [Mn] are a content of each element in mass%,
with the balance consisting of Fe and inevitable impurities, and

a microstructure containing 90 % or more of an austenite phase and 0.2 % or more of Ti carbides in area ratio.
(2) The steel material according to (1), wherein the austenite phase has a Vickers hardness of 200 HV or more.
(3) The steel material according to (1) or (2), further comprising, in mass%, in addition to the chemical composition, at least one selected from the group consisting of
Si: 0.01 % or more and 5.00 % or less,
Cu: 0.1 % or more and 10.0 % or less,
Ni: 0.1 % or more and 25.0 % or less,
Cr: 0.1 % or more and 30.0 % or less,
Mo: 0.1 % or more and 10.0 % or less,

Nb: 0.005 % or more and 2.000 % or less,
V: 0.01 % or more and 2.00 % or less,
W: 0.01 % or more and 2.00 % or less,
B: 0.0003 % or more and 0.1000 % or less,
Ca: 0.0003 % or more and 0.1000 % or less,
Mg: 0.0001 % or more and 0.1000 % or less, and
REM: 0.0005 % or more and 0.1000 % or less.

(4) A method of producing a steel material, wherein a casting process in which molten steel is smelted to obtain cast steel, a heating process in which the cast steel is heated, a hot rolling process in which the heated cast steel is subjected to hot rolling to obtain a steel material, and a cooling process in which the steel material is cooled, are sequentially performed, wherein
the cast steel comprises a chemical composition containing (consisting of), in mass%,

C: 0.10 % or more and 2.50 % or less,
Mn: 8.0 % or more and 45.0 % or less,
P: 0.300 % or less,
S: 0.1000 % or less,
Ti: 0.10 % or more and 5.00 % or less,
Al: 0.001 % or more and 5.000 % or less,
N: 0.5000 % or less, and
O (oxygen): 0.1000 % or less, where
C, Ti, and Mn are contained in ranges satisfying the following expression (1),

$$25([C] - 12.01[Ti]/47.87) + [Mn] \geq 25 \qquad (1)$$

where [C], [Ti] and [Mn] are a content of each element in mass%,
with the balance consisting of Fe and inevitable impurities,

a heating temperature in the heating process is 950°C or higher and 1300 °C or lower, and
the steel material is cooled at an average cooling rate of more than 1 °C/s in a temperature range of 900°C to 500 °C in the cooling process.

(5) The method of producing a steel material according to (4), wherein the cast steel further comprises, in mass%, in addition to the chemical composition, at least one selected from the group consisting of
Si: 0.01 % or more and 5.00 % or less,
Cu: 0.1 % or more and 10.0 % or less,
Ni: 0.1 % or more and 25.0 % or less,
Cr: 0.1 % or more and 30.0 % or less,
Mo: 0.1 % or more and 10.0 % or less,
Nb: 0.005 % or more and 2.000 % or less,
V: 0.01 % or more and 2.00 % or less,
W: 0.01 % or more and 2.00 % or less,
B: 0.0003 % or more and 0.1000 % or less,
Ca: 0.0003 % or more and 0.1000 % or less,
Mg: 0.0001 % or more and 0.1000 % or less, and
REM: 0.0005 % or more and 0.1000 % or less.

(6) The method of producing a steel material according to (4) or (5), wherein the hot rolling has a total rolling reduction of 25 % or more in a temperature range of 950 °C or lower.

(Advantageous Effect)

[0012] According to the present disclosure, it is possible to provide an austenitic steel material excellent in wear resistance that has both excellent sliding wear resistance and excellent impact wear resistance, which has remarkable effects in industry. Further, the present disclosure also has an effect of extending the life of industrial machinery, transportation machinery and the like working in various wear environments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] In the accompanying drawings:

FIG. 1 schematically illustrates an outline of a wear test apparatus used in Examples; and
FIG. 2 schematically illustrates an outline of a wear test apparatus used in Examples

DETAILED DESCRIPTION

[0014] The austenitic steel material of the present disclosure has a chemical composition containing, in mass%, C: 0.10 % or more and 2.50 % or less, Mn: 8.0 % or more and 45.0 % or less, P: 0.300 % or less, S: 0.1000 % or less, Ti: 0.10 % or more and 5.00 % or less, Al: 0.001 % or more and 5.000 % or less, N: 0.5000 % or less, O (oxygen): 0.1000 % or less, where C, Ti, and Mn are contained in ranges that satisfy a relation of the following expression (1),

$$25([C] - 12.01[Ti]/47.87) + [Mn] \geq 25 \qquad (1)$$

where [C], [Ti] and [Mn] are a content of each element in mass%,
with the balance consisting of Fe and inevitable impurities.

[0015] First, the reasons for limiting the chemical composition of the steel material will be described. Note that in the following description, "mass%" in the chemical composition is simply indicated as "%" unless otherwise specified.

C: 0.10 % or more and 2.50 % or less

[0016] C is an element that stabilizes an austenite phase and is an important element for obtaining an austenite microstructure at normal temperature. To obtain the effect, the C content should be 0.10 % or more. If the C content is less than 0.10 %, the stability of the austenite phase is insufficient, and a sufficient austenite microstructure cannot be obtained at normal temperature. On the other hand, if the C content exceeds 2.50 %, the hardness is increased, and the toughness of a welded portion is deteriorated. Therefore, in the present disclosure, the C content is limited to the range of 0.10 % or more and 2.50 % or less. It is preferably 0.12 % or more and 2.00 % or less.

Mn: 8.0 % or more and 45.0 % or less

[0017] Mn is an element that stabilizes an austenite phase and is an important element for obtaining an austenite microstructure at normal temperature. To obtain the effect, the Mn content should be 8.0 % or more. If the Mn content is less than 8.0 %, the stability of the austenite phase is insufficient, and a sufficient austenite microstructure cannot be obtained. On the other hand, if the Mn content exceeds 45.0 %, the effect of stabilizing the austenite phase is saturated, which is economically disadvantageous. Therefore, in the present disclosure, the Mn content is limited to the range of 8.0 % or more and 45.0 % or less. It is preferably 10.0 % or more and 40.0 % or less.

P: 0.300 % or less

[0018] P is an element that segregates at grain boundaries, embrittles the grain boundaries, and deteriorates the toughness of the steel material. In the present disclosure, it is desirable to have a P content as low as possible, yet an amount of 0.300 % or less is acceptable. It is preferably 0.250 % or less. Although P is an element inevitably contained in the steel as an impurity whose content is preferably as low as possible, excessively reduction of P content leads to a rise in refining time and refining cost. Therefore, the P content is preferably 0.001 % or more.

S: 0.1000 % or less

[0019] S is an element that disperses in the steel mainly as a sulfide-based inclusion and deteriorates the ductility and toughness of the steel. Therefore, in the present disclosure, it is desirable to have a S content as low as possible, yet an amount of 0.1000 % or less is acceptable. It is preferably 0.0800 % or less. Although the S content is preferably as low as possible, excessively reduction of S content leads to a rise in refining time and refining cost. Therefore, the S content is preferably 0.0001 % or more.

Ti: 0.10 % or more and 5.00 % or less

[0020] Ti is an important element in the present disclosure, which forms a hard carbide to improve the sliding wear resistance of an austenite microstructure. To obtain the effect, the Ti content should be 0.10 % or more. On the other hand, if the Ti content exceeds 5.00 %, the ductility and the toughness are deteriorated. Therefore, the Ti content is limited to the range of 0.10 % or more and 5.00 % or less. It is preferably 0.60 % or more and 4.50 % or less.

Al: 0.001 % or more and 5.000 % or less

[0021] Al is an element that effectively acts as a deoxidizer. To obtain the effect, the Al content should be 0.001 % or more. On the other hand, if the Al content exceeds 5.000 %, the cleanliness of the steel is reduced, and the ductility and the toughness are deteriorated. Therefore, the Al content is set to 0.001 % or more and 5.000 % or less. It is preferably 0.003 % or more and 4.500 % or less.

N: 0.5000 % or less

[0022] N is an element inevitably contained in the steel as an impurity, which deteriorates the ductility and toughness of a welded portion. It is desirable to have a N content as low as possible, yet an amount of 0.5000 % or less is acceptable. It is preferably 0.3000 % or less. Although the N content is preferably as low as possible, excessively reduction of N content leads to a rise in refining time and refining cost. Therefore, the N content is preferably 0.0005 % or more.

O (oxygen): 0.1000 % or less

[0023] O is an element inevitably contained in the steel as an impurity, which exists in the steel as an inclusion such as an oxide and deteriorates the ductility and the toughness. It is desirable to have an O content as low as possible, yet an amount of 0.1000 % or less is acceptable. It is preferably 0.0500 % or less. Although the O content is preferably as low as possible, excessively reduction of O content leads to a rise in refining time and refining cost. Therefore, the O content is preferably 0.0005 % or more.

