



(11) **EP 3 587 610 A1**

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

(43) Date of publication:
01.01.2020 Bulletin 2020/01

(51) Int Cl.:
C22C 38/00 ^(2006.01) **C21D 9/46** ^(2006.01)
C22C 38/50 ^(2006.01) **C22C 38/54** ^(2006.01)

(21) Application number: **18790531.0**

(86) International application number:
PCT/JP2018/016545

(22) Date of filing: **24.04.2018**

(87) International publication number:
WO 2018/199062 (01.11.2018 Gazette 2018/44)

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

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(30) Priority: **27.04.2017 JP 2017087756**

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(54) **HOT-ROLLED AND ANNEALED FERRITIC STAINLESS STEEL SHEET, AND METHOD FOR MANUFACTURING SAME**

(57) The present invention provides a hot-rolled and annealed ferritic stainless steel sheet which has sufficient corrosion resistance and in which cracks can be prevented during blanking into a thick flange, and a method for manufacturing the same. A hot-rolled and annealed ferritic stainless steel sheet has a chemical composition containing, in percent by mass, C: 0.001% to 0.020%,

Si: 0.05% to 1.00%, Mn: 0.05% to 1.00%, P: 0.04% or less, S: 0.01% or less, Al: 0.001% to 0.100%, Cr: 10.0% to 19.0%, Ni: 0.65% to 1.50%, Ti: 0.10% to 0.40%, and N: 0.001% to 0.020%, with the balance being Fe and unavoidable impurities, and has a threshold stress intensity factor K_{IC} of 35 MPa · m^{1/2} or more.

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Description

Technical Field

- 5 **[0001]** The present invention relates to a hot-rolled and annealed ferritic stainless steel sheet having excellent workability and being suitable for use in flanges and the like and a method for manufacturing the same.

Background Art

- 10 **[0002]** In recent years, there has been increased tightening of regulations on exhaust gas in automobiles and there has been an urgent need to improve the fuel efficiency. Accordingly, an exhaust gas recirculation (EGR) system, in which exhaust gas from an automobile engine is used again as intake air of the engine, has been increasingly used. The exhaust gas from the engine is passed through an EGR cooler for lowering the gas temperature, and then supplied again to the engine. In circulating the exhaust gas, exhaust system components are each jointed with a flange in order to prevent gas leakage. The flange used for such an exhaust system component is required to have sufficient rigidity. Therefore, for such an exhaust system component, a thick flange (e.g., with a sheet thickness of 5 mm or more) is used.
- 15 **[0003]** Ordinary steels have been hitherto used for thick flanges. However, flanges used for components through which high-temperature exhaust gas passes, for such as ones in EGR systems, are required to have sufficient corrosion resistance. Therefore, studies have been conducted on use of stainless steel, which has better corrosion resistance than ordinary steels, in particular, ferritic stainless steel, which has a relatively low coefficient of thermal expansion and in which thermal stress is unlikely to occur, and there has been a strong demand for a ferritic stainless steel sheet having a large thickness (e.g., a sheet thickness of 5 mm or more) that can be used for thick flanges.
- 20 **[0004]** In response to the market demand, for example, Patent Literature 1 discloses a hot-rolled ferritic stainless steel sheet containing, in percent by mass, C: 0.015% or less, Si: 0.01% to 0.4%, Mn: 0.01% to 0.8%, P: 0.04% or less, S: 0.01% or less, Cr: 14.0% to less than 18.0%, Ni: 0.05% to 1%, Nb: 0.3% to 0.6%, Ti: 0.05% or less, N: 0.020% or less, Al: 0.10% or less, and B: 0.0002% to 0.0020%, with the balance being Fe and unavoidable impurities, in which the contents of Nb, C, and N satisfy the formula: $Nb/(C + N) \geq 16$, and the hot-rolled ferritic stainless steel sheet has a Charpy impact value at 0°C of 10 J/cm² or more and a sheet thickness of 5.0 to 9.0 mm.

30 Citation List

Patent Literature

- 35 **[0005]** PTL 1: International Publication No. 2014/157576

Summary of Invention

Technical Problem

- 40 **[0006]** However, when the present inventors tried to work the hot-rolled ferritic stainless steel sheet described in Patent Literature 1 into the shape of a thick flange having a burring working part, in spite of the fact that the steel sheet had a sufficient Charpy impact value, in some cases, cracks occurred in the burring working part, in particular, at the central part in the sheet thickness direction, and it was not possible to obtain a predetermined flange shape, revealing that the hot-rolled ferritic stainless steel sheet was not sufficient enough to be used as a thick flange.
- 45 **[0007]** It is an object of the present invention to solve the problem described above and to provide a hot-rolled and annealed ferritic stainless steel sheet which has sufficient corrosion resistance and in which cracks can be prevented during blanking into a thick flange, and a method for manufacturing the same.

Solution to Problem

- 50 **[0008]** In order to solve the problem, the present inventors have conducted detailed studies, and as a result, have found that by increasing a threshold stress intensity factor K_{IC} of a steel sheet, the steel sheet can be worked into a thick flange having a burring working part without occurrence of cracks. Specifically, it has been found that, by setting the threshold stress intensity factor K_{IC} at 35 MPa · m^{1/2} or more, when a steel sheet worked into a thick flange having a burring working part, occurrence of cracks in the burring working part can be effectively prevented, and the steel sheet can be sufficiently put into practical use for a thick flange having a burring working part.
- 55 **[0009]** It has also been found that, by performing hot-rolled sheet annealing at an appropriate temperature on a hot-rolled steel sheet obtained by subjecting ferritic stainless steel having an appropriate chemical composition to finish hot-

rolling with multiple passes including three or more passes while appropriately controlling the accumulated rolling reduction of final three passes ($= 100 - (\text{final sheet thickness} / \text{sheet thickness before start of final three-pass rolling}) \times 100[\%]$), the threshold stress intensity factor K_{IC} is improved. The present invention has been made on the basis of the findings described above, and the gist of the invention is as follows.

[1] A hot-rolled and annealed ferritic stainless steel sheet having a chemical composition containing, in percent by mass, C: 0.001% to 0.020%, Si: 0.05% to 1.00%, Mn: 0.05% to 1.00%, P: 0.04% or less, S: 0.01% or less, Al: 0.001% to 0.100%, Cr: 10.0% to 19.0%, Ni: 0.65% to 1.50%, Ti: 0.10% to 0.40%, and N: 0.001% to 0.020%, with the balance being Fe and unavoidable impurities, and having a threshold stress intensity factor K_{IC} of $35 \text{ MPa} \cdot \text{m}^{1/2}$ or more.

