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(54) AUSTENITIC STAINLESS STEEL

(57) An objective of the present invention is to provide an austenitic stainless steel that is excellent in polythionic acid SCC resistance and also excellent in creep ductility. An austenitic stainless steel according to the present invention includes a chemical composition consisting of, in mass%, C: 0.030% or less, Si: 0.10 to 1.00%, Mn: 0.20 to 2.00%, P: 0.040% or less, S: 0.010% or less, Cr: 16.0 to 25.0%, Ni: 10.0 to 30.0%, Mo: 0.1 to 5.0%, Nb: 0.20 to 1.00%, N: 0.050 to 0.300%, sol.Al: 0.0005 to 0.100%, and B: 0.0010 to 0.0080%, with the balance being Fe and impurities, and satisfying Formula (1):

$$B + 0.004 - 0.9C + 0.017Mo^2 \geq 0 \qquad (1)$$

where symbols of elements in Formula (1) are to be substituted by contents of corresponding elements (mass%).

EP 3 508 602 A1

Description

TECHNICAL FIELD

[0001] The present invention relates to a stainless steel, more specifically to an austenitic stainless steel.

BACKGROUND ART

[0002] Some components for plant facilities, such as a heating furnace pipe of a thermal boiler, an oil-refining and petrochemical plant, or other facilities, are used under a high-temperature corrosive environment, the temperature of which is as high as 600 to 700°C, and a corrosive fluid containing sulfide and/or chloride is contained in the environment. When such a plant facility is not operated due to a regular inspection or other reasons, air, moisture, and sulfide scale react to form polythionic acid on a surface of a component. The polythionic acid induces stress corrosion cracking in a grain boundary (hereafter, referred to as polythionic acid SCC). Accordingly, components used in the high-temperature corrosive environment described above are required to have an excellent polythionic acid SCC resistance.

[0003] A steel with an increased polythionic acid SCC resistance is proposed in Japanese Patent Application Publication No. 2003-166039 (Patent Literature 1) and International Application Publication No. WO2009/044802 (Patent Literature 2). The polythionic acid SCC occurs due to Cr precipitating in a form of an $M_{23}C_6$ carbide in a grain boundary and a resultant Cr depleted zone formed in the proximity of the grain boundary. Therefore, according to Patent Literature 1 and Patent Literature 2, the polythionic acid SCC resistance is increased by reducing an amount of C to inhibit the formation of the $M_{23}C_6$ carbide.

[0004] Specifically, an heat resistant austenitic steel disclosed in Patent Literature 1 contains, in mass%, C: 0.005 to less than 0.03%, Si: 0.05 to 0.4%, Mn: 0.5 to 2%, P: 0.01 to 0.04%, S: 0.0005 to 0.005%, Cr: 18 to 20%, Ni: 7 to 11%, Nb: 0.2 to 0.5%, V: 0.2 to 0.5%, Cu: 2 to 4%, N: 0.10 to 0.30%, and B: 0.0005 to 0.0080%, with the balance being Fe and unavoidable impurities. A total of contents of Nb and V is 0.6% or more, and a solubility of Nb in the steel is 0.15% or more. In addition, $N/14 \geq Nb/93 + V/51$ and $Cr - 16C - 0.5Nb - V \geq 17.5$ are satisfied. In Patent Literature 1, the polythionic acid SCC resistance is increased by reducing the amount of C and regulating a relation between Cr, and C, Nb, and V.

[0005] An austenitic stainless steel disclosed in Patent Literature 2 contains in mass%, C: less than 0.04%, Si: 1.5% or less, Mn: 2% or less, Cr: 15 to 25%, Ni: 6 to 30%, N: 0.02 to 0.35%, and Sol.Al: 0.03% or less, and further contains one or more elements selected from the group consisting of Nb: 0.5% or less, Ti: 0.4% or less, V: 0.4% or less, Ta: 0.2% or less, Hf: 0.2% or less, and Zr: 0.2% or less, with the balance being Fe and impurities. The impurities include P: 0.04% or less, S: 0.03% or less, Sn: 0.1% or less, As: 0.01% or less, Zn: 0.01% or less, Pb: 0.01% or less, and Sb: 0.01% or less. In addition, $F1 = S + \{(P + Sn) / 2\} + \{(As + Zn + Pb + Sb) / 5\} \leq 0.075$ and $0.05 \leq Nb + Ta + Zr + Hf + 2Ti + (V/10) \leq 1.7 - 9 \times F1$ are satisfied. In Patent Literature 2, the polythionic acid SCC resistance is increased by setting the amount of C at less than 0.05%. In addition, grain boundary embrittling elements in the steel such as P, S, and Sn are reduced by reducing C immobilizing elements such as Nb and Ti, thereby enhancing embrittlement cracking resistance in a weld heat affected zone (HAZ).

CITATION LIST

PATENT LITERATURE

[0006]

Patent Literature 1: Japanese Patent Application Publication No. 2003-166039
Patent Literature 2: International Application Publication No. WO2009/044802

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0007] Components used in the high-temperature corrosive environment described above have recently been required to have high creep ductilities. As described above, a plant facility may undergo a regular inspection with its equipment deactivated. The regular inspection involves examination of what components are in need of replacement. A high creep ductility allows checking how much a component deforms to be used as a criterion for replacing the component in the regular inspection.

[0008] Patent Literature 1 and Patent Literature 2 aim at improving the polythionic acid SCC resistance but do not aim

at enhancing the creep ductility. The steels proposed in these Patent Literatures each have a reduced amount of C in order to increase the polythionic acid SCC resistance. In this instance, there are cases where a high creep ductility cannot be obtained.

[0009] An objective of the present invention is to provide an austenitic stainless steel excellent in the polythionic acid SCC resistance and excellent in the creep ductility.

SOLUTION TO PROBLEM

[0010] An austenitic stainless steel according to the present invention includes a chemical composition consisting of, in mass%, C: 0.030% or less, Si: 0.10 to 1.00%, Mn: 0.20 to 2.00%, P: 0.040% or less, S: 0.010% or less, Cr: 16.0 to 25.0%, Ni: 10.0 to 30.0%, Mo: 0.1 to 5.0%, Nb: 0.20 to 1.00%, N: 0.050 to 0.300%, sol.Al: 0.0005 to 0.100%, B: 0.0010 to 0.0080%, Cu: 0 to 5.0%, W: 0 to 5.0%, Co: 0 to 1.0%, V: 0 to 1.00%, Ta: 0 to 0.2%, Hf: 0 to 0.20%, Ca: 0 to 0.010%, Mg: 0 to 0.010%, and rare earth metals: 0 to 0.10%, with the balance being Fe and impurities, and satisfying Formula (1):

$$B + 0.004 - 0.9C + 0.017Mo^2 \geq 0 \qquad (1)$$

where symbols of elements in Formula (1) are to be substituted by contents of corresponding elements (mass%).