[0024] In the present disclosure, C, Ti, and Mn are contained within the above ranges respectively and satisfy a relation of the following expression (1),

$$25([C] - 12.01[Ti]/47.87) + [Mn] \geq 25 \qquad (1)$$

where [C], [Ti] and [Mn] are the content of each element in mass%.

[0025] The left side of the expression (1) represents the degree of stabilization of the austenite phase, and the larger the value of the left side is, the higher the degree of stabilization of the austenite phase is. The left side of the expression (1) is obtained by multiplying the sum of the contents of C and Mn, which are elements contributing to the stabilization of the austenite phase, by a coefficient of austenite stabilizing ability in consideration of the austenite stabilizing ability of each element. Note that the C content is an effective content obtained by subtracting the amount of C that precipitates as Ti carbides and does not contribute to the stabilization of the austenite phase.

[0026] If the C, Ti, and Mn contents do not satisfy the expression (1), the austenite stability is insufficient, and a desired austenite microstructure cannot be obtained at normal temperature.

[0027] Further, from the viewpoint of the degree of stabilization of the austenite phase, the value of the left side of the expression (1) is preferably 30 or more.

[0028] The above-mentioned components are basic components in the present disclosure. In addition to these basic components, the present disclosure may further contain, as selective components if necessary, at least one selected from the group consisting of Si: 0.01 % or more and 5.00 % or less, Cu: 0.1 % or more and 10.0 % or less, Ni: 0.1 % or more and 25.0 % or less, Cr: 0.1 % or more and 30.0 % or less, Mo: 0.1 % or more and 10.0 % or less, Nb: 0.005 % or more and 2.000 % or less, V: 0.01 % or more and 2.00 % or less, W: 0.01 % or more and 2.00 % or less, B: 0.0003 % or more and 0.1000 % or less, Ca: 0.0003 % or more and 0.1000 % or less, Mg: 0.0001 % or more and 0.1000 % or less, and REM: 0.0005 % or more and 0.1000 % or less.

[0029] All of Si, Cu, Ni, Cr, Mo, Nb, V, W, B, as well as Ca, Mg, and REM are elements that improve the strength of the steel material (the strength of base metal and the strength of a welded portion), and at least one of them may be selected and contained if necessary.

Si: 0.01 % or more and 5.00 % or less

[0030] Si is an element that effectively acts as a deoxidizer and contributes to increasing the hardness of the steel material through solid solution. To obtain the effect, the Si content should be 0.01 % or more. If the Si content is less than 0.01 %, the above-mentioned effect cannot be sufficiently obtained. On the other hand, a content exceeding 5.00 % causes problems such as deterioration of ductility and toughness and an increase in the amount of inclusion. Therefore, when it is contained, the Si content is preferably in the range of 0.01 % or more and 5.00 % or less and more preferably in the range of 0.05 % or more and 4.50 % or less.

Cu: 0.1 % or more and 10.0 % or less

[0031] Cu is an element that dissolves or precipitates to contribute to improving the strength of the steel material. To obtain the effect, the Cu content should be 0.1 % or more. On the other hand, if the Cu content exceeds 10.0 %, the effect is saturated, which is economically disadvantageous. Therefore, when it is contained, the Cu content is preferably in the range of 0.1 % or more and 10.0 % or less and more preferably 0.5 % or more and 8.0 % or less.

Ni: 0.1 % or more and 25.0 % or less

[0032] Ni is an element that contributes to improving the strength of the steel material and improves the toughness. To obtain the effect, the Ni content should be 0.1 % or more. On the other hand, if the Ni content exceeds 25.0 %, the effect is saturated, which is economically disadvantageous. Therefore, when it is contained, the Ni content is preferably in the range of 0.1 % or more and 25.0 % or less and more preferably 0.5 % or more and 20.0 % or less.

Cr: 0.1 % or more and 30.0 % or less

[0033] Cr is an element that contributes to improving the strength of the steel. To obtain the effect, the Cr content should be 0.1 % or more. On the other hand, if the Cr content exceeds 30.0 %, the effect is saturated, which is economically disadvantageous. Therefore, when it is contained, the Cr content is preferably in the range of 0.1 % or more and 30.0 % or less and more preferably 0.5 % or more and 28.0 % or less.

Mo: 0.1 % or more and 10.0 % or less

[0034] Mo is an element that contributes to improving the strength of the steel. To obtain the effect, the Mo content should be 0.1 % or more. On the other hand, if the Mo content exceeds 10.0 %, the effect is saturated, which is economically disadvantageous. Therefore, when it is contained, the Mo content is preferably in the range of 0.1 % or more and 10.0 % or less and more preferably 0.5 % or more and 8.0 % or less.

Nb: 0.005 % or more and 2.000 % or less

[0035] Nb is an element that precipitates as carbonitrides to contribute to improving the strength of the steel. To obtain the effect, the Nb content should be 0.005 % or more. On the other hand, if the Nb content exceeds 2.000 %, the toughness is deteriorated. Therefore, when it is contained, the Nb content is preferably in the range of 0.005 % or more and 2.000 % or less and more preferably 0.007 % or more and 1.700 % or less.

V: 0.01 % or more and 2.00 % or less

[0036] V is an element that precipitates as carbonitrides to contribute to improving the strength of the steel. To obtain the effect, the V content should be 0.01 % or more. On the other hand, if the V content exceeds 2.00 %, the toughness is deteriorated. Therefore, when it is contained, the V content is preferably in the range of 0.01 % or more and 2.00 % or less and more preferably 0.02 % or more and 1.80 % or less.

W: 0.01 % or more and 2.00 % or less

[0037] W is an element that contributes to improving the strength of the steel. To obtain the effect, the W content should be 0.01 % or more. On the other hand, if the W content exceeds 2.00 %, the toughness is deteriorated. Therefore, when it is contained, the W content is preferably in the range of 0.01 % or more and 2.00 % or less and more preferably 0.02 % or more and 1.80 % or less.

B: 0.0003 % or more and 0.1000 % or less

[0038] B is an element that segregates at grain boundaries and contributes to improving the strength of the grain boundaries. To obtain the effect, the B content should be 0.0003 % or more. On the other hand, if the B content exceeds 0.1000 %, the toughness is deteriorated due to precipitation of carbonitrides at the grain boundaries. Therefore, when it is contained, the B content is preferably in the range of 0.0003 % to 0.1000 % and more preferably 0.0005 % or more and 0.0800 % or less.

Ca: 0.0003 % or more and 0.1000 % or less

[0039] Ca forms oxysulfides that are highly stable at high temperatures to pin grain boundaries, and particularly suppresses the coarsening of crystal grains in a welded portion and keeps the crystal grains fine to contribute to improving the strength and toughness of a weld joint. To obtain the effect, the Ca content should be 0.0003 % or more. On the other hand, if the Ca content exceeds 0.1000 %, the cleanliness is reduced, and the toughness of the steel is deteriorated. Therefore, when it is contained, the Ca content is preferably in the range of 0.0003 % or more and 0.1000 % or less and more preferably 0.0005 % or more and 0.0800 % or less.

Mg: 0.0001 % or more and 0.1000 % or less

[0040] Mg forms oxysulfides that are highly stable at high temperatures to pin grain boundaries, and particularly suppresses the coarsening of crystal grains in a welded portion and keeps the crystal grains fine to contribute to improving the strength and toughness of a weld joint. To obtain the effect, the Mg content should be 0.0001 % or more. On the other hand, if the Mg content exceeds 0.1000 %, the cleanliness is reduced, and the toughness of the steel is deteriorated. Therefore, when it is contained, the Mg content is preferably in the range of 0.0001 % or more and 0.1000 % or less and more preferably 0.0005 % or more and 0.0800 % or less.

REM: 0.0005 % or more and 0.1000 % or less

[0041] REM (rare earth metal) forms oxysulfides that are highly stable at high temperatures to pin grain boundaries, and particularly suppresses the coarsening of crystal grains in a welded portion and keeps the crystal grains fine to contribute to improving the strength and toughness of a weld joint. To obtain the effect, the REM content should be 0.0005 % or more. On the other hand, if the REM content exceeds 0.1000 %, the cleanliness is reduced, and the toughness of the steel material is deteriorated. Therefore, when it is contained, the REM content is preferably in the range of 0.0005 % or more and 0.1000 % or less and more preferably in the range of 0.0010 % or more and 0.0800 % or less.

[0042] The balance other than the above-mentioned components consist of Fe and inevitable impurities.

[0043] The austenitic steel material of the present disclosure has the chemical composition described above, and further has a microstructure containing 90 % or more of an austenite phase and 0.2 % or more of Ti carbides in area ratio.