[2] The hot-rolled and annealed ferritic stainless steel sheet according to [1], in which the chemical composition further contains, in percent by mass, one or two or more selected from Cu: 0.01% to 1.00%, Mo: 0.01% to 2.00%, W: 0.01% to 0.20%, and Co: 0.01% to 0.20%.

[3] The hot-rolled and annealed ferritic stainless steel sheet according to [1] or [2], in which the chemical composition further contains, in percent by mass, one or two or more selected from V: 0.01% to 0.20%, Nb: 0.01% to 0.10%, Zr: 0.01% to 0.20%, REM: 0.001% to 0.100%, B: 0.0002% to 0.0025%, Mg: 0.0005% to 0.0030%, and Ca: 0.0003% to 0.0030%.

[4] A method for manufacturing the hot-rolled and annealed ferritic stainless steel sheet according to any one of [1] to [3], including a hot rolling step of performing finish rolling with three or more passes and a hot-rolled sheet annealing step of performing hot-rolled sheet annealing at 600°C to $1,100^{\circ}\text{C}$ on a hot-rolled steel sheet obtained in the hot rolling step, in which, in the hot rolling step, the temperature of final three passes of finish rolling is set at 800°C to $1,100^{\circ}\text{C}$, and the accumulated rolling reduction of the final three passes is set at 25% or more.

[0010] Here, the term "threshold stress intensity factor K_{IC} " refers to a stress intensity factor obtained by taking a CT specimen according to ASTM E399 from the central part in the sheet width direction such that a fatigue pre-crack is introduced in a direction perpendicular to the rolling direction and the stress axis is in a direction parallel to the rolling direction and by conducting a test according to ASTM E399.

Advantageous Effects of Invention

[0011] According to the present invention, it is possible to obtain a hot-rolled and annealed ferritic stainless steel sheet which has sufficient corrosion resistance and excellent toughness so that cracks can be prevented during blanking into a thick flange.

[0012] In the present invention, the term "sufficient corrosion resistance" means that in the case where a steel sheet whose surface is polish-finished with #600 emery paper and whose edge surfaces are then sealed is subjected to a cyclic salt spray test specified in JIS H 8502 for five cycles (each cycle including salt spraying (5% by mass NaCl, 35°C , spraying for 2 hours) $\rightarrow$ drying (60°C , 4 hours, relative humidity: 40%) $\rightarrow$ wetting (50°C , 2 hours, relative humidity $\geq 95\%$)), the rust area ratio ($= \text{rust area} / \text{total area of steel sheet} \times 100[\%]$) in the surface of the steel sheet is 25% or less.

[0013] Furthermore, the expression "excellent toughness so that cracks can be prevented during blanking into a thick flange" means that a threshold stress intensity factor K_{IC} is $35 \text{ MPa} \cdot \text{m}^{1/2}$ or more, the threshold stress intensity factor K_{IC} being obtained by taking a CT specimen according to ASTM E399 from the central part in the sheet width direction such that a fatigue pre-crack is introduced in a direction perpendicular to the rolling direction and the stress axis is in a direction parallel to the rolling direction and by conducting a test according to ASTM E399.

Description of Embodiments

[0014] The embodiments of the present invention will be described below. Note that the present invention is not limited to the embodiments described below.

[0015] A hot-rolled and annealed ferritic stainless steel sheet according to the present invention has a chemical composition containing, in percent by mass, C: 0.001% to 0.020%, Si: 0.05% to 1.00%, Mn: 0.05% to 1.00%, P: 0.04% or less, S: 0.01% or less, Al: 0.001% to 0.100%, Cr: 10.0% to 19.0%, Ni: 0.65% to 1.50%, Ti: 0.10% to 0.40%, and N: 0.001% to 0.020%, with the balance being Fe and unavoidable impurities, and has a threshold stress intensity factor K_{IC} of $35 \text{ MPa} \cdot \text{m}^{1/2}$ or more.

[0016] The term "threshold stress intensity factor K_{IC} " refers to a stress intensity factor obtained by taking a CT specimen according to ASTM E399 from the central part in the sheet width direction such that a fatigue pre-crack is introduced in a direction perpendicular to the rolling direction and the stress axis is in a direction parallel to the rolling direction and by conducting a test according to ASTM E399.

[0017] The present invention will be described in detail below.

[0018] The present inventors have investigated in detail the reason for the occurrence of cracks when various ferritic stainless steel sheets with a sheet thickness of 5.0 mm are each formed into a flange having a burring working part in which a flange hole (30 mm ϕ) is raised by 10 mm from the surface of the steel sheet as blanked. As a result, it has been found that in the steel sheets in which cracks occur, microcracks generated in the vicinity of the central part in the sheet thickness direction of the blanked edge surface markedly propagate during burring, resulting in cracks.

[0019] The present inventors have investigated in detail the relationship between the marked propagation of microcracks and material characteristics. As a result, it has been found that propagation of microcracks tends to occur as the threshold stress intensity factor of the steel sheet decreases. Accordingly, by using various hot-rolled and annealed ferritic stainless steel sheets (sheet thickness 5.0 mm), formation into the flange has been tried. As a result, it has been found that cracks due to propagation of microcracks tend to occur in particular in a steel sheet in which the threshold stress intensity factor determined by a predetermined measurement method is less than 35 MPa $\cdot$ m^{1/2}.

[0020] Furthermore, in order to clarify why the steel sheet in which cracks occur during forming into the flange has a small threshold stress intensity factor, the present inventors have examined in detail cracked portions of the steel sheet. As a result, it has been found that in the steel sheet in which cracks occur, cracks generated in the vicinity of the central part in the sheet thickness direction of the blanked edge surface markedly propagate at grain boundaries in the vicinity of the central part in the sheet thickness direction.