ADVANTAGEOUS EFFECTS OF INVENTION

[0011] The austenitic stainless steel according to the present invention is excellent in the polythionic acid SCC resistance and excellent in the creep ductility.

DESCRIPTION OF EMBODIMENTS

[0012] The present inventors conducted investigations and studies on steels that are excellent not only in the polythionic acid SCC resistance but also in the creep ductility.

[0013] When a content of C is reduced to 0.030% or less, the formation of $M_{23}C_6$ carbide in use under a high-temperature corrosive environment is inhibited, and the formation of a Cr depleted zone in the proximity of a grain boundary is inhibited. Furthermore, in the present invention, 0.20 to 1.00% of Nb is contained to immobilize C with Nb, so as to further reduce an amount of dissolved C, which causes the formation of $M_{23}C_6$ carbide. In the present invention, Mo is further contained at 0.1 to 5.0%. Mo inhibits formation of the $M_{23}C_6$ carbide. Therefore, the formation of the Cr depleted zone is reduced. With the measures described above, the polythionic acid SCC resistance can be increased.

[0014] However, investigations conducted by the present inventors showed that reducing the content of C to 0.030% or less leads to a decrease in the creep ductility. The reason is considered as follows. Precipitates produced in grain boundaries increase grain boundary strength. With an increase in the grain boundary strength, the creep ductility is increased. However, if the content of C is reduced to 0.030% or less, the precipitates (carbide, or the like) produced in the grain boundaries are also reduced. As a result, the grain boundary strength is less likely to be obtained, which results in the decrease in the creep ductility.

[0015] Hence, the present inventors conducted further studies about an austenitic stainless steel which can establish compatibility between an excellent polythionic acid SCC resistance and an excellent creep ductility. B (boron) is considered to be able to increase the grain boundary strength through segregating in crystal grain boundaries under the high-temperature corrosive environment at 600 to 700°C described above.

[0016] The present inventors thus considered that the compatibility between the excellent polythionic acid SCC resistance and the excellent creep ductility can be established with an austenitic stainless steel consisting of, in mass%, C: 0.030% or less, Si: 0.10 to 1.00%, Mn: 0.20 to 2.00%, P: 0.040% or less, S: 0.010% or less, Cr: 16.0 to 25.0%, Ni: 10.0 to 30.0%, Mo: 0.1 to 5.0%, Nb: 0.20 to 1.00%, N: 0.050 to 0.300%, sol.Al: 0.0005 to 0.100%, B: 0.0010 to 0.0080%, Cu: 0 to 5.0%, W: 0 to 5.0%, Co: 0 to 1.0%, V: 0 to 1.00%, Ta: 0 to 0.2%, Hf: 0 to 0.20%, Ca: 0 to 0.010%, Mg: 0 to 0.010%, and rare earth metals: 0 to 0.10%, with the balance being Fe and impurities.

[0017] However, results of investigations into polythionic acid SCC resistance and creep ductility of the austenitic stainless steel having the chemical composition described above showed that the excellent creep ductility could not always be obtained, although the excellent polythionic acid SCC resistance could be obtained. The present inventors thus conducted further studies. As a result, it was found that a possible mechanism of the creep ductility is as follows.

[0018] As described above, the present embodiment involves both setting the content of C at 0.030% or less to increase the polythionic acid SCC resistance, and making 0.20 to 1.00% of Nb contained to immobilize C on Nb, so as to reduce the dissolved C. Specifically, Nb combines with C through solution treatment or short-time aging, precipitating in a form

of MX carbo-nitride. However, in an environment in which the steel material according to the present embodiment is supposed to be used (a high-temperature corrosive environment at 600 to 700°C), the MX carbo-nitride is of a metastable phase. Therefore, when a steel material having the chemical composition described above is used in the high-temperature corrosive environment at 600 to 700°C for a long-time, an MX carbo-nitride of Nb transforms into a Z phase (CrNbN), a stable phase, and an $M_{23}C_6$ carbide. B segregating in grain boundaries is replaced with C being part of the $M_{23}C_6$ carbide, so as to be absorbed into the $M_{23}C_6$ carbide. Therefore, an amount of B segregating in the grain boundaries is reduced, resulting in a decrease in the grain boundary strength. Consequently, obtaining a sufficient creep ductility fails.

[0019] Thus, the present inventors conducted further studies on a method for restricting the reduction in the amount of segregating B in grain boundaries in use under the high-temperature corrosive environment at 600 to 700°C. As a result, it was found that the following mechanism can be conceived.

[0020] As described above, Mo restricts the formation of the $M_{23}C_6$ carbide itself. In addition, Mo may be replaced with M being part of $M_{23}C_6$ carbide, being dissolved into the $M_{23}C_6$ carbide. The $M_{23}C_6$ carbide with Mo dissolved therein is defined herein as "Mo-dissolved $M_{23}C_6$ carbide". The Mo-dissolved $M_{23}C_6$ carbide resists allowing B to be dissolved therein. therefore, even when the MX carbo-nitride containing Nb transforms into the Z phase and the $M_{23}C_6$ carbide in use under the high-temperature corrosive environment, it is possible to restrict the dissolution of B into the $M_{23}C_6$ carbide and restrict the reduction in the amount of segregating B in grain boundaries, as long as the $M_{23}C_6$ carbide is an Mo-dissolved $M_{23}C_6$ carbide. It is considered that compatibility between an excellent polythionic acid SCC resistance and an excellent creep ductility can be consequently established.

[0021] Hence, for the austenitic stainless steel having the chemical composition described above, the present inventors conducted further studies on a chemical composition that can form Mo-dissolved $M_{23}C_6$ carbide to restrict reduction in an amount of segregating B in grain boundaries even when MX carbo-nitride containing Nb transforms into a Z phase and an $M_{23}C_6$ carbide in use under a high-temperature corrosive environment at 600 to 700°C. As a result, it was found that restricting the reduction in the amount of segregating B by the formation of the Mo-dissolved $M_{23}C_6$ carbide has a close relation with B, C, and Mo in the chemical composition described above. It was then found that compatibility between an excellent polythionic acid SCC resistance and an excellent creep ductility can be established when B, C, and Mo in the chemical composition described above satisfy Formula (1) even in use under the high-temperature corrosive environment at 600 to 700°C:

$$B + 0.004 - 0.9C + 0.017Mo^2 \geq 0 \qquad (1)$$

where symbols of elements in Formula (1) are to be substituted by contents of corresponding elements (mass%).