Austenite phase in the microstructure: 90 % or more

[0044] The microstructure of the steel material of the present disclosure is mainly an austenite phase from the viewpoint of improving the impact wear resistance. To obtain the effect, the austenite phase is set to 90 % or more in area ratio. If the austenite phase is less than 90 % in area ratio, the impact wear resistance is deteriorated, and further, the ductility, toughness, workability, and the toughness of a welded portion (heat-affected zone) are also deteriorated. Therefore, the austenite phase in the microstructure is 90 % or more and may be 100 % in area ratio. As used herein, the ratio of "austenite phase in the microstructure" means a ratio (area ratio) of the austenite phase to a total of the microstructure excluding inclusions and precipitates. The microstructure other than the austenite phase may be one or more of a ferrite phase, a bainite microstructure, a martensite microstructure and a pearlite microstructure having a total area ratio of less than 10 %.

[0045] The area ratio of the austenite phase in the microstructure is determined by performing electron back scattering pattern (EBSP) analysis to obtain an inverse pole figure map and calculating the ratio of the austenite phase to the total of the microstructure excluding inclusions and precipitates (the total of ferrite phase, bainite microstructure, martensite microstructure, pearlite microstructure, and austenite phase) from the obtained inverse pole figure map. As used herein, the "ratio of the austenite phase" is a value measured at a position of a depth of 1 mm below a surface of the steel material.

[0046] To further improve the wear resistance, especially the impact wear resistance, it is preferable to maintain the hardness of the matrix (austenite phase), that is, the hardness of the austenite phase itself high. When the hardness, especially the Vickers hardness, of the austenite phase is 200 HV or more, a remarkable improvement in impact wear resistance is observed. When the hardness of the austenite phase is less than 200 HV, there is little improvement in

impact wear resistance. Therefore, from the viewpoint of improving the impact wear resistance, the hardness of the austenite phase is preferably 200 HV or more and more preferably 250 HV or more. In addition, it is preferably 400 HV or less and more preferably 380 HV or less to ensure ductility.

Ti carbide: 0.2 % or more

[0047] In the present disclosure, the microstructure contains Ti carbides that are particles harder than sand and rock components such as Al_2O_3 and SiO_2. The Ti carbides contained in the microstructure are hard particles, which have a resistance to sliding wear caused by sand and rock components, thereby improving the sliding wear resistance. To obtain the effect, the Ti carbides should be contained in the microstructure in an area ratio of 0.2 % or more. Therefore, the content of the Ti carbides is limited to 0.2 % or more in area ratio. It is preferably 0.5 % or more. The upper limit of the content of the Ti carbides is not particularly limited, yet it is preferably 10 % or less in area ratio from the viewpoint of the ductility and toughness of the steel material. It is more preferably 8.0 % or less.

[0048] In the present disclosure, the Ti carbides are identified using energy-dispersive X-ray spectroscopy (EDS) of a scanning electron microscope (SEM), the total area of the Ti carbides is measured using image analysis software, and the area ratio of the Ti carbides is calculated. During the measurement of EDS, precipitates containing 10 at% or more of Ti and 30 at% or more of C in atomic fraction are counted as Ti carbides. As used herein, the "content of the Ti carbides" is a value measured at a position of a depth of 1 mm below a surface of the steel material.

[0049] Next, a preferred method of producing a steel material having the above-mentioned chemical composition and microstructure will be described.

[0050] In a preferred method of producing a steel material of the present disclosure, molten steel is first smelted in a common melting furnace such as an electric heating furnace or a vacuum melting furnace, and then a casting process in which the molten steel is cast to obtain cast steel and a heating process in which the cast steel is heated are performed in the stated order. Subsequently, a hot rolling process in which the heated cast steel is subjected to hot rolling (hot working) to obtain a steel material, and, after the hot rolling process, a cooling process in which the obtained steel material is cooled are performed. Examples of the steel material obtained by these processes include a plate-shaped steel sheet, a rod-shaped steel bar, a linear wire rod, and shaped steel having various cross-sectional shapes such as H shape.

[0051] In the preferred production method of the present disclosure, a casting process is first performed, in which molten steel smelted in a common melting furnace such as an electric heating furnace or a vacuum melting furnace is cast to obtain cast steel having the predetermined chemical composition described above.

[0052] The cooling rate during casting is usually very slow, so that C contained in the steel may precipitate as carbides other than Ti carbides during the casting. When the C contained in the steel is precipitated as carbides other than Ti carbides, the stability of the austenite phase is lowered. As a result, it is difficult to stably form an austenite phase after the steel is cooled to normal temperature.

[0053] Therefore, the present disclosure includes a heating process in which the cast steel having the chemical composition described above is heated.

[0054] As used herein, the temperature of "heating", that is, the "heating temperature" refers to a temperature range of 950°C or higher and 1300 °C or lower, which is a temperature range in which carbides other than Ti carbides dissolve. The Ti carbides are formed during the cooling after the molten steel is solidified, and its dissolving temperature is very high, close to the melting point of the steel. Therefore, in the process in which the steel is heated to the above temperature range, the Ti carbides remain rather than dissolve, and carbides other than the Ti carbides dissolve.

[0055] If the heating temperature is lower than 950°C, the carbides precipitated during the casting do not dissolve. Therefore, the amount of dissolved C is insufficient, the stability of the austenite phase is low, and an austenite phase cannot be obtained after the steel is cooled to room temperature. On the other hand, if the heating temperature exceeds 1300 °C, the heating temperature is too high, and the cost for heating increases, which is economically disadvantageous. Therefore, the heating temperature is limited to a temperature in the range of 950°C or higher and 1300 °C or lower. It is preferably 980°C or higher and 1270 °C or lower. The above-mentioned temperature is a temperature at a position 1 mm below a surface of the steel material.

[0056] Subsequently, a hot rolling process is performed, in which the heated cast steel is subjected to hot rolling (hot working) to obtain a steel material having a predetermined shape.

[0057] In the present disclosure, the rolling (working) conditions such as temperature and rolling reduction are not particularly limited as long as a steel material having a desired size and shape can be obtained after the rolling (working). To further improve the wear resistance, especially the impact wear resistance of the steel material, it is necessary to increase the hardness of the austenite phase, which is the matrix. In this case, it is preferable to perform the hot rolling under conditions of a total rolling reduction of 25 % or more in a temperature range of 950°C or lower.

[0058] The total rolling reduction r in the temperature range of 950°C or lower can be calculated by the following expression.

$$r\ (\%) = \{(ti - tf) / ti\} \times 100$$

(where "ti" is the sheet thickness (mm) when the temperature of the steel sheet reaches 950 °C during the rolling, and "tf" is the sheet thickness (mm) at the end of the rolling, hereinafter the "sheet thickness" means both sheet thickness and plate thickness.)

[0059] When the hot rolling is performed under the conditions of a total rolling reduction of 25 % or more in a temperature range of 950 °C or lower, the hardness of the austenite phase is as high as 200 HV or more, and the wear resistance, especially the impact wear resistance is improved. If the total rolling reduction in a temperature range of 950 °C or lower is less than 25 %, the hardness of the austenite phase cannot be improved sufficiently. The total rolling reduction is preferably 30 % or more. Further, the total rolling reduction is preferably 80 % or less and more preferably 70 % or less in consideration of rolling efficiency. Dislocations introduced under pressure in a temperature range exceeding 950 °C are consumed by recrystallization of the austenite phase, which contributes little to the improvement of the hardness of the austenite phase. From this point of view, the rolling finish temperature is preferably 930°C or lower. Further, the rolling finish temperature is preferably 600 °C or higher and more preferably 650°C or higher in consideration of operating efficiency.

[0060] Following the process of subjecting the heated cast steel to hot rolling, a cooling process is performed, in which the steel is cooled at an average cooling rate of more than 1 °C/s in a temperature range of 900°C or lower and 500 °C or higher.

[0061] In the cooling process, the average cooling rate between 900°C and 500 °C is adjusted to more than 1 °C/s. When the average cooling rate between 900°C and 500 °C is 1 °C/s or less, carbides are precipitated, the amount of dissolved C is reduced, and the stability of austenite is insufficient. As a result, a desired austenite phase cannot be obtained after the cooling. Therefore, during the cooling, the average cooling rate in the temperature range of 900°C to 500 °C is set to more than 1 °C/s. It is preferably 2 °C/s or more. The cooling method may be any common cooling method with which the above-mentioned cooling rate can be achieved.

[0062] Although the upper limit of the average cooling rate is not particularly limited, expensive cooling equipment is required for realizing rapid cooling at an average cooling rate of more than 300 °C/s. Therefore, the average cooling rate between 900°C and 500 °C during the cooling is preferably 300 °C/s or less and more preferably 200 °C/s or less. The above-mentioned temperature is a temperature at a position 1 mm below a surface of the steel material.

[0063] The following further describes the present disclosure based on Examples.

EXAMPLES

(Example 1)

[0064] First, molten steel was smelted and cast in a vacuum melting furnace to obtained cast steel (thickness: 100 mm to 200 mm) having the chemical composition listed in Table 1. Next, the obtained cast steel was subjected to a heating process in which the cast steel was heated to the heating temperature listed in Table 2, a hot rolling process in which the heated cast steel was subjected to hot rolling under the conditions listed in Table 2 to obtain a steel sheet (steel material) having the sheet thickness listed in Table 2, and then a cooling process in which the obtained steel sheet was cooled from 900 °C to 500 °C at an average cooling rate listed in Table 2, in the stated order to obtain a steel material (steel sheet). Hot rolling for some of the steel material Nos. was performed with adjusting the rolling reduction (cumulative rolling reduction) in a temperature range of 950 °C or lower.