[0021] From the results of examination and analysis of the microstructure of the steel sheet by an SEM/EBSD method, it has been found that, regarding crystal grains in a portion where cracks markedly propagate, although they are independent crystal grains, adjacent crystal grains have substantially the same crystal orientation, i.e., the crystal grains form colonies (groups of crystal grains having similar crystal orientations). In general, a crystal grain has a crystal orientation different from those of its adjacent crystal grains, and when cracks propagate along grain boundaries, grain boundaries having different orientations function as obstacles to propagation of the cracks. However, in a colony, since adjacent crystal grains have substantially the same crystal orientation, the effect of suppressing crack propagation due to grain boundaries between the individual crystal grains inside the colony is decreased. It has been found that because of this, in a steel sheet in which colonies are formed, the threshold stress intensity factor decreases, and cracks occur during forming into the flange.

[0022] Accordingly, the present inventors have performed thorough studies on the technique of improving the threshold stress intensity factor in a hot-rolled and annealed ferritic stainless steel sheet. As a result, it has been found that by subjecting ferritic stainless steel having an appropriate chemical composition to hot rolling under the conditions that the temperature of final three passes of finish rolling with multiple passes is set at 800°C to 1,100°C, and the accumulated rolling reduction of final three passes (= 100 - (final sheet thickness/sheet thickness before start of final three-pass rolling) $\times$ 100[%]) is set at 25% or more, and by performing hot-rolled sheet annealing at 600°C to 1,100°C on the resulting hot-rolled steel sheet, colonies are effectively destroyed, and a threshold stress intensity factor K_{IC} of 35 MPa $\cdot$ m^{1/2} or more can be obtained.

[0023] The sheet thickness of the hot-rolled and annealed ferritic stainless steel sheet according to the present invention is not particularly limited, but is desirably a sheet thickness that can be used for a thick flange. The lower limit of the sheet thickness is preferably 5.0 mm or more, and more preferably 9.0 mm or more. The upper limit of the sheet thickness is preferably 15.0 mm or less, and more preferably 10.0 mm or less.

[0024] The reason why destruction of colonies is promoted by the above-described technique will be described below.

[0025] In the central part in the thickness direction of a slab of ferritic stainless steel before being hot-rolled, coarse and elongated colonies (groups of crystal grains having similar crystal orientations) are distributed so as to extend in the casting direction. On the other hand, when a steel sheet is rolled, the steel sheet is deformed and elongated starting from the surface layer portion thereof. Therefore, in the case where the rolling reduction is small, the amount of deformation at the central part in the sheet thickness direction is small, and almost no rolling strain is introduced into the central part in the sheet thickness direction. Consequently, in hot rolling according to existing techniques, rolling strain is not sufficiently introduced into elongated grains at the central part in the sheet thickness direction of the steel sheet, recrystallization sites in the subsequent hot-rolled sheet annealing become insufficient, and although recrystallization occurs in the vicinity of the center in the sheet thickness direction during hot-rolled sheet annealing, colonies tend to remain without being broken. Thus, a threshold stress intensity factor K_{IC} of 35 MPa $\cdot$ m^{1/2} or more required in the present invention cannot be obtained.

[0026] Furthermore, in ferritic stainless steel, dynamic recrystallization hardly occurs during hot rolling, and recovery of work strain tends to occur during hot rolling. Therefore, in hot rolling according to existing techniques, excessive recovery of the work strain introduced by rolling occurs, and the work strain cannot be effectively maintained after hot rolling. Consequently, recrystallization sites become insufficient, colonies are not effectively destroyed in the subsequent hot-rolled sheet annealing step, and a predetermined threshold stress intensity factor K_{IC} cannot be obtained.

[0027] In view of the above, the present inventors have performed thorough studies on the effective technique of decreasing colonies remaining after hot-rolled sheet annealing from the viewpoint of both the steel composition and the hot rolling method. As a result, it has been found that it is effective to form a predetermined amount of an austenite

phase in the hot rolling step by controlling the steel composition, in particular, Cr and Ni contents, to appropriate ranges and to perform rolling with a large accumulated rolling reduction while controlling the temperature of final three passes of finish hot-rolling in the hot rolling step to an appropriate range.

[0028] In this way, colonies formed during casting can be destroyed by formation of the austenite phase, and in hot rolling, while suppressing recovery of rolling strain, rolling strain can be sufficiently and effectively introduced into the central part in the sheet thickness direction. Thereby, it is possible to obtain a hot-rolled sheet microstructure in which the number of colonies formed during casting that remain after hot rolling is markedly small compared with existing techniques, and the rolling strain acting as recrystallization sites in the subsequent hot-rolled sheet annealing step sufficiently remains. Consequently, colonies are further effectively removed in the subsequent hot-rolled sheet annealing step, and an excellent threshold stress intensity factor can be obtained.

[0029] Specifically, it has been invented, regarding a steel in which the Cr content is adjusted to 10.0% to 19.0% and the Ni content is adjusted to 0.65% to 1.50% so that an austenite phase is formed during heating before hot rolling, to perform hot rolling by appropriately controlling such that the temperature of final three passes of finish hot-rolling with three or more passes is set at 800°C to 1,100°C, and the accumulated rolling reduction of the final three passes ($= 100 - (\text{final sheet thickness/sheet thickness before start of final three-pass rolling}) \times 100[\%]$) is set at 25% or more.

[0030] Furthermore, the present inventors have performed thorough studies on the suitable conditions for the subsequent hot-rolled sheet annealing step. The hot-rolled sheet annealing step is a step of recrystallizing the deformed microstructure formed by hot rolling. Therefore, it is necessary to perform annealing at a temperature at which sufficient recrystallization occurs. However, when hot-rolled sheet annealing is performed at an excessively high temperature, although recrystallization occurs, recrystallized grains are markedly coarsened. The markedly coarse recrystallized grains are independent single crystal grains, but the grain boundary length increases markedly. Therefore, it has been found that, as in the case where colonies are present, the effect of suppressing crack propagation due to grain boundaries having different orientations is decreased, and a predetermined threshold stress intensity factor cannot be obtained.

[0031] Accordingly, the present inventors have investigated in detail the relationship between the grain size of recrystallized grains and the annealing temperature. As a result, it has been found that by controlling the hot-rolled sheet annealing temperature to 1,100°C or lower, formation of coarse recrystallized grains is prevented, thus making it possible to obtain a good threshold stress intensity factor.

[0032] The chemical composition of the hot-rolled and annealed ferritic stainless steel sheet according to the present invention will be described below. Hereinafter, unless otherwise stated, "%", which is the unit of measure for the content of each element, means "percent by mass".