[0022] The present inventors further conducted studies, and it was found as a result that, in a case where the above austenitic stainless steel contains Cu, an optional element, containing Cu at 5.0% or less makes it possible to obtain an excellent creep strength as well as to keep a creep ductility, but setting an upper limit of a content of Cu at 1.9% or less makes it possible to further enhance the creep strength as well as to keep a higher creep ductility. The reason is considered as follows. In use under a high-temperature corrosive environment, Cu precipitates in grains, forming Cu phases. The Cu phases enhance creep strength but can degrade creep ductility. Accordingly, for an austenitic stainless steel including the above chemical composition and satisfying Formula (1), it is more preferable that the content of Cu is 1.9% or less. When the content of Cu is 1.9% or less, it is possible to keep an excellent creep ductility more effectively.

[0023] The present inventors further conducted studies, and it was found as a result that the creep ductility is further enhanced when a content of Mo is set at 0.5% or more. The reason for this is unclear, but the following idea is conceivable. When the content of Mo is additionally set at 0.5% or more in the above chemical composition (satisfying Formula (1)), Mo further segregates in grain boundaries and forms its intermetallic compounds in use under a high-temperature corrosive environment at 600 to 700°C. This grain-boundary segregation and intermetallic compounds further enhance the grain boundary strength. As a result, the creep ductility is further enhanced. Accordingly, a lower limit of the content of Mo is preferably 0.5%. In order to further enhance the creep ductility, a lower limit of the content of Mo is preferably 0.8%, more preferably 1.0%, more preferably 2.0%.

[0024] An austenitic stainless steel according to the present invention that is made based on the findings described above includes a chemical composition consisting of, in mass%, C: 0.030% or less, Si: 0.10 to 1.00%, Mn: 0.20 to 2.00%, P: 0.040% or less, S: 0.010% or less, Cr: 16.0 to 25.0%, Ni: 10.0 to 30.0%, Mo: 0.1 to 5.0%, Nb: 0.20 to 1.00%, N: 0.050 to 0.300%, sol.Al: 0.0005 to 0.1000%, B: 0.0010 to 0.0080%, Cu: 0 to 5.0%, W: 0 to 5.0%, Co: 0 to 1.0%, V: 0 to 1.00%, Ta: 0 to 0.2%, Hf: 0 to 0.20%, Ca: 0 to 0.010%, Mg: 0 to 0.010%, and rare earth metals: 0 to 0.10%, with the balance being Fe and impurities, and satisfying Formula (1):

$$B + 0.004 - 0.9C + 0.017Mo^2 \geq 0 \qquad (1)$$

where symbols of elements in Formula (1) are to be substituted by contents of corresponding elements (mass%).

[0025] The chemical composition may contain one or more elements selected from the group consisting of, in mass%, Cu: 0.1 to 5.0%, W: 0.1 to 5.0%, and Co: 0.1 to 1.0%.

[0026] The chemical composition may contain one or more elements selected from the group consisting of, in mass%, V: 0.1 to 1.00%, Ta: 0.01 to 0.2%, and Hf: 0.01 to 0.20%.

[0027] The chemical composition may contain one or more elements selected from the group consisting of, in mass%, Ca: 0.0005 to 0.010%, Mg: 0.0005 to 0.010%, and rare earth metals: 0.001 to 0.10%.

[0028] The chemical composition may contain, in mass%, Cu: 0 to 1.9%.

[0029] The chemical composition may contain, in mass%, Mo: 0.5 to 5.0%.

[0030] Hereafter, the austenitic stainless steel according to the present embodiment will be described in detail. The sign "%" following each element means mass percent unless otherwise noted.

[Chemical Composition]

[0031] The austenitic stainless steel according to the present embodiment has a chemical composition containing the following elements.

C: 0.030% or less

[0032] Carbon (C) is contained unavoidably. When the austenitic stainless steel according to the present embodiment is in use under the high-temperature corrosive environment at 600 to 700°C, C produces $M_{23}C_6$ carbide in grain boundaries, degrading polythionic acid SCC resistance. Accordingly, a content of C is 0.030% or less. An upper limit of the content of C is preferably 0.020%, more preferably 0.015%. The content of C is preferably as low as possible. However, since C is contained unavoidably as described above, at least 0.0001% of C can be contained in industrial production. Accordingly, a lower limit value of the content of C is preferably 0.0001%.

Si: 0.10 to 1.00%

[0033] Silicon (Si) deoxidizes steel. In addition, Si enhances oxidation resistance and steam oxidation resistance of steel. An excessively low content of Si fails to provide the effects described above. Meanwhile, an excessively high content of Si causes a sigma phase (σ phase) to precipitate in steel, degrading toughness of the steel. Accordingly, a content of Si is 0.10 to 1.00%. An upper limit of the content of Si is preferably 0.75%, more preferably 0.50%.

Mn: 0.20 to 2.00%

[0034] Manganese (Mn) deoxidizes steel. In addition, Mn stabilizes austenite, enhancing the creep strength. An excessively low content of Mn fails to provide the effects described above. Meanwhile, an excessively high content of Mn degrades creep strength of steel. Accordingly, a content of Mn is 0.20 to 2.00%. A lower limit of the content of Mn is preferably 0.40%, more preferably 0.50%. An upper limit of the content of Mn is preferably 1.70%, more preferably 1.50%.

P: 0.040% or less

[0035] Phosphorus (P) is an impurity. P decreases hot workability and toughness of steel. Accordingly, a content of P is 0.040% or less. An upper limit of the content of P is preferably 0.035%, more preferably 0.032%. The content of P is preferably as low as possible. However, since P is contained unavoidably, at least 0.0001% of P can be contained in industrial production. Accordingly, a lower limit value of the content of P is preferably 0.0001%.

S: 0.010% or less

[0036] Sulfur (S) is an impurity. S degrades hot workability and creep ductility of steel. Accordingly, a content of S is 0.010% or less. An upper limit of the content of S is preferably 0.005%. The content of S is preferably as low as possible. However, since S is contained unavoidably, at least 0.0001% of S can be contained in industrial production. Accordingly, a lower limit value of the content of S is preferably 0.0001%.

Cr: 16.0 to 25.0%

[0037] Chromium (Cr) enhances polythionic acid SCC resistance of steel. In addition, Cr enhances oxidation resistance, steam oxidation resistance, high-temperature corrosion resistance, and the like of steel. An excessively low content of

Cr fails to provide the effects described above. In contrast, an excessively high Cr content degrades creep strength and toughness of steel. Accordingly, a content of Cr is 16.0 to 25.0%. A lower limit of the content of Cr is preferably 16.5%, more preferably 17.0%. An upper limit of the content of Cr is preferably 24.0%, more preferably 23.0%.

Ni: 10.0 to 30.0%

[0038] Nickel (Ni) stabilizes austenite, enhancing creep strength. An excessively low content of Ni fails to provide the effect described above. In contrast, an excessively high content of Ni results in saturation of the effect described above and in addition, increases production costs. Accordingly, a content of Ni is 10.0 to 30.0%. A lower limit of the content of Ni is preferably 11.0%, more preferably 13.0%. An upper limit of the content of Ni is preferably 25.0%, more preferably 22.0%.