[0065] In the cooling process after the hot rolling process, the cooling may be water cooling, air cooling, or a combination thereof. The average cooling rate was calculated based on a temperature measured by a thermocouple attached at a position 1 mm below a surface of the steel sheet. When the cooling start temperature was lower than 900 °C, the average cooling rate was calculated between the cooling start temperature and 500 °C.

[0066] The obtained steel sheet was subjected to a hardness measurement test, microstructure observation, and a wear test to determine the hardness of austenite phase, the area ratio of austenite phase, and the area ratio of Ti carbides 1 mm below the surface. In addition, the sliding wear resistance and the impact wear resistance were evaluated. The testing methods were as follows.

(1) Hardness measurement test

[0067] A test piece for hardness measurement was collected from a predetermined position of each of the obtained steel sheets, and the test piece was polished so that a cross section in the sheet thickness direction was the measurement surface. Then, the Vickers hardness HV of austenite phase at ten positions 1 mm below the surface was measured respectively with a Vickers hardness meter (test force: 10 kgf), and an average value was taken as the hardness of the

steel sheet. If there was no austenite phase, the hardness was not measured.

(2) Microstructure observation

[0068] A test piece for microstructure observation was collected from a predetermined position of each of the obtained steel sheets so that the observation surface was located 1 mm below the surface, and the observation surface was ground and polished (to a mirror plane).

(2-1) Area ratio of austenite phase

[0069] Electron back scattering pattern (EBSP) analysis was performed on the mirror-polished observation surface using the collected test piece for microstructure observation. The EBSP analysis was performed in an area of 1 mm × 1 mm under conditions of measurement voltage: 20 kV and step size: 1 μm, and the ratio (area ratio) of the austenite phase to the total of the microstructure excluding inclusions and precipitates (the total of ferrite phase, bainite microstructure, martensite microstructure, pearlite microstructure, and austenite phase) was calculated from the obtained inverse pole figure map.

(2-2) Area ratio of Ti carbide

[0070] Using the collected test piece for microstructure observation, the mirror-polished observation surface was analyzed in an area of 1 mm × 1 mm under conditions of accelerating voltage: 15 kV and step size: 1 μm by energy-dispersive X-ray spectroscopy (EDS) of a scanning electron microscope (SEM), Ti carbides were identified, the total area of the Ti carbides was measured using image analysis software, and the area ratio of the Ti carbides was calculated. During the measurement of EDS, precipitates containing 10 at% or more of Ti and 30 at% or more of C in atomic fraction were counted as Ti carbides.

(3) Wear test

[0071] The wear resistance of a steel material is mainly determined by the surface characteristics. A wear test piece 10 (thickness 10 mm × width 25 mm × length 75 mm) was collected so that a position 1 mm below the surface of the obtained steel sheet was the test position (test surface). When the thickness of the steel sheet was more than 10 mm, the thickness of the test piece was adjusted and reduced to 10 mm. When the thickness of the steel sheet was 10 mm or less, no thickness reduction was performed other than the adjustment of the test position (1 mm below the surface).

(3-1) Impact wear test

[0072] Three wear test pieces 10 were collected from each steel sheet, and the three test pieces 10 were simultaneously mounted on the wear test apparatus illustrated in FIG. 1 to perform an impact wear test. The test pieces were mounted so that the test surface collided with a wear material 2. The conditions of the wear test were as follows:

drum rotation speed: 45 rpm,
test piece rotation speed: 600 rpm.

[0073] The test was performed by replacing the wear material every 10,000 rotations of the test piece, and the test was terminated when the total number of rotations of the test piece reached 50,000. A stone containing 90 % or more of SiO_2 (equivalent circular diameter: 5 mm to 35 mm) was used as the wear material 2. The same wear test was performed on a wear test piece collected from a mild steel sheet (SS400) for comparison.

[0074] After the test, the amount of wear (the changed (decreased) amount of weight before and after the test) of each test piece was measured. An average value of the obtained amounts of wear of each test piece was used as a representative value of the amount of wear of each steel sheet.

[0075] From the obtained amount of wear, a ratio of the amount of wear of the mild steel sheet to the amount of wear of each steel sheet (test steel sheet), that is, (amount of wear of mild steel sheet)/(amount of wear of each steel sheet (test steel sheet)) was calculated as an impact wear resistance ratio. The larger the impact wear resistance ratio is, the better the impact wear resistance of each steel sheet is. As used herein, a steel material having an impact wear resistance ratio of 1.7 or more was evaluated as having excellent impact wear resistance, that is, passing, and other steel materials were evaluated as failing.

(3-2) Sliding wear test

[0076] The wear test piece 10 collected from each steel sheet was mounted on the wear test apparatus illustrated in FIG. 2, and a sliding wear test was performed in accordance with the regulations of AMTM G-65. The wear test was performed on three wear test pieces of each steel sheet. Sand containing 90 % or more of SiO_2 (equivalent circular diameter: 210 μm to 300 μm) was used as the wear material. The same wear test was performed on a wear test piece collected from a mild steel sheet (SS400) for comparison. The test conditions were as follows:

flow rate of wear material (sand): 300 g/min,
rotation speed of rubber wheel: 200 rpm ± 10 rpm,
load: 130 N ± 3.9 N.

[0077] The test was terminated when the number of rotations of the rubber wheel reached 2000.

[0078] After the test, the amount of wear (the changed (decreased) amount of weight before and after the test) of each test piece was measured. An average value of the obtained amounts of wear of each test piece was used as a representative value of the amount of wear of each steel sheet.

[0079] From the obtained amount of wear, a ratio of the amount of wear of the mild steel sheet to the amount of wear of each steel sheet (test steel sheet), that is, (amount of wear of mild steel sheet)/(amount of wear of each steel sheet (test steel sheet)) was calculated as a sliding wear resistance ratio. The larger the sliding wear resistance ratio is, the better the sliding wear resistance of each steel sheet is. As used herein, a steel material having a sliding wear resistance ratio of 3.0 or more was evaluated as having excellent sliding wear resistance, that is, passing, and other steel materials were evaluated as failing.

[0080] The results are listed in Table 2.

Table 1

Steel sample ID	Chemical composition (mass%)									Expression (1)*	Remarks
	C	Mn	P	S	Ti	Al	N	O	Si,Cu,Ni,Cr,Mo,Nb,V,W,B,Ca,Mg,REM	Value of left side	
A	0.14	27.6	0.012	0.0174	0.34	0.015	0.0118	0.0035	-	29	Conforming example
B	2.25	43.8	0.255	0.0015	2.24	0.042	0.0085	0.0018	-	86	Conforming example
C	1.54	32.7	0.036	0.0521	1.29	4.360	0.1250	0.0632	-	63	Conforming example
D	1.21	10.0	0.016	0.0085	0.89	0.151	0.0078	0.0051	-	35	Conforming example
E	1.62	18.4	0.041	0.0152	4.10	0.176	0.0045	0.0021	-	33	Conforming example
F	0.92	25.4	0.022	0.0317	0.18	2.384	0.0022	0.0148	-	47	Conforming example
G	2.36	39.8	0.018	0.065	1.18	0.035	0.4051	0.0050	-	91	Conforming example
H	0.28	33.5	0.151	0.0052	0.51	0.069	0.0345	0.0105	-	37	Conforming example
I	1.02	14.2	0.026	0.0304	1.04	0.604	0.0056	0.0029	Si:0.28	33	Conforming example
J	1.61	36.4	0.002	0.0015	0.66	0.025	0.0098	0.0013	Si:4.15	73	Conforming example
K	0.67	26.8	0.011	0.0026	0.38	1.002	0.0056	0.0105	Cu:0.8	41	Conforming example
L	2.34	40.3	0.054	0.0105	3.84	0.062	0.0013	0.0052	Cu:6.3	75	Conforming example
M	1.84	30.5	0.031	0.0015	2.58	0.018	0.0051	0.0026	Ni:0. 7	60	Conforming example
N	1.35	13.8	0.009	0.0006	0.60	0.028	0.0028	0.0008	Ni:23.5	44	Conforming example
O	0.58	28.4	0.006	0.0015	1.49	2.135	0.0246	0.0051	Cr:0.4	34	Conforming example
P	2.18	36.8	0.178	0.0231	3.65	0.038	0.3642	0.0029	Cr:22.8	68	Conforming example
Q	1.94	36.1	0.035	0.0264	0.96	0.084	0.0152	0.0036	Mo:2.5	79	Conforming example
R	2.01	30.6	0.028	0.0008	0.46	0.031	0.0512	0.0084	Nb:0.036	78	Conforming example
S	1.51	16.8	0.005	0.0141	0.29	0.054	0.0079	0.0025	Nb:1.684	53	Conforming example
T	1.07	24.5	0.015	0.0028	0.75	0.019	0.0028	0.0084	V:0.06	47	Conforming example
U	0.75	31.5	0.163	0.0084	1.36	0.028	0.0270	0.0152	V:1.83	42	Conforming example
V	2.17	40.6	0.011	0.0018	1.82	0.108	0.0052	0.0037	W:0.3 5	83	Conforming example
W	1.50	18.8	0.029	0.0036	0.56	0.040	0.0028	0.0162	W:1.56	53	Conforming example
X	0.46	37.1	0.115	0.0124	0.38	0.081	0.0362	0.0085	B:0.0052	46	Conforming example