C: 0.001% to 0.020%

[0033] When the C content exceeds 0.020%, workability and corrosion resistance in the weld zone noticeably deteriorate. A lower C content is more desirable from the viewpoint of corrosion resistance and workability. However, in order to set the C content at less than 0.001%, it takes a long time to perform refining, which is undesirable in terms of manufacturing. Therefore, the C content is set in a range of 0.001% to 0.020%. The lower limit thereof is preferably 0.003% or more, and more preferably 0.004% or more. The upper limit thereof is preferably 0.015% or less, and more preferably 0.012% or less.

Si: 0.05% to 1.00%

[0034] Si is an element that has an effect of improving corrosion resistance of weld zone by being concentrated in an oxide layer formed during welding and is also effective as a deoxidizing element in the steelmaking process. These effects are obtained when a Si content is 0.05% or more, and increase with the increase of the Si content. However, when the Si content exceeds 1.00%, an increase in rolling load and marked formation of scales are caused in the hot rolling step, and deterioration in the pickling property due to formation of a Si concentration layer at the surface layer of the steel sheet is caused in the annealing step, inducing an increase in surface defects and a rise in production cost, all of which are undesirable. Therefore, the Si content is set at 0.05% to 1.00%. The lower limit thereof is preferably 0.15% or more, and more preferably 0.20% or more. The upper limit thereof is preferably 0.60% or less, and more preferably 0.40% or less.

Mn: 0.05% to 1.00%

[0035] Mn has an effect of increasing the strength of steel and also acts as a deoxidizer. In order to obtain such effects, a Mn content of 0.05% or more is necessary. However, when the Mn content exceeds 1.00%, precipitation of MnS, which becomes a starting point of corrosion is promoted, resulting in deterioration in corrosion resistance. Therefore, the Mn content is set at 0.05% to 1.00%. The lower limit thereof is preferably 0.10% or more, and more preferably 0.20%

or more. The upper limit thereof is preferably 0.60% or less, and more preferably 0.40% or less.

P: 0.04% or less

[0036] P is an element that is unavoidably contained in steel. Since P is an element harmful to corrosion resistance and workability, it is desirable to decrease the amount of P as much as possible. In particular, when the P content exceeds 0.04%, workability is markedly deteriorated by solid solution strengthening. Therefore, the P content is set at 0.04% or less. Preferably, the P content is 0.03% or less. Since an excessive reduction in the P content requires excessive production cost, the P content is preferably 0.01% or more in consideration of production cost.

S: 0.01% or less

[0037] S is also an element that is unavoidably contained in steel as in P. Since S is an element harmful to corrosion resistance and workability, it is desirable to decrease the amount of S as much as possible. In particular, when the S content exceeds 0.01%, corrosion resistance is markedly deteriorated. Therefore, the S content is set at 0.01% or less. Preferably, the S content is 0.008% or less. More preferably, the S content is 0.003% or less. Since an excessive reduction in the S content requires excessive production cost, the S content is preferably 0.001% or more in consideration of production cost.

Al: 0.001% to 0.100%

[0038] Al is an effective deoxidizer. Furthermore, since Al has higher affinity for nitrogen than Cr, in the case where nitrogen enters a weld zone, by precipitating nitrogen as Al nitrides instead of Cr nitrides, Al has an effect of suppressing sensitization. These effects can be obtained at an Al content of 0.001% or more. However, when the Al content exceeds 0.100%, since the penetration characteristics for welding is deteriorated, welding workability is deteriorated, which is undesirable. Therefore, the Al content is set in a range of 0.001% to 0.100%. The lower limit thereof is preferably 0.010% or more, and more preferably 0.020% or more. The upper limit thereof is preferably 0.080% or less, and more preferably 0.060% or less.

Cr: 10.0% to 19.0%

[0039] Cr is the most important element for ensuring corrosion resistance of stainless steel. When the Cr content is less than 10.0%, sufficient corrosion resistance cannot be obtained in an automobile exhaust gas atmosphere. On the other hand, when the Cr content exceeds 19.0%, even if a predetermined amount of Ni is contained, a predetermined amount of an austenite phase is not formed during heating in the hot rolling step. Consequently, a sufficient effect of destroying colonies cannot be obtained, and a predetermined threshold stress intensity factor cannot be obtained. Therefore, the Cr content is set in a range of 10.0% to 19.0%. The lower limit thereof is preferably 10.5% or more, and more preferably 11.0% or more. The upper limit thereof is preferably 16.5% or less, more preferably 12.5% or less, and still more preferably 11.5% or less.

Ni: 0.65% to 1.50%

[0040] Ni is an austenite-forming element and has an effect of increasing the amount of austenite formed during heating before rolling in the hot rolling step. In the present invention, by controlling the contents of Cr and Ni to predetermined values, an austenite phase is formed during heating in the hot rolling step. Owing to the formation of the austenite phase, colonies of the ferrite phase formed during casting are destroyed. Furthermore, at the heating temperature before hot rolling, the metallic microstructure is formed into a two-phase structure of ferrite phase + austenite phase. In the case where the metallic microstructure is formed into a two-phase structure of ferrite phase + austenite phase, the interface between different phases, i.e., between the ferrite phase existing before heating and the austenite phase formed during heating, functions as an obstacle to growth of crystal grains, and therefore, the metallic microstructure before hot rolling is refined. As a result, the metallic microstructure after hot rolling is refined and that after the subsequent hot-rolled sheet annealing step is also refined. Thus, it becomes possible to exhibit a better effect of improving toughness. Depending on the steel composition, there may be a case where, at the heating temperature before hot rolling, the metallic microstructure is formed into an austenite single phase. Even in the case where the metallic microstructure at the heating temperature is formed into an austenite single-phase structure, as in the above, the effect of destroying colonies due to formation of the austenite phase can be obtained. In addition, in the austenite phase, since coarsening of crystal grains hardly occur in the slab heating temperature range before hot rolling, the metallic microstructure before hot rolling is finer than that of ferritic stainless steel based on existing techniques, and as in the above, the effect of improving

toughness due to refinement of crystal grains can be obtained. These effects can be obtained at a Ni content of 0.65% or more. When the Ni content is 0.65% or more, owing to these effects, a threshold stress intensity factor of 35 MPa $\cdot$ m^{1/2} or more can be obtained. On the other hand, when the Ni content exceeds 1.50%, the effect of improving the threshold stress intensity factor is saturated, and workability is deteriorated. Furthermore, stress corrosion cracking easily occur. Therefore, the Ni content is set at 0.65% to 1.50%. The lower limit thereof is preferably 0.70% or more, and more preferably 0.75% or more. The upper limit thereof is preferably 1.00% or less, and more preferably, the Ni content is 0.90% or less.