Mo: 0.1 to 5.0%

[0039] Molybdenum (Mo) restricts formation of $M_{23}C_6$ carbide in grain boundaries in use under a high-temperature corrosive environment at 600 to 700°C. In addition, in use under the high-temperature corrosive environment at 600 to 700°C, Mo restricts dissolution of B into $M_{23}C_6$ carbide when MX carbo-nitride of Nb transforms into the $M_{23}C_6$ carbide, restricting reduction of an amount of segregating B in grain boundaries under the high-temperature corrosive environment. This allows a sufficient creep ductility to be obtained in the high-temperature corrosive environment. An excessively low content of Mo fails to provide the effects described above. In contrast, an excessively high content of Mo degrades stability of austenite. Accordingly, a content of Mo is 0.1 to 5.0%. A lower limit of the content of Mo is preferably 0.2%, more preferably 0.3%.

[0040] When the content of Mo is 0.5% or more, Mo segregates in grain boundaries and forms intermetallic compounds, further enhancing grain boundary strength. In this case, a further excellent creep strength can be obtained under the high-temperature corrosive environment. Accordingly, a lower limit of the content of Mo is more preferably 0.5%, still more preferably 0.8%, still more preferably 1.0%, still more preferably 1.5%, still more preferably 2.0%. A content of Mo of 1.5% or more also enhances creep strength. An upper limit of the content of Mo is preferably 4.5%, more preferably 4.0%. A content of Mo of 1.5% or more also enhances creep strength.

Nb: 0.20 to 1.00%

[0041] Niobium (Nb) combines with C in use under a high-temperature corrosive environment at 600 to 700°C to form MX carbo-nitride, reducing an amount of dissolved C in steel. This enhances polythionic acid SCC resistance of the steel. The formed MX carbo-nitride of Nb also enhances creep strength. An excessively low content of Nb fails to provide the effects described above. In contrast, an excessively high content of Nb causes δ ferrite to be produced, degrading long-term creep strength, toughness, and weldability of steel. Accordingly, a content of Nb is 0.20 to 1.00%. A lower limit of the content of Nb is preferably 0.25%. An upper limit of the content of Nb is preferably 0.90%, more preferably 0.80%.

N: 0.050 to 0.300%

[0042] Nitrogen (N) is dissolved in a matrix (parent phase) to stabilize austenite, enhancing creep strength. In addition, N forms its fine carbo-nitride in grains, enhancing creep strength of steel. That is, N contributes to the creep strength through both solid-solution strengthening and precipitation strengthening. An excessively low content of N fails to provide the effects described above. In contrast, an excessively high content of N causes Cr nitride to be formed in grain boundaries, degrading polythionic acid SCC resistance in a welding heat affected zone (HAZ). In addition, an excessively high content of N also degrades workability of steel. Accordingly, a content of N is 0.050 to 0.300%. A lower limit of the content of N is preferably 0.070%. An upper limit of the content of N is preferably 0.250%, more preferably 0.200%.

sol.Al: 0.0005 to 0.100%

[0043] Aluminum (Al) deoxidizes steel. An excessively low content of Al fails to provide the above effect. In contrast, an excessively high content of Al degrades cleanliness of steel, degrading workability and ductility of the steel. Accordingly, a content of Al is 0.0005 to 0.100%. A lower limit of the content of Al is preferably 0.001%, more preferably 0.002%. An upper limit of the content of Al is preferably 0.050%, more preferably 0.030%. In the present embodiment, the content of Al means a content of acid-soluble Al (sol.Al).

B: 0.0010 to 0.0080%

[0044] Boron (B) segregates in grain boundaries in use under a high-temperature corrosive environment at 600 to 700°C, enhancing grain boundary strength. As a result, creep ductility can be enhanced. An excessively low content of B fails to provide the effects described above. In contrast, an excessively high content of B degrades weldability and hot workability at high temperature. Accordingly, a content of B is 0.0010 to 0.0080%. A lower limit of the content of B is preferably 0.0015%, more preferably 0.0020%. An upper limit of the content of B is preferably less than 0.0060%, more preferably 0.0050%.

[0045] The balance of the chemical composition of the austenitic stainless steel according to the present embodiment is Fe and impurities. Here, the impurities mean elements that are mixed from ores and scraps used as raw material, a producing environment, or the like when the austenitic stainless steel is produced in an industrial manner, and are allowed to be mixed within ranges within which the impurities have no adverse effect on the austenitic stainless steel of the present embodiment.

[Optional Elements]

[0046] The austenitic stainless steel according to the present embodiment may further contain, in lieu of a part of Fe, one or more elements selected from the group consisting of Cu, W, and Co. These elements all enhance creep strength of steel.

Cu: 0 to 5.0%

[0047] Copper (Cu) is an optional element and need not be contained. When contained, Cu precipitates in use under a high-temperature corrosive environment at 600 to 700°C in a form of Cu phases in grains, exerting precipitation strengthening to enhance creep strength of steel. However, an excessively high content of Cu degrades hot workability and weldability of steel. Accordingly, a content of Cu is 0 to 5.0%. In order to enhance the creep strength more effectively, a lower limit of the content of Cu is preferably 0.1%, more preferably 2.0%, more preferably 2.5%. An upper limit of the content of Cu is preferably 4.5%, more preferably 4.0%. Meanwhile, in order to keep a more excellent creep ductility, the content of Cu is preferably 0 to 1.9%, and a more preferable upper limit of the content of Cu is 1.8%.

W: 0 to 5.0%

[0048] Tungsten (W) is an optional element and may not be contained. When contained, W is dissolved in a matrix (parent phase), enhancing creep strength of steel. However, an excessively high content of W degrades stability of austenite, degrading creep strength and toughness of steel. Accordingly, a content of W is 0 to 5.0%. A lower limit of the content of W is preferably 0.1%, more preferably 0.2%. An upper limit of the content of W is preferably 4.5%, more preferably 4.0%.

Co: 0 to 1.0 %

[0049] Cobalt (Co) is an optional element and need not be contained. When contained, Co stabilizes austenite, enhancing creep strength. However, an excessively high content of Co increases a raw-material cost. Accordingly, a content of Co is 0 to 1.0%. A lower limit of the content of Co is preferably 0.1%, more preferably 0.2%.

[0050] The austenitic stainless steel according to the present embodiment may further contain, in lieu of a part of Fe, one or more elements selected from the group consisting of V, Ta, and Hf. These elements all enhance polythionic acid SCC resistance and creep strength of steel.