(continued)

Steel sample ID	Chemical composition (mass%)									Expression (1)*	Remarks
	C	Mn	P	S	Ti	Al	N	O	Si,Cu,Ni,Cr,Mo,Nb,V,W,B,Ca,Mg,REM	Value of left side	
Y	1.74	26.5	0.028	0.0051	2.15	0.225	0.0040	0.0018	Ca:0.0061	57	Conforming example
Z	1.15	25.0	0.015	0.0024	1.16	0.033	0.0061	0.0054	Mg:0.0038	46	Conforming example
AA	2.02	40.4	0.009	0.0015	0.68	0.018	0.0052	0.0026	REM:0.0095	87	Conforming example
AB	1.31	34.8	0.006	0.0025	0.92	0.009	0.0150	0.0034	Si:0.85,Cu:3.5,Ni:13.2,B:0.0012	62	Conforming example
AC	0.28	26.4	0.015	0.0082	0.33	0.061	0.0254	0.0113	Ni:5.5,Cr:12.5,Mo:2.2,Ca:0.0011	31	Conforming example
AD	0.80	22.0	0.009	0.0006	1.13	0.021	0.0085	0.0009	Si:0.25,Nb:0.516,V:0.28,Mg:0.0071	35	Conforming example
AE	1.28	18.4	0.042	0.0162	0.55	0.105	0.0028	0.0041	Cu:5.6,W:0.84,REM:0.0215	47	Conforming example
AF	0.06	26.3	0.015	0.0106	0.42	0.052	0.0069	0.0026	-	25	Comparative example
AG	0.95	6.50	0.026	0.0085	0.36	0.033	0.0026	0.0051	-	28	Comparative example
AH	0.16	11.2	0.029	0.0136	0.62	0.008	0.0046	0.0014	-	11	Comparative example
AI	0.04	27.5	0.009	0.0025	0.40	0.015	0.0018	0.0022	Si:0.31,Mo:0.5,Nb:0.109,Ca:0.0023	26	Comparative example
AJ	0.12	16.8	0.011	0.0012	0.84	0.038	0.0074	0.0036	Cu:1.6,Ni:2.2	15	Comparative example
AK	0.98	5.20	0.029	0.0086	0.56	0.014	0.0015	0.0040	Cr:3.5,B:0.0035,REM:0.0027	26	Comparative example
AL	0.83	23.4	0.041	0.0025	0.04	0.047	0.0051	0.0016	-	44	Comparative example
AM	1.16	16.7	0.006	0.0039	0.03	0.082	0.0027	0.0041	Si:0.49,Cu:2.5,Ni:1.5,Mg:0.0015	46	Comparative example

*) $25([C] - 12.01[Ti]/47.87) + [Mn] \geq 25$ ..... (1)

Table 2

Steel Material No.	Steel sample ID	Heating process	Hot rolling process			Cooling process		Microstructure		Hardness**	Wear resistance		Remarks
		Heating temperature (°C)	Total rolling reduction at 950°C or lower (%)	Rolling finish temperature (°C)	Sheet thickness (mm)	Cooling start temperature (°C)	Average cooling rate* (°C/s)	Area ratio of austenite phase (%)	Area ratio of Ti carbide (%)	HV	Sliding wear resistance ratio	Impact wear resistance ratio	
1	A	1210	13	935	32	919	63	95	0.9	168	4.3	1.7	Example
2	B	1080	15	930	50	915	58	99	4.6	251	8.8	2.5	Example
3	C	1020	0	952	25	933	78	99	2.9	220	6.8	2.2	Example
4	D	1260	9	943	76	931	28	98	2.3	231	5.6	2.0	Example
5	E	1150	0	961	101	953	20	98	6.8	138	12.5	2.2	Example
6	F	980	0	955	8	908	134	98	0.5	205	3.9	2.1	Example
7	G	1030	10	938	63	924	48	99	2.8	379	6.3	2.4	Example
8	H	1200	0	954	3	905	3	98	1.2	135	4.5	1.8	Example
9	I	1170	6	947	19	914	72	98	2.2	180	5.8	2.0	Example
10	J	1130	13	940	60	921	50	99	1.6	295	4.9	2.2	Example
11	K	1050	0	952	4	908	156	98	0.9	172	4.0	1.8	Example
12	L	1250	0	960	10	914	92	99	7.4	119	12.5	1.7	Example
13	M	1150	0	958	45	938	56	99	5.2	156	9.8	2.2	Example
14	N	990	18	932	80	921	41	98	1.6	293	4.8	2.1	Example
15	O	1040	0	951	19	913	73	97	3.1	139	7.2	1.8	Example
16	P	1160	12	945	90	930	38	98	6.5	302	12.6	2.3	Example
17	Q	1230	17	934	23	914	72	98	1.9	335	6.2	2.2	Example
18	R	1170	16	929	60	911	63	99	1.1	364	4.5	2.3	Example
19	S	1160	21	918	51	904	58	98	0.7	332	4.3	2.2	Example
20	T	1200	0	956	125	935	18	98	1.6	195	5.2	2.1	Example
21	U	1090	0	969	4	914	3	99	2.9	119	6.9	2.0	Example

(continued)

Steel Material No.	Steel sample ID	Heating process	Hot rolling process			Cooling process		Microstructure		Hardness**	Wear resistance		Remarks
		Heating temperature (°C)	Total rolling reduction at 950°C or lower (%)	Rolling finish temperature (°C)	Sheet thickness (mm)	Cooling start temperature (°C)	Average cooling rate* (°C/s)	Area ratio of austenite phase (%)	Area ratio of Ti carbide (%)	HV	Sliding wear resistance ratio	Impact wear resistance ratio	
22	V	1280	8	939	70	914	42	98	3.8	265	8.2	2.2	Example
23	W	1260	13	933	36	909	62	98	1.6	290	4.6	1.9	Example
24	X	1160	8	943	58	928	51	99	1.2	189	4.3	1.7	Example
25	Y	1170	6	942	115	932	22	99	4.3	178	9.5	2.3	Example
26	Z	1230	0	955	90	937	31	99	2.6	205	6.5	2.2	Example
27	AA	1180	11	937	16	903	74	99	1.9	325	5.8	2.3	Example
28	AB	1090	0	954	160	943	13	99	2.3	205	5.9	2.1	Example
29	AC	1150	0	968	80	950	35	97	1.5	146	4.2	1.8	Example
30	AD	1100	0	958	28	918	61	98	2.5	148	5.8	1.9	Example
31	AE	1070	10	936	32	915	64	99	1.6	250	4.9	2.1	Example
32	AF	1200	0	951	51	930	53	19	1.3	114	3.8	1.3	Comparative example
33	AG	1250	0	966	46	952	58	4	1.2	204	3.6	1.4	Comparative example
34	AH	1160	9	938	75	924	43	38	1.5	124	4.1	1.2	Comparative example
35	AI	1180	11	936	19	914	72	25	1.1	130	3.8	1.3	Comparative example
36	AJ	1050	0	954	26	924	71	28	2.2	118	5.0	1.3	Comparative example
37	AK	990	8	945	63	916	48	3	1.5	213	4.1	1.4	Comparative example

(continued)

Steel Material No.	Steel sample ID	Heating process	Hot rolling process			Cooling process		Microstructure		Hardness**	Wear resistance		Remarks
		Heating temperature (°C)	Total rolling reduction at 950°C or lower (%)	Rolling finish temperature (°C)	Sheet thickness (mm)	Cooling start temperature (°C)	Average cooling rate* (°C/s)	Area ratio of austenite phase (%)	Area ratio of Ti carbide (%)	HV	Sliding wear resistance ratio	Impact wear resistance ratio	
38	AL	1220	15	937	80	912	41	98	0.1	257	2.5	1.9	Comparative example
39	AM	1170	11	928	15	904	80	98	0.1	280	2.3	2.0	Comparative example
40	E	1160	0	958	85	933	1	0	6.3	-	6.9	1.2	Comparative example
41	K	1030	13	935	61	914	1	0	1.1	-	3.1	1.2	Comparative example
42	S	920	75	908	25	895	34	69	0.8	284	4.3	1.4	Comparative example
43	V	880	57	868	43	860	3	53	3.6	230	6.9	1.3	Comparative example
44	AD	1160	0	958	52	932	0.6	0	2.3	-	5.1	1.2	Comparative example
45	Y	1220	0	974	70	959	0.5	0	4.1	-	7.8	1.3	Comparative example
46	A	910	11	895	45	889	19	66	1.1	177	3.5	1.3	Comparative example

*) Average cooling rate between 900 °C and 500 °C
**) Hardness HV at a position 1 mm below the surface

[0081] All Examples (steel materials Nos. 1 to 31) have a microstructure containing 90 % or more of an austenite phase and 0.2 % or more of Ti carbides, which are steel materials (steel sheets) having both excellent sliding wear resistance and excellent impact wear resistance. On the other hand, for Comparative Examples (steel materials Nos. 32 to 45) that are outside the scope of the present disclosure, the microstructure has an austenite phase of less than 90 % or a Ti carbide content of less than 0.2 %, and at least one of the sliding wear resistance and the impact wear resistance is deteriorated.