Ti: 0.10% to 0.40%

[0041] In the present invention, Ti is a very important element. Since Ti preferentially combines with C and N, which suppresses precipitation of Cr carbonitrides and lowers the recrystallization temperature, Ti has an effect of suppressing deterioration of corrosion resistance caused by sensitization due to precipitation of Cr carbonitrides. In order to obtain these effects, a Ti content of 0.10% or more is necessary. However, when the Ti content exceeds 0.40%, since the amount of solute Ti excessively increases, the recrystallization temperature rather rises, and the technique of the present invention cannot be used. Furthermore, when the Ti content exceeds 0.40%, coarse Ti carbonitrides are formed in the casting step, resulting in surface defects, which is also undesirable in terms of manufacturing. Therefore, the Ti content is set at 0.10% to 0.40%. The lower limit thereof is preferably 0.15% or more, more preferably 0.20% or more, and still more preferably 0.25% or more. The upper limit thereof is preferably 0.35% or less, and more preferably 0.30% or less. From the viewpoint of corrosion resistance of weld zone, the Ti content is preferably set so as to satisfy the formula: $Ti/(C + N) \geq 8$, where Ti, C, and N denote contents of the individual elements (percent by mass).

N: 0.001% to 0.020%

[0042] When the N content exceeds 0.020%, workability and corrosion resistance in the weld zone noticeably deteriorate. A lower N content is more desirable from the viewpoint of corrosion resistance. However, in order to decrease the N content to less than 0.001%, it is necessary to perform refining for a long time, resulting in an increase in production cost and a decrease in productivity, which are undesirable. Therefore, the N content is set in a range of 0.001% to 0.020%. The lower limit thereof is preferably 0.005% or more, and more preferably 0.007% or more. The upper limit thereof is preferably 0.015% or less, and more preferably 0.012% or less.

[0043] The present invention relates to a ferritic stainless steel featured by containing the above-described essential elements, with the balance being Fe and unavoidable impurities. Furthermore, as necessary, the ferritic stainless steel may contain one or two or more selected from Cu, Mo, W, and Co and/or one or two or more selected from V, Nb, Zr, REM, B, Mg, and Ca in the ranges described below. In the case where any range has a lower limit, even if the relevant element is contained in an amount less than the lower limit, the advantageous effects of the present invention are not impaired. Therefore, in the case where the element is contained in an amount less than the lower limit, the element is considered as an unavoidable impurity.

Cu: 0.01% to 1.00%

[0044] Cu is a particularly effective element in improving corrosion resistance of the base metal and weld zone in an aqueous solution or when weakly acidic water drops adhere thereto. This effect is obtained at a Cu content of 0.01% or more and increases with increasing Cu content. However, when the Cu content exceeds 1.00%, hot workability deteriorates, which may induce surface defects in some cases. Furthermore, descaling after annealing may become difficult in some cases. Therefore, when Cu is contained, the Cu content is preferably set in a range of 0.01% to 1.00%. The lower limit thereof is more preferably 0.10% or more, and still more preferably 0.30% or more. The upper limit thereof is more preferably 0.60% or less, and still more preferably 0.45% or less.

Mo: 0.01% to 2.00%

[0045] Mo is an element that remarkably improves the corrosion resistance of stainless steel. This effect is obtained at a Mo content of 0.01% or more and improves with increasing content. However, when the Mo content exceeds 2.00%, the rolling load during hot rolling increases, which may deteriorate productivity, and the strength of the steel sheet may be excessively increased in some cases. Furthermore, since Mo is an expensive element, a large content of Mo increases the production cost. Therefore, when Mo is contained, the Mo content is preferably set at 0.01% to 2.00%. The lower limit thereof is more preferably 0.10% or more, and still more preferably 0.30% or more. The upper limit thereof is more preferably 1.40% or less, and still more preferably 0.90% or less.

W: 0.01% to 0.20%

[0046] W has an effect of improving corrosion resistance, similarly to Mo. This effect is obtained at a W content of 0.01% or more. However, when the W content exceeds 0.20%, strength is increased, which may cause deterioration in productivity due to an increase in the rolling load and the like in some cases. Therefore, when W is contained, the W content is preferably set in a range of 0.01% to 0.20%. The lower limit thereof is more preferably 0.05% or more. The upper limit thereof is more preferably 0.15% or less.

Co: 0.01% to 0.20%

[0047] Co is an element that improves toughness. This effect is obtained at a Co content of 0.01% or more. On the other hand, when the Co content exceeds 0.20%, workability may be deteriorated in some cases. Therefore, when Co is contained, the Co content is preferably set in a range of 0.01% to 0.20%.

V: 0.01% to 0.20%

[0048] Since V combines with C and N as carbonitrides and suppresses precipitation of Cr carbonitrides, V improves corrosion resistance of weld zone. This effect is obtained at a V content of 0.01% or more. On the other hand, when the V content exceeds 0.20%, workability and toughness may be markedly deteriorated in some cases. Therefore, the V content is preferably set at 0.01% to 0.20%. The lower limit thereof is more preferably 0.02% or more. The upper limit thereof is more preferably 0.10% or less.

Nb: 0.01% to 0.10%

[0049] Nb has an effect of refining crystal grains and an effect of improving the toughness of the steel sheet by being dissolved in the matrix phase. These effects are obtained at a Nb content of 0.01% or more. On the other hand, Nb also has an effect of increasing the recrystallization temperature. When the Nb content exceeds 0.10%, there may be a case where the annealing temperature required to cause sufficient recrystallization in hot-rolled sheet annealing becomes excessively high, recrystallized grains are markedly coarsened during annealing such that the crystal grain size is 300 μm or more at maximum, and a predetermined threshold stress intensity factor cannot be obtained. Therefore, when Nb is contained, the Nb content is preferably set in a range of 0.01% to 0.10%. The lower limit thereof is more preferably 0.02% or more. The upper limit thereof is more preferably 0.08% or less.