V: 0 to 1.00%

[0051] Vanadium (V) is an optional element and need not be contained. When contained, V combines with C to form its carbo-nitride in use under a high-temperature corrosive environment at 600 to 700°C, so as to reduce dissolved C, enhancing polythionic acid SCC resistance of steel. The formed V carbo-nitride also enhances creep strength. However, an excessively high content of V causes δ ferrite to be produced, degrading creep strength, toughness, and weldability of steel. Accordingly, a content of V is 0 to 1.00%. In order to enhance the polythionic acid SCC resistance and the creep strength more effectively, a lower limit of the content of V is preferably 0.10%. An upper limit of the content of V is preferably 0.90%, more preferably 0.80%.

Ta: 0 to 0.2%

[0052] Tantalum (Ta) is an optional element and need not be contained. When contained, Ta combines with C to form its carbo-nitride in use under a high-temperature corrosive environment at 600 to 700°C, so as to reduce dissolved C, enhancing polythionic acid SCC resistance of steel. The formed Ta carbo-nitride also enhances creep strength. However, an excessively high content of Ta causes δ ferrite to be produced, degrading creep strength, toughness, and weldability of steel. Accordingly, a content of Ta is 0 to 0.2%. In order to enhance the polythionic acid SCC resistance and the creep strength more effectively, a lower limit of the content of Ta is preferably 0.01%, more preferably 0.02%.

Hf: 0 to 0.20%

[0053] Hafnium (Hf) is an optional element and need not be contained. When contained, Hf combines with C to form its carbo-nitride in use under a high-temperature corrosive environment at 600 to 700°C, so as to reduce dissolved C, enhancing polythionic acid SCC resistance of steel. The formed Hf carbo-nitride also enhances creep strength. However, an excessively high content of Hf causes δ ferrite to be produced, degrading creep strength, toughness, and weldability of steel. Accordingly, a content of Hf is 0 to 0.20%. A lower limit of the content of Hf is preferably 0.01%, more preferably 0.02%.

[0054] The austenitic stainless steel according to the present embodiment may further contain, in lieu of a part of Fe, one or more elements selected from the group consisting of Ca, Mg, and rare earth metals. These elements all enhance hot workability and creep ductility of steel.

Ca: 0 to 0.010%

[0055] Calcium (Ca) is an optional element and need not be contained. When contained, Ca immobilizes O (oxygen) and S (sulfur) in forms of its inclusions, enhancing hot workability and creep ductility of steel. However, an excessively high content of Ca degrades hot workability and creep ductility of steel. Accordingly, a content of Ca is 0 to 0.010%. A lower limit of the content of Ca is preferably 0.0005%, more preferably 0.001%. An upper limit of the content of Ca is preferably 0.008%, more preferably 0.006%.

Mg: 0 to 0.010%

[0056] Magnesium (Mg) is an optional element and need not be contained. When contained, Mg immobilizes O (oxygen) and S (sulfur) in forms of its inclusions, enhancing hot workability and creep ductility of steel. However, an excessively high content of Mg degrades hot workability and long-term creep ductility of steel. Accordingly, a content of Mg is 0 to 0.010%. A lower limit of the content of Mg is preferably 0.0005%, more preferably 0.001%. An upper limit of the content of Mg is preferably 0.008%, more preferably 0.006%.

Rare earth metals: 0 to 0.10%

[0057] Rare earth metals (REMs) are optional elements and need not be contained. When contained, REMs immobilize O (oxygen) and S (sulfur) in forms of its inclusions, enhancing hot workability and creep ductility of steel. However, an excessively high content of REMs degrades hot workability and long-term creep ductility of steel. Accordingly, a content of REMs is 0 to 0.01%. A lower limit of the content of REMs is preferably 0.001%, more preferably 0.002%. An upper limit of the content of REMs is preferably 0.08%, more preferably 0.06%.

[0058] REMs herein contain at least one element of Sc, Y, and lanthanoid (La, with atomic number 57, to Lu, with atomic number 71), and the content of REMs means a total content of these elements.

[Formula (1)]

[0059] The above chemical composition further satisfies Formula (1).

$$B + 0.004 - 0.9C + 0.017Mo^2 \geq 0 \qquad (1)$$

Symbols of elements in Formula (1) are to be substituted by contents of corresponding elements (in mass%).

[0060] As described above, the present embodiment involves both setting the content of C at 0.030% or less to increase the polythionic acid SCC resistance, and making 0.20 to 1.00% of Nb contained to produce MX carbo-nitride of Nb in

use under a high-temperature corrosive environment at 600 to 700°C, reducing an amount of dissolved C. However, the MX carbo-nitride of Nb transforms into a Z phase and an $M_{23}C_6$ carbide in use under the above high-temperature use environment because the MX carbo-nitride of Nb is a metastable phase. B segregating in grain boundaries is dissolved in the $M_{23}C_6$ carbide, and an amount of segregating B in the grain boundaries is reduced. As a result, the creep ductility deteriorates.

[0061] However, when Mo is dissolved in the $M_{23}C_6$ carbide to form a "Mo-dissolved $M_{23}C_6$ carbide", B is hard to be dissolved in the Mo-dissolved $M_{23}C_6$ carbide. Therefore, the amount of segregating B in the grain boundaries is kept, which enables obtaining an excellent polythionic acid SCC resistance as well as an excellent creep ductility.

[0062] Let F1 be defined as $F1 = B + 0.004 - 0.9C + 0.017Mo^2$. F1 is an index indicating a ratio of an Mo-dissolved $M_{23}C_6$ carbide to a plurality of kinds of $M_{23}C_6$ carbides formed in steel in use under a high-temperature corrosive environment. If F1 is zero or more, the ratio of the Mo-dissolved $M_{23}C_6$ carbide is high even when the plurality of kinds of $M_{23}C_6$ carbides are formed in the steel in use under the high-temperature corrosive environment. Therefore, B segregating in grain boundaries is hard to be dissolved in the $M_{23}C_6$ carbides, and therefore an amount of B segregating in the grain boundaries is kept. As a result, it is possible to establish compatibility between an excellent polythionic acid SCC resistance and an excellent creep ductility. Accordingly, F1 is zero (0.00000) or more. F1 is preferably 0.00100 or more, more preferably 0.00200 or more, more preferably 0.00400 or more, more preferably 0.00500 or more, more preferably 0.00800 or more, most preferably 0.01000 or more.

[0063] When the above chemical composition of the austenitic stainless steel contains Cu, it is preferable that the upper limit of the content of Cu is 1.9% or less as described above. Considering enhancing a creep strength as well as obtaining an excellent creep ductility, the content of Cu is preferably 0% to 1.9%. When the content of Cu is 1.9% or less, a Cu phase is subjected to precipitation strengthening, which makes it possible to keep the excellent creep ductility with the excellent creep strength obtained.