[0082] For example, for steel materials Nos. 32 and 35 whose C content is low, the austenite stability is low, and the ratio of the austenite phase is low. As a result, the impact wear resistance is deteriorated. For steel materials Nos. 33 and 37 whose Mn content is low, the austenite stability is low, and the ratio of the austenite phase is low. As a result, the impact wear resistance is deteriorated. For steel materials Nos. 34 and 36 that do not satisfy the expression (1), the austenite stability is low, and the ratio of the austenite phase is low. As a result, the impact wear resistance is deteriorated. Further, for steel materials Nos. 38 and 39 whose Ti content is low, the sliding wear resistance is deteriorated due to a low content of Ti carbides. For steel materials Nos. 40, 41, 44, and 45 whose cooling rate after heating is low, the formation of an austenite phase is not observed, and the impact wear resistance is deteriorated. Moreover, for steel materials Nos. 42, 43, and 46 whose heating temperature is low, the ratio of the austenite phase is small. As a result, the impact wear resistance is deteriorated.

(Example 2)

[0083] Molten steel was smelted and cast in a vacuum melting furnace to obtained cast steel (thickness: 100 mm to 200 mm) having the chemical composition listed in Table 3. Next, the obtained cast steel was subjected to a heating process in which the cast steel was heated to the heating temperature listed in Table 4, a hot rolling process in which the heated cast steel was subjected to hot rolling under the conditions listed in Table 2 to obtain a steel sheet (steel material) having the thickness listed in Table 4, and then a cooling process in which the steel sheet was cooled from 900 °C to 500 °C at an average cooling rate listed in Table 4, in the stated order to obtain a steel material (steel sheet). During the hot rolling process, the rolling reduction (cumulative rolling reduction) in a temperature range of 950 °C or lower was adjusted as listed in Table 4, and the hot rolling was performed to have a rolling finish temperature listed in Table 4.

[0084] In the cooling process after the hot rolling process, the cooling may be water cooling, air cooling, or a combination thereof. The average cooling rate was calculated based on a temperature measured by a thermocouple attached at a position 1 mm below a surface of the steel sheet. When the cooling start temperature was lower than 900 °C, the average cooling rate was calculated between the cooling start temperature and 500 °C.

[0085] The obtained steel sheet was subjected to a hardness measurement test, microstructure observation, and a wear test in the same manner as in Example 1 to determine the hardness of austenite phase, the area ratio of austenite phase, and the area ratio of Ti carbides 1 mm below the surface. In addition, the sliding wear resistance and the impact wear resistance were evaluated in the same manner as in Example 1.

[0086] The results are also listed in Table 4.

Table 3

Steel sample ID	Chemical composition (mass%)									Expression (1)*	Remarks
	C	Mn	P	S	Ti	Al	N	O	Si,Cu,Ni,Cr,Mo,Nb,V,W,B,Ca,Mg,REM	Value of left side	
A1	0.13	31.5	0.009	0.0152	0.28	0.054	0.0106	0.0028	-	33	Conforming example
B1	0.74	22.6	0.212	0.0059	0.50	0.105	0.0065	0.0034	-	38	Conforming example
C1	1.30	14.8	0.027	0.0527	1.41	0.030	0.0089	0.0240	-	38	Conforming example
D1	2.29	43.4	0.051	0.0384	4.28	0.009	0.4128	0.0027	-	74	Conforming example
E1	1.82	27.1	0.016	0.0009	2.50	4.510	0.0248	0.0018	-	57	Conforming example
F1	1.57	18.5	0.072	0.0051	3.47	0.205	0.0081	0.0041	-	36	Conforming example
G1	0.49	36.5	0.154	0.0348	0.47	2.415	0.0049	0.0558	-	46	Conforming example
H1	1.57	10.8	0.002	0.0048	0.19	0.028	0.0022	0.0016	-	49	Conforming example
I1	1.62	42.8	0.041	0.0152	1.45	0.107	0.0084	0.0059	Si:0.54	74	Conforming example
J1	2.04	35.2	0.009	0.0324	0.95	1.058	0.1250	0.0025	Si:4.62	80	Conforming example
K1	0.94	13.2	0.135	0.0027	1.28	0.035	0.0028	0.0009	Cu:0.4	29	Conforming example
L1	1.52	25.5	0.014	0.0006	0.39	0.028	0.0062	0.0047	Cu:7.8	61	Conforming example
M1	1.19	12.5	0.028	0.0102	0.69	0.158	0.0028	0.0046	Ni:0.5	38	Conforming example
N1	1.71	14.0	0.009	0.0254	1.84	0.036	0.0045	0.0221	Ni:20.4	45	Conforming example
O1	1.55	23.8	0.039	0.0108	3.52	0.187	0.0105	0.0028	Cr:0.7	40	Conforming example
P1	1.94	26.3	0.048	0.0084	4.31	0.854	0.1152	0.0284	Cr:21.1	48	Conforming example
Q1	2.11	41.5	0.018	0.0015	2.45	0.036	0.0025	0.0105	Mo:4.3	79	Conforming example
R1	0.55	28.5	0.088	0.0155	1.85	0.028	0.0049	0.0062	Nb:0.025	31	Conforming example
S1	0.48	39.4	0.051	0.0084	1.17	0.086	0.0028	0.0012	Nb:1.659	44	Conforming example
T1	1.74	27.6	0.025	0.0364	0.78	0.028	0.1054	0.0085	V:0.04	66	Conforming example
U1	0.84	31.3	0.108	0.0052	0.39	2.214	0.0058	0.0051	V:1.83	50	Conforming example
V1	2.02	18.5	0.085	0.0025	0.93	0.084	0.1528	0.0052	W:0.22	63	Conforming example
W1	1.74	24.5	0.018	0.0013	0.66	0.035	0.0028	0.0025	W:1.86	64	Conforming example
X1	1.36	33.5	0.226	0.0058	0.53	0.028	0.0095	0.0624	B:0.0028	64	Conforming example

(continued)

Steel sample ID	Chemical composition (mass%)									Expression (1)*	Remarks
	C	Mn	P	S	Ti	Al	N	O	Si,Cu,Ni,Cr,Mo,Nb,V,W,B,Ca,Mg,REM	Value of left side	
Y1	1.28	17.3	0.006	0.0009	0.39	0.105	0.1238	0.0052	Ca:0.0018	47	Conforming example
Z1	0.75	22.6	0.004	0.0028	1.85	0.006	0.0085	0.0025	Mg:0.0029	30	Conforming example
AA1	1.82	28.5	0.026	0.0035	2.31	0.042	0.0028	0.0052	REM:0.0056	60	Conforming example
AB1	0.98	16.5	0.035	0.0028	0.69	0.052	0.0421	0.0022	Si:0.26,Cu:5.2,Ni:10.5,V:0.09	37	Conforming example
AC1	1.32	19.9	0.006	0.0152	0.43	0.028	0.0125	0.0063	Ni:7.5,Cr:15.3,Mg:0.0054	50	Conforming example
AD1	1.52	16.3	0.028	0.0055	1.28	0.033	0.0033	0.0023	Cu:2.8,Mo:1.8,W:0.41,REM:0.0082	46	Conforming example
AE1	1.08	25.3	0.018	0.0028	0.60	0.013	0.0028	0.0052	Nb:0.052,V:0.15,Ca:0.0031	49	Conforming example
AF1	0.04	27.6	0.009	0.0105	0.38	0.105	0.0040	0.0026	-	26	Comparative example
AG1	0.88	5.2	0.033	0.0052	0.25	0.051	0.0025	0.0016	-	26	Comparative example
AH1	0.35	13.8	0.026	0.0185	0.53	0.028	0.0045	0.0022	-	19	Comparative example
AI1	0.07	26.3	0.006	0.0028	0.31	0.036	0.0088	0.0026	Cu:1.1,W:0.15,Mg:0.0011	26	Comparative example
AJ1	0.33	14.5	0.105	0.0152	0.45	0.026	0.0025	0.0063	Si:0.35,Cr:3.3,Nb:0.012,REM:0.0025	20	Comparative example
AK1	0.95	4.6	0.013	0.0085	0.28	0.033	0.0029	0.0019	Cu:3.3,V:0.26,W:0.31,B:0.0012	27	Comparative example
AL1	1.52	11.5	0.009	0.0025	0.03	0.024	0.0062	0.0033	-	49	Comparative example
AM1	0.85	16.2	0.004	0.0023	0.02	0.031	0.0018	0.0009	Ni:3.6,Cr:1.8,V:0.05,Ca:0.0009	37	Comparative example