Zr: 0.01% to 0.20%

[0050] Since Zr combines with C and N as carbonitrides and suppressing precipitation of Cr carbonitrides, Zr improves corrosion resistance of weld zone by. This effect is obtained at a Zr content of 0.01% or more. On the other hand, when the Zr content exceeds 0.20%, workability may be markedly deteriorated in some cases. Therefore, when Zr is contained, the Zr content is preferably set in a range of 0.01% to 0.20%. The lower limit thereof is more preferably 0.03% or more. The upper limit thereof is more preferably 0.10% or less.

REM: 0.001% to 0.100%

[0051] Since REM (Rare Earth Metals) has an effect of improving oxidation resistance, which suppresses formation of an oxide layer (temper color by welding) in weld zone and formation of a Cr-depleted region immediately below the oxide layer, REM improves corrosion resistance of weld zone. This effect is obtained at an REM content of 0.001% or more. On the other hand, when the REM content exceeds 0.100%, productivity, such as picklability, during cold-rolled annealing may be deteriorated in some cases. Therefore, when REM is contained, the REM content is preferably set in a range of 0.001% to 0.100%. The lower limit thereof is more preferably 0.005% or more. The upper limit thereof is more preferably 0.050% or less.

B: 0.0002% to 0.0025%

[0052] B is an element effective in improving resistance to secondary work embrittlement after deep drawing. This effect is obtained at a B content of 0.0002% or more. On the other hand, when the B content exceeds 0.0025%, workability and toughness may be deteriorated in some cases. Therefore, when B is contained, the B content is preferably set in a range of 0.0002% to 0.0025%. The lower limit thereof is more preferably 0.0003% or more. The upper limit thereof is more preferably 0.0006% or less.

Mg: 0.0005% to 0.0030%

[0053] Mg increases the equiaxed crystal ratio of a slab and is an element effective in improving workability and toughness. Furthermore, Mg has an effect of suppressing coarsening of Ti carbonitrides; in steel containing Ti as in the present invention, when Ti carbonitrides are coarsened, toughness deteriorates. These effects are obtained at a Mg content of 0.0005% or more. On the other hand, when the Mg content exceeds 0.0030%, surface properties of steel may be deteriorated in some cases. Therefore, when Mg is contained, the Mg content is preferably set in a range of 0.0005% to 0.0030%. The lower limit thereof is more preferably 0.0010% or more. The upper limit thereof is more preferably 0.0020% or less.

Ca: 0.0003% to 0.0030%

[0054] Ca is an element effective in preventing nozzle blockage due to crystallization of Ti-based inclusions which tends to occur during continuous casting. The effect is obtained at a Ca content of 0.0003% or more. However, when the Ca content exceeds 0.0030%, corrosion resistance may be deteriorated by formation of CaS in some cases. Therefore, when Ca is contained, the Ca content is preferably set in a range of 0.0003% to 0.0030%. The lower limit thereof is more preferably 0.0005% or more, and still more preferably 0.0006% or more. The upper limit thereof is more preferably 0.0015% or less, and still more preferably 0.0010% or less.

[0055] A method for manufacturing a hot-rolled and annealed ferritic stainless steel sheet according to the present invention will be described below.

[0056] A hot-rolled and annealed ferritic stainless steel sheet according to the present invention is obtained by subjecting a steel slab having the chemical composition described above to hot rolling which includes rough rolling and finish rolling with three or more passes, under the conditions that the temperature of final three passes of finish rolling is set at 800°C to 1,100°C, and the accumulated rolling reduction of the final three passes is set at 25% or more, to obtain a hot-rolled steel sheet, and further performing hot-rolled sheet annealing on the hot-rolled steel sheet at 600°C to 1,100°C.

[0057] First, molten steel having the chemical composition described above is produced by a known method using a converter, an electric furnace, a vacuum melting furnace, or the like and is formed into a steel (slab) by a continuous casting process or an ingot casting-slabbing process.

[0058] The slab is, after being heated at 1,050°C to 1,250°C for 1 to 24 hours, or without being heated, directly as cast, subjected to hot rolling. In the present invention, rough rolling is not particularly limited, however, in the case where the cast structure is effectively destroyed before finish hot-rolling, this is advantageous to refinement of crystal grains in the subsequent finish hot-rolling. Therefore, the accumulated rolling reduction in rough rolling is preferably set at 65% or more. Then, finish hot-rolling is performed until a predetermined sheet thickness is reached, in which the temperature of final three passes of finish rolling is set in a range of 800°C to 1,100°C, and the accumulated rolling reduction of the final three passes is set at 25% or more.

[0059] Rolling temperature range of final three passes: 800°C to 1,100°C

Accumulated rolling reduction of final three passes: 25% or more

Although the coarse cast structure is destroyed in rough rolling before finish rolling, the crystal grains in the resultant structure are still markedly coarse. In order to obtain a predetermined threshold stress intensity factor after hot-rolled sheet annealing, it is necessary to effectively introduce rolling strain, in particular, to the central part in the sheet thickness direction while suppressing recovery of strain during the rolling by appropriately controlling the rolling temperature and the accumulated rolling reduction of final three passes.

[0060] The reason why it is necessary to effectively introduce rolling strain to the central part in the sheet thickness direction is as follows. In rolling, by subjecting a steel sheet to shear deformation, the thickness of the steel sheet is reduced. The amount of shear strain in rolling (hereinafter, expressed as "rolling strain") decreases from the surface layer toward the central part in the sheet thickness direction. Accordingly, when the rolling reduction is small, while a large amount of rolling strain is introduced to the surface layer and its vicinity of the steel sheet, the amount of rolling strain introduced to the central part in the sheet thickness direction is small. Rolling strain acts as recrystallization sites in the subsequent hot-rolled sheet annealing step. However, in the case where the amount of rolling strain introduced to the central part in the sheet thickness direction is small, recrystallization at the central part in the sheet thickness direction becomes insufficient during hot-rolled sheet annealing, the metallic microstructure of the hot-rolled sheet annealed steel sheet becomes non-uniform in the sheet thickness direction, and a predetermined threshold stress intensity factor cannot be obtained. Therefore, in order to effectively introduce rolling strain to the central part in the sheet thickness direction, it is necessary to perform rolling with a certain rolling reduction or more and by the time at which recovery of rolling strain occurs.

[0061] In order to introduce a sufficient number of recrystallization sites so that a predetermined metallic microstructure can be obtained in the subsequent hot-rolled sheet annealing step, it is necessary to effectively introduce rolling strain to the central part in the sheet thickness direction by setting the rolling temperature of the final three passes in a range

of 800°C to 1,100°C and setting the accumulated rolling reduction of final three passes ($= 100 - (\text{final sheet thickness} / \text{sheet thickness before start of final three-pass rolling}) \times 100[\%]$) at 25% or more, while preventing removal of the rolling strain introduced by the final three passes due to recovery,.