[0064] In the above chemical composition of the austenitic stainless steel, a lower limit of the content of Mo is preferably 0.5%. In the case, in use under a high-temperature corrosive environment at 600 to 700°C, Mo additionally segregates in grain boundaries and forms intermetallic compounds. This grain-boundary segregation and intermetallic compounds further enhance the grain boundary strength. As a result, the creep ductility is further enhanced. Accordingly, the lower limit of the content of Mo is preferably 1.0%. Note that, when the lower limit of the content of Mo is 1.0% or more, an F1 value is preferably 0.00500 or more, more preferably 0.00800 or more, more preferably 0.01000 or more.

[Producing Method]

[0065] An example of a producing method of the austenitic stainless steel according to the present invention will be described. The present producing method includes a preparation process of preparing a starting material, a hot working process of performing hot working on the starting material to produce a steel material, a cold working process of, as necessary, performing cold working on the steel material subjected to the hot working, and a solution treatment process of, as necessary, performing solution treatment on the steel material. The producing method will be described below.

[Preparation Process]

[0066] A molten steel having the above chemical composition and satisfying Formula (1) is produced. The molten steel is produced using, for example, an electric furnace, an AOD (Argon Oxygen Decarburization) furnace, or a VOD (Vacuum Oxygen Decarburization) furnace. As necessary, the produced molten steel is subjected to a well-known degassing treatment. From the molten steel subjected to the degassing treatment, a starting material is produced. Examples of the producing method for the starting material include a continuous casting process. By the continuous casting process, a continuous casting material (the starting material) is produced. The continuous casting material is, for example, a slab, a bloom, a billet, and the like. The molten steel may be subjected to an ingot-making process into an ingot.

[Hot Working Process]

[0067] The prepared starting material (a continuous casting material or an ingot) is subjected to hot working to be produced into an austenitic stainless steel material. For example, the starting material is subjected to the hot rolling to be produced into a steel plate, a steel bar, or a wire rod. Alternatively, the starting material is subjected to hot-extrusion process, hot piercing-rolling, or the like to be produced into an austenitic stainless steel pipe. A specific method of the hot working is not specially limited, and performing hot working conforming to a shape of a finished product will suffice. A finish working temperature of the hot working is, for example, 1050°C or more. The finish working temperature used herein means a temperature of the steel material immediately after completion of final hot working.

[Cold Working Process]

[0068] Cold working may be performed, as necessary, on the austenitic stainless steel material subjected to the hot working. When the austenitic stainless steel material is a steel bar, a wire rod, or a steel pipe, the cold working is, for example, cold drawing or cold rolling. When the austenitic stainless steel material is a steel plate, the cold working is cold rolling or the like.

[Solution Treatment Process]

[0069] After the hot working or the cold working, solution treatment may be performed as necessary. A solution treatment step involves uniformizing a structure and dissolving a carbo-nitride. A preferable solution treatment temperature is as follows.

Preferable solution treatment temperature: 1000 to 1250°C

[0070] When the solution treatment temperature is 1000°C or more, a carbo-nitride of Nb is dissolved sufficiently, further increasing the creep strength. When the solution treatment temperature is 1250°C or less, excessive dissolution of C can be restricted, further increasing the polythionic acid SCC resistance.

[0071] A retention duration in the solution treatment at the above solution treatment temperature is, for example but not specially limited to, 2 minutes to 60 minutes.

[0072] In place of the solution treatment, rapid cooling may be performed immediately after the hot working on the steel material produced through the hot working step. In this case, a finish working temperature of the hot working is preferably set at 1000°C or more. When the finish hot working temperature is 1000°C or more, the carbo-nitride of Nb is dissolved sufficiently, which makes it possible to establish compatibility between an excellent polythionic acid SCC resistance and an excellent creep ductility in use under a high-temperature corrosive environment at 600 to 700°C, and the carbo-nitride of Nb is formed in use under a high temperature environment, which allows a sufficient creep strength to be obtained.

[0073] A shape of the austenitic stainless steel of the present embodiment is not specially limited. The austenitic stainless steel of the present embodiment may be a steel plate, a steel pipe, a steel bar or a wire rod, or a shape steel.

EXAMPLES

[0074] Molten steels having chemical compositions shown in Table 1 were produced.

[Table 1]

[0075]

TABLE 1

Test number	Chemical composition (in mass%, balance being Fe and impurities)														F1
	C	Si	Mn	P	S	Cr	Ni	Mo	Nb	N	sol.Al	B	Cu	Other	
1	0.010	0.25	0.68	0.019	0.001	17.1	14.2	0.8	0.43	0.099	0.005	0.0033	-	-	0.00918
2	0.012	0.23	0.85	0.024	0.001	18.5	13.1	0.5	0.35	0.086	0.008	0.0045	3.2	-	0.00195
3	0.010	0.25	0.98	0.008	0.001	17.8	14.5	0.6	0.34	0.091	0.004	0.0041	1.5	-	0.00522
4	0.010	0.33	0.56	0.018	0.001	18.1	14.2	0.5	0.38	0.100	0.009	0.0029	0.8	-	0.00215
5	0.017	0.18	0.77	0.026	0.001	17.6	14.2	1.2	0.32	0.085	0.003	0.0023	-	-	0.01548
6	0.015	0.23	0.65	0.029	0.001	17.4	15.2	1.6	0.31	0.098	0.008	0.0031	-	-	0.03712
7	0.015	0.39	1.52	0.018	0.001	17.5	14.9	2.3	0.41	0.120	0.015	0.0035	-	0.15V, 0.002Ca	0.08393
8	0.008	0.19	1.32	0.031	0.002	17.6	13.2	0.4	0.25	0.110	0.004	0.0025	2.8	1.0W, 0.1Ta	0.00202
9	0.006	0.42	0.63	0.021	0.001	18.2	14.3	0.3	0.28	0.092	0.030	0.0020	3.4	0.5Co	0.00213
10	0.014	0.33	0.94	0.019	0.001	22.7	16.2	0.9	0.62	0.180	0.021	0.0031	2.5	0.002Mg	0.00827
11	0.020	0.23	1.23	0.013	0.001	20.3	21.3	3.8	0.33	0.110	0.007	0.0023	-	0.08Hf, 0.03Nd	0.23378
12	0.012	0.43	0.51	0.031	0.002	16.8	13.4	3.1	0.27	0.110	0.026	0.0026	-	0.5W	0.15917
13	0.008	0.26	0.85	0.025	0.001	18.2	15.3	0.7	0.43	0.120	0.010	0.0028	-	01V	0.00793
14	0.007	0.25	1.05	0.028	0.001	17.9	14.8	0.8	0.35	0.092	0.009	0.0029	-	0.004Ca	0.01148
15	0.009	0.18	0.65	0.015	0.001	17.5	11.2	0.4	0.29	0.078	0.008	0.0045	1.8	-	0.00312
16	0.008	0.25	0.69	0.012	0.001	17.6	11.3	0.3	0.35	0.082	0.005	0.0046	-	-	0.00293
17	0.020	0.24	1.11	0.028	0.001	18.0	13.9	0.3	0.35	0.086	0.010	0.0025	-	-	-0.00997
18	0.016	0.23	0.62	0.003	0.001	17.8	14.2	0.4	0.32	0.086	0.012	0.0012	-	-	-0.00648
19	0.040	0.20	0.85	0.027	0.001	17.5	12.8	1.3	0.42	0.110	0.007	0.0055	-	-	0.00223
20	0.012	0.24	1.05	0.002	0.001	18.2	12.9	0.4	0.34	0.095	0.012	0.0025	2.5	-	-0.00158
21	0.012	0.26	1.03	0.022	0.002	17.2	13.2	-	0.33	0.130	0.023	0.0019	-	2.8W	-0.00490
22	0.016	0.35	0.80	0.018	0.001	17.8	14.7	2.4	0.28	0.110	0.080	0.0002	-	-	0.08772
23	0.013	0.23	0.78	0.023	0.001	18.6	13.8	0.5	-	0.130	0.015	0.0041	-	0.4Co, 0.003Ca	0.00065