*)

$$25([C] - 12.01[Ti]/47.87) + [Mn] \geq 25 \ldots\ldots (1)$$

Table 4

Steel Material No.	Steel sample ID	Heating process	Hot rolling process			Cooling process		Microstructure		Hardness**	Wear resistance		Remarks
		Heating temperature (°C)	Total rolling reduction at 950 °C or lower (%)	Rolling finish temperature (°C)	Sheet thickness (mm)	Cooling start temperature (°C)	Average cooling rate* (°C/s)	Area ratio of austenite phase (%)	Area ratio of Ti carbide (%)	HV	Sliding wear resistance ratio	Impact wear resistance ratio	
51	A1	1150	52	928	51	918	53	97	0.6	275	3.7	2.1	Example
52	B1	990	68	920	13	901	87	98	1.1	374	4.5	2.6	Example
53	C1	1260	29	935	105	931	22	98	2.9	255	7.3	2.5	Example
54	D1	1130	35	925	92	917	33	99	7.9	235	13.3	2.2	Example
55	E1	1050	88	918	13	902	182	99	4.8	401	8.8	2.9	Example
56	F1	1120	65	922	19	909	75	97	6.6	256	11.5	2.3	Example
57	G1	1040	50	925	23	913	71	98	1.1	310	4.5	2.5	Example
58	HI	1210	35	940	50	931	54	98	0.4	385	3.8	2.6	Example
59	I1	1100	40	926	63	918	46	99	3	326	7.2	2.4	Example
60	J1	1080	32	938	72	931	43	99	2.3	381	5.8	2.5	Example
61	K1	1260	48	934	45	928	56	97	2.9	296	6.6	2.5	Example
62	L1	980	51	926	38	914	62	99	1.2	401	4.1	2.7	Example
63	M1	1180	70	921	20	907	74	98	1.9	389	4.8	2.8	Example
64	N1	1070	75	925	14	902	155	98	3.5	392	8.0	2.6	Example
65	O1	1150	65	928	11	905	87	98	6.5	256	13.5	2.1	Example
66	P1	1200	30	941	125	936	17	99	8.1	298	15	2.4	Example
67	Q1	1230	35	936	95	928	31	99	4.9	289	8.9	2.3	Example
68	R1	1050	80	928	6	905	123	97	3.8	302	8.1	2.5	Example
69	S1	1170	75	926	11	908	87	98	2.6	326	6.3	2.6	Example
70	T1	1220	58	930	35	912	62	99	1.9	428	5.5	2.9	Example
71	U1	1090	25	938	150	933	11	99	0.8	295	4.2	2.3	Example

(continued)

Steel Material No.	Steel sample ID	Heating process	Hot rolling process			Cooling process		Microstructure		Hardness**	Wear resistance		Remarks
		Heating temperature (°C)	Total rolling reduction at 950 °C or lower (%)	Rolling finish temperature (°C)	Sheet thickness (mm)	Cooling start temperature (°C)	Average cooling rate* (°C/s)	Area ratio of austenite phase (%)	Area ratio of Ti carbide (%)	HV	Sliding wear resistance ratio	Impact wear resistance ratio	
72	V1	1160	33	931	72	925	43	99	1.9	392	5.5	2.6	Example
73	W1	1140	40	928	48	919	52	98	1.3	401	5.1	2.7	Example
74	X1	1210	45	924	63	916	47	99	1.1	391	4.6	2.5	Example
75	Y1	1150	50	922	25	909	71	98	0.7	401	4.2	2.8	Example
76	Z1	1080	31	933	101	925	28	97	3.5	256	9.0	2.2	Example
77	AA1	1190	78	929	5	906	136	98	4.2	390	8.8	2.5	Example
78	AB1	1250	29	940	93	933	33	98	1.8	283	5.2	2.2	Example
79	AC1	1080	30	939	80	931	40	98	1.1	331	4.6	2.3	Example
80	AD1	1150	40	929	35	915	65	99	2.6	322	6.5	2.4	Example
81	AE1	1120	53	923	26	905	60	99	1.2	360	5.1	2.5	Example
82	AF1	1130	62	925	18	909	75	23	0.8	295	4.0	1.3	Comparative example
83	AG1	1250	45	928	24	919	71	5	0.6	406	3.3	1.4	Comparative example
84	AH1	1080	33	933	62	918	49	29	1.1	336	3.5	1.2	Comparative example
85	AI1	1160	40	924	30	910	64	35	0.6	326	3.1	1.3	Comparative example
86	AJ1	1200	38	935	55	923	52	39	0.9	310	3.6	1.3	Comparative example
87	AK1	1210	30	928	90	922	36	4	0.6	425	3.0	1.4	Comparative example

(continued)

Steel Material No.	Steel sample ID	Heating process	Hot rolling process			Cooling process		Microstructure		Hardness**	Wear resistance		Remarks
		Heating temperature (°C)	Total rolling reduction at 950 °C or lower (%)	Rolling finish temperature (°C)	Sheet thickness (mm)	Cooling start temperature (°C)	Average cooling rate* (°C/s)	Area ratio of austenite phase (%)	Area ratio of Ti carbide (%)	HV	Sliding wear resistance ratio	Impact wear resistance ratio	
88	AL1	1180	45	930	18	909	79	98	0.1	425	2.6	2.7	Comparative example
89	AMI	1060	62	928	21	908	74	98	0.1	396	2.5	2.5	Comparative example
90	D1	1130	59	925	50	914	1	0	8.1	-	4.8	1.2	Comparative example
91	K1	1160	43	929	33	908	1	0	2.7	-	5.3	1.3	Comparative example
92	F1	910	37	898	63	890	25	65	6.8	305	5.2	1.5	Comparative example
93	W1	890	29	870	90	862	3	58	1.1	331	4.2	1.5	Comparative example
94	AA1	1150	27	939	105	934	1	0	4.2	-	6.3	1.2	Comparative example
95	C1	1120	50	928	55	918	1	0	3	-	5.9	1.2	Comparative example
96	A1	1200	18	923	49	911	55	98	0.7	182	3.5	1.7	Example
97	G1	1080	13	925	25	909	68	98	1.2	192	4.1	1.8	Example
98	K1	1230	0	975	46	934	68	98	2.7	161	5.8	1.7	Example

*) Average cooling rate between 900 °C and 500 °C
**) Hardness HV at a position 1 mm below the surface

[0087] All Examples (steel materials Nos. 51 to 81) have a microstructure containing 90 % or more of an austenite phase and 0.2 % or more of Ti carbides, where the hardness of the austenite phase (at a position 1 mm below the surface) is 200 HV or more. All Examples are steel materials (steel sheets) having both excellent sliding wear resistance and excellent impact wear resistance. In particular, the impact wear resistance is significantly improved compared with Examples (steel materials Nos. 96 to 98) where the hardness of the austenite phase (at a position 1 mm below the surface) is less than 200 HV.

[0088] On the other hand, for Comparative Examples (steel materials Nos. 82 to 95) that are outside the scope of the present disclosure, the microstructure has an austenite phase of less than 90 % or a Ti carbide content of less than 0.2 %, and at least one of the sliding wear resistance and the impact wear resistance is deteriorated.

[0089] For example, for steel materials Nos. 82 and 85 whose C content is low, the austenite stability is low, and the ratio of the austenite phase is low. As a result, the impact wear resistance is deteriorated. For steel materials Nos. 83 and 87 whose Mn content is low, the austenite stability is low, and the ratio of the austenite phase is low. As a result, the impact wear resistance is deteriorated. For steel materials Nos. 84 and 86 that do not satisfy the expression (1), the austenite stability is low, and the ratio of the austenite phase is low. As a result, the impact wear resistance is deteriorated. Further, for steel materials Nos. 88 and 89 whose Ti content is low, the sliding wear resistance is deteriorated due to a low content of Ti carbides. For steel materials Nos. 90, 91, 94, and 95 whose cooling rate after heating is low, the formation of an austenite phase is not observed, and the impact wear resistance is deteriorated. Moreover, for steel materials Nos. 92 and 93 whose heating temperature is low, the ratio of the austenite phase is small. As a result, the impact wear resistance is deteriorated.