[0062] When the accumulated rolling reduction of final three passes is less than 25%, since rolling strain is not effectively introduced to the central part in the sheet thickness direction, colonies remain in the subsequent hot-rolled sheet annealing step, and a predetermined threshold stress intensity factor cannot be obtained. Therefore, the accumulated rolling reduction of final three passes is set at 25% or more. The accumulated rolling reduction is preferably 30% or more, and more preferably 35% or more. The upper limit of the accumulated rolling reduction is not particularly limited. However, when the accumulated rolling reduction is excessively increased, the rolling load increases, resulting in deterioration of productivity, and surface roughening may occur after rolling in some cases. Therefore, the upper limit of the accumulated rolling reduction is preferably set at 60% or less.

[0063] When the rolling temperature of final three passes is set at lower than 800°C, the rolling load markedly increases with a decrease in steel sheet temperature, which is undesirable in terms of production. Furthermore, low-temperature rolling may cause surface roughening in the steel sheet, resulting in deterioration of surface quality in some cases. On the other hand, when the rolling temperature of final three passes exceeds 1,100°C, recovery of the strain introduced by rolling occurs, and the number of recrystallization sites after the subsequent hot-rolled sheet annealing step becomes insufficient. Consequently, colonies remain after hot-rolled sheet annealing, and a predetermined threshold stress intensity factor cannot be obtained. Therefore, the rolling temperatures of final three passes are set in a range of 800°C to 1,100°C. The lower limit thereof is preferably 850°C or higher. The upper limit thereof is preferably 1,050°C or lower, and more preferably 1,000°C or lower. Regarding the rolling temperatures of final three passes, the rolling temperature of the final pass means the rolling end temperature, and the rolling temperatures of the other passes mean the respective rolling start temperatures.

[0064] Furthermore, in order to prevent an excessive rolling load from being applied at a specific pass in the final three passes, preferably, the rolling temperature at the first pass, among the final three passes, is set in a range of 950°C to 1,100°C, the rolling temperature at the second pass performed after the first pass is set in a range of 925°C to 1,075°C, and the rolling temperature at the third pass performed after the second pass is set in a range of 875°C to 1,050°C.

[0065] Furthermore, the method for manufacturing a hot-rolled and annealed ferritic stainless steel sheet according to the present invention is featured by controlling the temperature range and applying a large reduction in final three passes of finish hot-rolling with three or more passes. When rolling that applies a large reduction is performed in final four or more passes, even with the same accumulated rolling reduction as in the case of applying a large reduction in final three passes only, since the rolling reduction is distributed among the individual passes, strain is insufficiently introduced to the central part in the sheet thickness direction. Furthermore, since the accumulated transfer time for all the passes increases, recovery is promoted during the transfer period among the individual passes, and the effect of applying strain is decreased. Furthermore, when the rolling temperature and the accumulated rolling reduction of finish rolling are controlled only for final two passes or less, since a large reduction with a accumulated rolling reduction of 25% or more is performed in two passes, the rolling load is markedly increased, and productivity may be deteriorated in some cases, which is undesirable. Therefore, in the method for manufacturing the hot-rolled ferritic stainless steel sheet according to the present invention, the rolling temperature and the accumulated rolling reduction of final three passes of finish rolling are controlled.

[0066] In the method for manufacturing a hot-rolled ferritic stainless steel sheet according to the present invention, it is important to control the rolling temperature and the accumulated rolling reduction of final three passes, and as long as finish rolling includes three or more passes, finish rolling may be performed with any number of passes. However, when the maximum number of passes exceeds 15, the steel sheet temperature tends to be decreased because of an increased number of contacts with rolls in the rolling mill, leading to deterioration in productivity or an increase in production cost, for example, a need to perform heating from outside in order to maintain the steel sheet temperature within a predetermined temperature range. Therefore, the maximum number of passes is preferably 15 or less, and more preferably 10 or less.

[0067] After finish hot-rolling, the steel sheet is cooled, and then coiled to obtain a hot-rolled steel strip. In the present invention, the coiling temperature is not particularly limited. However, when the coiling temperature is set at higher than 450°C and lower than 500°C, embrittlement due to 475°C embrittlement may occur in some cases. Therefore, the coiling temperature is preferably set at 450°C or lower or 500°C or higher.

[0068] Hot-rolled sheet annealing temperature: 600°C to 1,100°C

In the present invention, after the hot rolling step is finished, hot-rolled sheet annealing is performed. In hot-rolled sheet annealing, the roll-deformed microstructure formed in the hot rolling step is recrystallized. In the present invention, by effectively introducing rolling strain in the hot rolling step so that the number of recrystallization sites is increased, destruction of colonies in hot-rolled sheet annealing is promoted. In order to obtain this effect, it is necessary to perform hot-rolled sheet annealing at a temperature in a range of 600°C to 1,100°C. When the annealing temperature is lower than 600°C, recrystallization becomes insufficient, and a predetermined threshold stress intensity factor cannot be

obtained. On the other hand, when the annealing temperature exceeds 1,100°C, recrystallized grains are markedly coarsened such that the crystal grain size is 300 μm or more at maximum, and a predetermined threshold stress intensity factor cannot be obtained. Therefore, the hot-rolled sheet annealing temperature is set in a range of 600°C to 1,100°C. The lower limit thereof is preferably 650°C or higher, and more preferably 700°C or higher. The upper limit thereof is preferably 1,050°C or lower, and more preferably 900°C or lower. Note that the holding time and the technique of hot-rolled sheet annealing are not particularly limited, and either box annealing (batch annealing) or continuous annealing may be performed.

[0069] The resulting hot-rolled and annealed steel sheet may be subjected, as necessary, to a descaling treatment by shot blasting or pickling. Furthermore, in order to improve surface properties, the steel sheet may be subjected to grinding, polishing, or the like. Moreover, the hot-rolled and annealed steel sheet provided by the present invention may be further subjected to cold rolling and cold-rolled sheet annealing.

EXAMPLES

[0070] The present invention will be described in more detail below on the basis of examples.