[0076] In a column "F1" of Table 1, a value of F1 of a steel of each test number is written. A symbol of an element in a column "OTHER" of a column "CHEMICAL COMPOSITION" and a numerical value preceding the symbol of the element means an optional element and its content (in mass%). Of the chemical composition of each test number, the balance, all but elements shown in Table 1 was Fe and impurities.

[0077] The molten steels were used to produce ingots each having an outer diameter of 120 mm and weighing 30 kg. The ingots were subjected to hot forging to be formed into steel plates each having a thickness of 40 mm. The steel plates were further subjected to the hot rolling into steel plates each having a thickness of 15 mm. Final working temperatures of the hot rolling was 1050°C or more for all test numbers. The steel plates subjected to the hot rolling were further subjected to the cold rolling to be produced into steel plates each having a thickness of 10.5 mm, a width of 50 mm, and a length of 100 mm. The steel plates subjected to the cold rolling were each subjected to the solution treatment. For all of the steel plates having the respective test numbers, the solution treatment temperature was 1150°C, and a solution treatment duration was 10 minutes. The steel plates subjected to the solution treatment were subjected to water cooling. Through the above steps, austenitic stainless steel materials were produced.

[0078] With a thickness of a produced austenitic stainless steel plate defined as t (mm), a sample taken from a position at t/4 depth from a surface of the steel plate was used to perform well-known component analysis methods (the infrared absorptiometric method after combustion for C and S, the thermal desorption spectroscopy for N, and the ICP spectrometry for other alloying elements). As a result, chemical compositions of the austenitic stainless steel plates having the respective test numbers matched those shown in Table 1.

[Evaluation Test for Polythionic Acid SCC Resistance]

[0079] The steel plates of the respective test numbers were subjected to a 5000-hour aging treatment at 600°C on the assumption that they are used under the high temperature environment. From these aging-treated materials, plate-shaped test specimens were taken, the test specimens each having a thickness of 2 mm, a width of 10 mm, and a length of 75 mm. An evaluation test for polythionic acid SCC resistance was conducted conforming to "Stress corrosion cracking test in chloride solution for stainless steels" in JIS G 0576(2001). Specifically, each test specimen was bended around a punch having an inside radius of 5 mm to have a U-bend shape. The test specimen with the U-bend shape was immersed in Wackenroder solution (solution made by blowing a large quantity of H_2S gas into H_2SO_3 saturated aqueous solution that is made by blowing SO_2 gas into distilled water) at normal temperature for 100 hours. The immersed test specimen was subjected to microscopic observation at 500x magnification to check for a crack.

[0080] When no crack was found in a test specimen, the test specimen was determined to be excellent in polythionic acid SCC resistance (marked as "E" (Excellent) in a column "POLYTHIONIC ACID SCC RESISTANCE" in Table 2). When any crack was found in a test specimen, the test specimen was determined to be low in polythionic acid SCC resistance (marked as "NA" (Not Accepted) in the column "POLYTHIONIC ACID SCC RESISTANCE" in Table 2).

[Evaluation Test for Creep Ductility and Creep Strength]

[0081] For each test number, a creep rupture test specimen conforming to JIS Z2271(2010) was fabricated from the steel plate. A cross section of the creep rupture test specimen perpendicular to its axial direction was in a round shape, and the creep rupture test specimen had an outer diameter of 6 mm and a parallel portion measuring 30 mm. The parallel portion was parallel to a rolling direction of the steel plate. The fabricated creep rupture test specimen was used to conduct a creep rupture test conforming to JIS Z2271(2010). Specifically, the creep rupture test specimen was heated at 750°C and then subjected to the creep rupture test. A test stress was set at 45 MPa, and a creep rupture time (hour) and a percentage reduction of area after creep rupture (%) were determined.

[0082] As to the creep strength, when a creep rupture time of a test specimen was 5000 to 10000 h or less, the test specimen was determined to be excellent in creep strength (marked as "G" (Good) in a column "CREEP STRENGTH" in Table 2). When a creep rupture time of a test specimen was more than 10000 hours, the test specimen was determined to be markedly excellent in creep strength (marked as "E" (Excellent) in the column "CREEP STRENGTH" in Table 2). When a creep rupture time of a test specimen was less than 5000 hours, the test specimen was determined to be low in creep strength (marked as "NA" (Not Accepted) in the column "CREEP STRENGTH" in Table 2). When a test specimen was marked as "G" or "E" in creep rupture time, it was determined that a sufficient creep strength was obtained with the test specimen.

[0083] As to the creep ductility, when a percentage reduction of area after creep rupture of a test specimen was 20.0% to 30.0% or less, the test specimen was determined to be good in creep ductility (marked as "P" (Passing) in a column "CREEP DUCTILITY" in Table 2). When a percentage reduction of area after creep rupture of a test specimen was more than 30.0% to 50.0% or less, the test specimen was determined to be excellent in creep ductility (marked as "G" (Good) in the column "CREEP DUCTILITY" in Table 2). When a percentage reduction of area after creep rupture of a test specimen was more than 50.0%, the test specimen was determined to be markedly excellent in creep ductility (marked

as "E" (Excellent) in the column "CREEP DUCTILITY" in Table 2). When a percentage reduction of area after creep rupture of a test specimen was less than 20.0%, the test specimen was determined to be low in creep ductility (marked as "NA" (Not Accepted) in the column "CREEP DUCTILITY" in Table 2). When a test specimen was marked as "P", "G", or "E" in percentage reduction of area after creep rupture, it was determined that a sufficient creep ductility was obtained with the test specimen.

[Test Results]

[0084] Table 2 shows test results.