REFERENCE SIGNS LIST

[0090]

1 drum

2 wear material (stone)

10 wear test piece

21 rubber wheel

22 weight

23 hopper

24 wear material (sand)

Claims

1. A steel material comprising a chemical composition containing, in mass%,
C: 0.10 % or more and 2.50 % or less,
Mn: 8.0 % or more and 45.0 % or less,
P: 0.300 % or less,
S: 0.1000 % or less,
Ti: 0.10 % or more and 5.00 % or less,
Al: 0.001 % or more and 5.000 % or less,
N: 0.5000 % or less, and
O (oxygen): 0.1000 % or less, where
C, Ti, and Mn are contained in ranges satisfying the following expression (1),

$$25([C] - 12.01[Ti]/47.87) + [Mn] \geq 25 \qquad (1)$$

where [C], [Ti] and [Mn] are a content of each element in mass%,
with the balance being Fe and inevitable impurities, and
a microstructure containing 90 % or more of an austenite phase and 0.2 % or more of Ti carbides in area ratio.

2. The steel material according to claim 1, wherein the austenite phase has a Vickers hardness of 200 HV or more.

3. The steel material according to claim 1 or 2, further comprising, in mass%, in addition to the chemical composition, at least one selected from the group consisting of
Si: 0.01 % or more and 5.00 % or less,
Cu: 0.1 % or more and 10.0 % or less,
Ni: 0.1 % or more and 25.0 % or less,
Cr: 0.1 % or more and 30.0 % or less,
Mo: 0.1 % or more and 10.0 % or less,
Nb: 0.005 % or more and 2.000 % or less,
V: 0.01 % or more and 2.00 % or less,
W: 0.01 % or more and 2.00 % or less,
B: 0.0003 % or more and 0.1000 % or less,
Ca: 0.0003 % or more and 0.1000 % or less,
Mg: 0.0001 % or more and 0.1000 % or less, and
REM: 0.0005 % or more and 0.1000 % or less.

4. A method of producing a steel material, wherein a casting process in which molten steel is smelted to obtain cast steel, a heating process in which the cast steel is heated, a hot rolling process in which the heated cast steel is subjected to hot rolling to obtain a steel material, and a cooling process in which the steel material is cooled, are sequentially performed, wherein
the cast steel comprises a chemical composition containing, in mass%,
C: 0.10 % or more and 2.50 % or less,
Mn: 8.0 % or more and 45.0 % or less,
P: 0.300 % or less,
S: 0.1000 % or less,
Ti: 0.10 % or more and 5.00 % or less,
Al: 0.001 % or more and 5.000 % or less,
N: 0.5000 % or less, and
O (oxygen): 0.1000 % or less, where
C, Ti, and Mn are contained in ranges satisfying the following expression (1),

$$25([C] - 12.01[Ti]/47.87) + [Mn] \geq 25 \qquad (1)$$

where [C], [Ti] and [Mn] are a content of each element in mass%,
with the balance being Fe and inevitable impurities,
a heating temperature in the heating process is 950 °C or higher and 1300 °C or lower, and
the steel material is cooled at an average cooling rate of more than 1 °C/s in a temperature range of 900 °C to 500 °C in the cooling process.

5. The method of producing a steel material according to claim 4, wherein the cast steel further comprises, in mass%, in addition to the chemical composition, at least one selected from the group consisting of
Si: 0.01 % or more and 5.00 % or less,
Cu: 0.1 % or more and 10.0 % or less,
Ni: 0.1 % or more and 25.0 % or less,
Cr: 0.1 % or more and 30.0 % or less,
Mo: 0.1 % or more and 10.0 % or less,
Nb: 0.005 % or more and 2.000 % or less,
V: 0.01 % or more and 2.00 % or less,
W: 0.01 % or more and 2.00 % or less,
B: 0.0003 % or more and 0.1000 % or less,
Ca: 0.0003 % or more and 0.1000 % or less,
Mg: 0.0001 % or more and 0.1000 % or less, and
REM: 0.0005 % or more and 0.1000 % or less.

6. The method of producing a steel material according to claim 4 or 5, wherein the hot rolling has a total rolling reduction of 25 % or more in a temperature range of 950 °C or lower.

FIG. 1

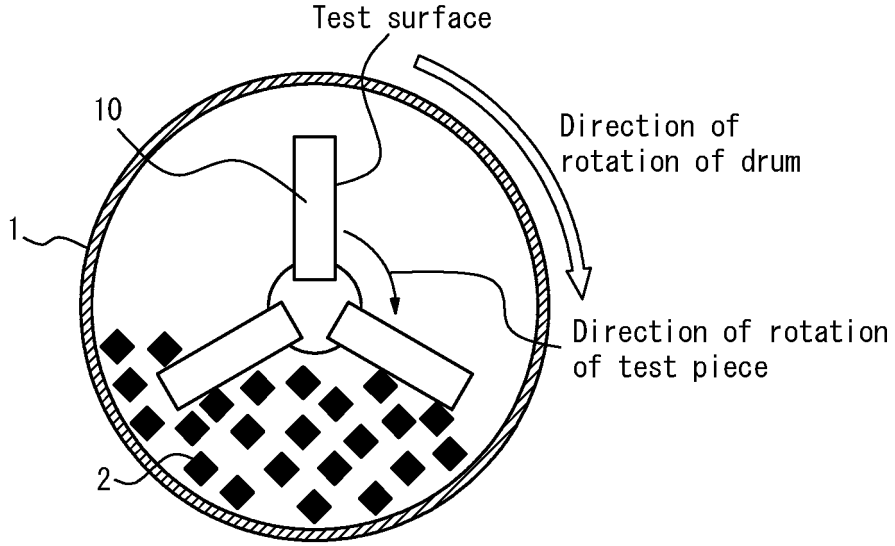
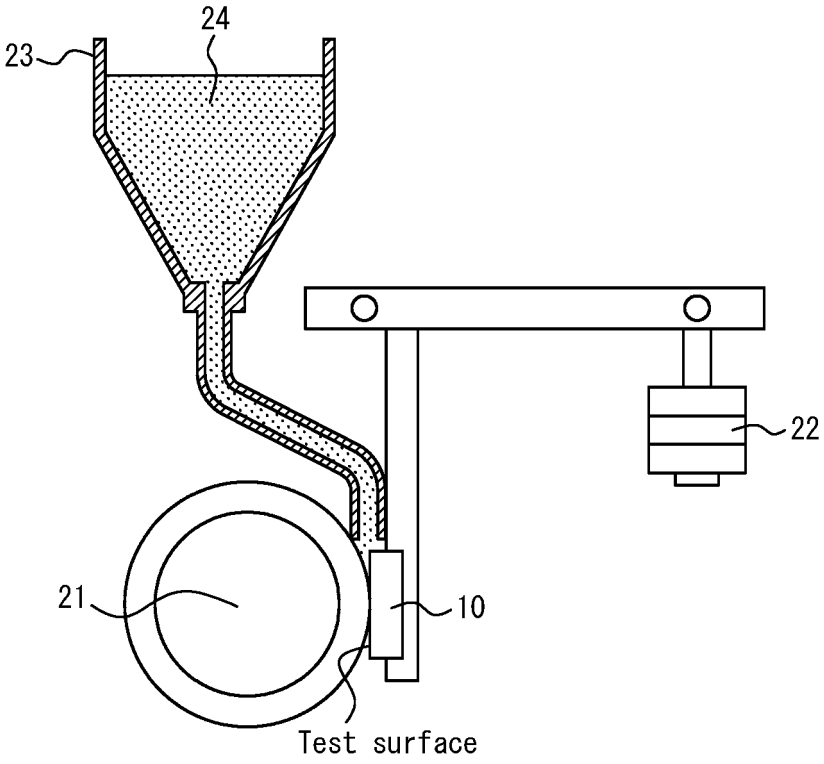

Test surface
10
Direction of
rotation of drum
1
Direction of rotation
of test piece
2

FIG. 2


24
23
22
21
10
Test surface

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2019/034830

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. C22C38/00(2006.01)i, C21D8/02(2006.01)i, C21D9/46(2006.01)i, C22C30/02(2006.01)i, C22C37/00(2006.01)i, C22C37/08(2006.01)i, C22C38/60(2006.01)i
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
Int.Cl. C22C1/00-49/14, C21D8/02, C21D9/46

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	1971-2019
Registered utility model specifications of Japan	1996-2019
Published registered utility model applications of Japan	1994-2019

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2017/169811 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 05 October 2017 & EP 3438312 A1 & CN 108884539 A	1-6
A	JP 2007-154295 A (KOBE STEEL, LTD.) 21 June 2007 (Family: none)	1-6
A	JP 62-027557 A (KOBE STEEL, LTD.) 05 February 1987 (Family: none)	1-6

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

* Special categories of cited documents:
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"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 20 November 2019 (20.11.2019)	Date of mailing of the international search report 03 December 2019 (03.12.2019)
Name and mailing address of the ISA/ Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2019/034830

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Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 105483539 A (CENTRAL IRON & STEEL RESEARCH INSTITUTE) 13 April 2016 (Family: none)	1-6

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REFERENCES CITED IN THE DESCRIPTION

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