[Table 2]

[0085]

TABLE 2

Test number	Polythionic acid SCC resistance	Creep ductility	Creep strength
1	E	E	G
2	E	G	E
3	E	E	E
4	E	E	E
5	E	E	G
6	E	E	E
7	E	E	E
8	E	P	E
9	E	P	E
10	E	G	E
11	E	E	E
12	E	E	E
13	E	G	G
14	E	G	G
15	E	G	E
16	E	G	G
17	E	NA	NA
18	E	NA	NA
19	NA	E	E
20	E	NA	E
21	E	NA	NA
22	E	NA	NA
23	NA	G	NA

[0086] Referring to Table 1 and Table 2, the contents of elements in the chemical compositions of the steels of the test numbers 1 to 16 were appropriate, and F1 of the steels satisfied Formula (1). Therefore, the steel plates of these test numbers provided excellent polythionic acid SCC resistances. In addition, the rupture times of the steel plates were 5000 hours or more, and excellent creep strengths were obtained. Furthermore, their percentage reductions of area after creep rupture were 20.0% or more, and excellent creep ductilities were obtained. Moreover, as to test numbers 2 to 4, 6 to 12, and 15, since they contained Cu or contained Mo in a large quantity, their rupture times in the creep rupture test was longer than those of test numbers 1, 5, 13, 14, and 16, 10000 hours or more, and superior creep strengths

were obtained.

[0087] In addition, as to test numbers 3 and 4, which contained Cu at 1.9% or less and contained Mo at 0.5% or more, and as to test numbers 5 to 7, 11, and 12, which did not contain Cu but contained Mo at 1.0% or more, sufficient creep strengths were obtained, and at the same time, superior creep ductilities were obtained.

[0088] In contrast, as to test numbers 17 and 18, their F1 failed to satisfy Formula (1). As a result, their percentage reductions of area after creep rupture were less than 20%, and creep ductilities of their steels were low. This is considered to be due to a failure to obtain a grain-boundary strengthening effect by grain-boundary segregation of B. In addition, their creep strengths were also low.

[0089] As to a test number 19, its content of C was excessively high. As a result, its polythionic acid SCC resistance was low.

[0090] As to a test number 20, it contained Cu, and therefore its creep strength was high whereas its F1 did not satisfy Formula (1). As a result, its percentage reduction of area after creep rupture was less than 20.0%, and a creep ductility of its steel was low.

[0091] As to a test number 21, it contained no Mo. In addition, its F1 was less than the lower limit of Formula (1). As a result, its percentage reduction of area after rupture was less than 20.0%, and a creep ductility of its steel was low. In addition, its creep strength was also low.

[0092] As to the test number 22, its content of B was low. As a result, its percentage reduction of area after creep rupture was less than 20.0%, and a creep ductility of its steel was low. In addition, its creep strength was also low.

[0093] As to a test number 23, it contained no Nb. As a result, its polythionic acid SCC resistance was low. In addition, its rupture time was less than 5000 hours, and a creep strength of its steel was low.

[0094] The embodiment according to the present invention has been described above. However, the aforementioned embodiment is merely an example for practicing the present invention. Therefore, the present invention is not limited to the aforementioned embodiment, and the aforementioned embodiment can be modified and implemented as appropriate without departing from the scope of the present invention.

Claims

1. An austenitic stainless steel comprising a chemical composition consisting of, in mass%:

C: 0.030% or less;
Si: 0.10 to 1.00%;
Mn: 0.20 to 2.00%;
P: 0.040% or less;
S: 0.010% or less;
Cr: 16.0 to 25.0%;
Ni: 10.0 to 30.0%;
Mo: 0.1 to 5.0%;
Nb: 0.20 to 1.00%;
N: 0.050 to 0.300%;
sol.Al: 0.0005 to 0.100%;
B: 0.0010 to 0.0080%;
Cu: 0 to 5.0%;
W: 0 to 5.0%;
Co: 0 to 1.0%;
V: 0 to 1.00%;
Ta: 0 to 0.2%;
Hf: 0 to 0.20%;
Ca: 0 to 0.010%;
Mg: 0 to 0.010%; and
rare earth metals: 0 to 0.10%,
with the balance being Fe and impurities,
and satisfying Formula (1):

$$B + 0.004 - 0.9C + 0.017Mo^2 \geq 0 \qquad (1)$$

where symbols of elements in Formula (1) are to be substituted by contents of corresponding elements (mass%).

2. The austenitic stainless steel according to claim 1, wherein the chemical composition contains one or more elements selected from the group consisting of:

Cu: 0.1 to 5.0%;
W: 0.1 to 5.0%; and
Co: 0.1 to 1.0%.

3. The austenitic stainless steel according to claim 1 or claim 2, wherein the chemical composition contains one or more elements selected from the group consisting of:

V: 0.1 to 1.00%;
Ta: 0.01 to 0.2%; and
Hf: 0.01 to 0.20%.

4. The austenitic stainless steel according to any one of claim 1 to claim 3, wherein the chemical composition contains one or more elements selected from the group consisting of:

Ca: 0.0005 to 0.010%;
Mg: 0.0005 to 0.010%; and
rare earth metals: 0.001 to 0.10%.

5. The austenitic stainless steel according to claim 1, wherein the chemical composition contains
Cu: 0 to 1.9%.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/031157

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, C22C38/58(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)
C22C38/00-C22C38/60

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

Japanese Published Examined Utility Model Applications	1922-1996
Japanese Published Unexamined Utility Model Applications	1971-2017
Japanese Examined Utility Model Registrations	1996-2017
Japanese Registered Utility Model Specifications	1994-2017

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.
Y A	JP 2014-5506 A (NIPPON STEEL & SUMITOMO METAL CORPORATION) 16 January 2014, claims, paragraphs [0001]-[0014], [0032]-[0055], [0069], table 1 (Family: none)	1-4 5
Y A	WO 2009/044802 A1 (SUMITOMO METAL INDUSTRIES, LTD.) 09 April 2009, paragraphs [0001], [0087] & US 2010/0054983 A1, paragraphs [0001], [0125] & US 2012/0141318 A1 & US 2015/0010425 A1 & EP 2199420 A1 & CA 2698562 A1 & KR 10-2010-0060026 A & CN 102317489 A & KR 10-2012-0137520 A & DK 2199420 T3 & ES 2420839 T3 & CN 104611624 A	1-4 5

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

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2012-1749 A (SANYO SPECIAL STEEL CO., LTD.) 05 January 2012, claims, paragraphs [0001], [0015]-[0029], [0032], table 1 (Family: none)	1-5
A	JP 2015-62910 A (NIPPON STEEL & SUMITOMO METAL CORPORATION) 09 April 2015 (Family: none)	1-5
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Form PCT/ISA/210 (continuation of second sheet) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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- JP 2003166039 A **[0003] [0006]**
- WO 2009044802 A **[0003] [0006]**