[0071] Molten stainless steels having the chemical compositions shown in Table 1 were each melted and refined in a converter with a capacity of 150 tons by a strong stirring-vacuum oxygen decarburization (SS-VOD) process, and a steel slab with a width of 1,000 mm and a thickness of 200 mm was formed by continuous casting. Except for No. 36, each of the slabs was heated at 1,150°C for one hour, and then subjected to rough rolling, as hot rolling, using a three-stand reversing mill to form a steel sheet with a thickness of about 40 mm. Subsequently, by subjecting the steel sheet to finish rolling with seven passes, in which final three passes (5th pass, 6th pass, and 7th pass) were performed under the conditions shown in Table 2, a hot-rolled steel sheet was obtained. Regarding No. 36, the slab was heated at 1,300°C for one hour, and then subjected to hot rolling. The resulting hot-rolled steel sheets were subjected to hot-rolled sheet annealing by a box annealing process under the conditions also shown in Table 2, and thus hot-rolled and annealed sheets were obtained. Note that the 7th pass end thickness corresponds to the thickness of the hot-rolled steel sheet. The following evaluations were made on the resulting hot-rolled and annealed steel sheets.

(1) Evaluation of threshold stress intensity factor K_{IC}

[0072] A CT (compact tension) specimen according to ASTM E399 was taken from the central part in the sheet width direction of each of the hot-rolled and annealed steel sheets such that a fatigue pre-crack introduced in a direction perpendicular to the rolling direction and the stress axis was in a direction parallel to the rolling direction. The specimens were tested in accordance with ASTM E399 to obtain a threshold stress intensity factor K_{IC} . Specimens with a threshold stress intensity factor of 35 MPa · m^{1/2} or more were evaluated as "pass", and specimens with a threshold stress intensity factor of less than 35 MPa · m^{1/2} were evaluated as "rejection".

(2) Evaluation of corrosion resistance

[0073] A specimen of 60 × 100 mm was taken from each of the hot-rolled and annealed steel sheets. After a surface to be evaluated of the specimen was polish-finished with #600 emery paper, edge surfaces and a back surface of the specimen were sealed in order to eliminate influences from the edge surfaces and the back surface. Then, the specimen was subjected to a cyclic salt spray test specified in JIS H 8502. In the cyclic salt spray test, five cycles were performed, each cycle including salt spraying (5% by mass NaCl, 35°C, spraying for 2 hours) → drying (60°C, 4 hours, relative humidity: 40%) → wetting (50°C, 2 hours, relative humidity ≥ 95%). After the cyclic salt spray test was conducted for five cycles, the surface to be evaluated of the specimen was photographed, and the rust area in the surface of the specimen was measured by image analysis. From the ratio of the rust area to the total area of the specimen, the rust area ratio ((rust area in specimen/total area of specimen) × 100[%]) was calculated. Specimens with a rust area ratio of 10% or less were evaluated as "pass" (○) with particularly excellent corrosion resistance, specimens with a rust area ratio of more than 10% and 25% or less were evaluated as "pass" (○), and specimens with a rust area ratio of more than 25% were evaluated as "rejection" (×).

[0074] The test results together with hot rolling and hot-rolled sheet annealing conditions are shown in Table 2.

[Table 1]

Steel symbol	Chemical composition (mass%)											Remarks
	C	Si	Mn	P	S	Al	Cr	Ni	Ti	N	Others	
A1	0.007	0.23	0.22	0.03	0.002	0.03	10.6	1.21	0.29	0.006	-	Example
A2	0.008	0.21	0.22	0.03	0.002	0.03	11.4	0.79	0.24	0.009	-	Example
A3	0.007	0.58	0.26	0.03	0.004	0.04	10.9	0.70	0.26	0.010	-	Example
A4	0.013	0.74	0.25	0.04	0.005	0.04	11.2	0.67	0.27	0.014	-	Example
A5	0.009	0.19	0.54	0.03	0.004	0.03	10.6	0.72	0.25	0.011	-	Example
A6	0.010	0.22	0.96	0.04	0.005	0.04	11.5	0.65	0.26	0.012	-	Example
A7	0.008	0.14	0.18	0.04	0.001	0.02	17.3	1.02	0.33	0.009	-	Example
A8	0.010	0.28	0.26	0.04	0.003	0.03	16.1	1.11	0.29	0.005	-	Example
A9	0.009	0.26	0.26	0.03	0.002	0.04	18.7	1.25	0.24	0.013	-	Example
A10	0.007	0.23	0.28	0.01	0.002	0.02	16.4	0.76	0.22	0.013	-	Example
A11	0.008	0.25	0.25	0.03	0.003	0.02	15.8	1.13	0.28	0.009	-	Example
A12	0.008	0.27	0.28	0.03	0.005	0.02	15.9	1.48	0.28	0.007	-	Example
A13	0.006	0.21	0.27	0.01	0.004	0.02	10.5	0.67	0.27	0.010	Cu: 0.34, B:0.0011	Example
A14	0.006	0.28	0.29	0.03	0.001	0.03	18.8	0.68	0.27	0.013	-	Example
A15	0.011	0.21	0.24	0.03	0.004	0.04	10.6	1.46	0.24	0.007	Mo:0.51, Zr:0.16	Example
A16	0.009	0.24	0.29	0.04	0.004	0.02	19.0	1.48	0.27	0.005	-	Example
A17	0.006	0.26	0.22	0.01	0.005	0.03	16.7	0.81	0.38	0.011	Cu:0.43	Example
A18	0.012	0.22	0.25	0.02	0.002	0.03	16.2	0.83	0.32	0.011	Mo:1.22	Example
A19	0.011	0.23	0.21	0.01	0.002	0.03	10.9	0.85	0.19	0.009	W:0.08	Example
A20	0.005	0.22	0.29	0.03	0.004	0.03	11.7	0.82	0.36	0.011	Co:0.11	Example
A21	0.010	0.26	0.28	0.02	0.003	0.02	11.2	0.76	0.17	0.011	V:0.10	Example
A22	0.007	0.27	0.27	0.03	0.006	0.03	11.0	0.75	0.28	0.014	V:0.04, Nb:0.06	Example
A23	0.019	0.27	0.26	0.03	0.004	0.04	10.8	0.84	0.38	0.019	Zr:0.06	Example
A24	0.007	0.23	0.25	0.03	0.002	0.04	16.1	0.90	0.33	0.010	REM:0.007	Example

(continued)

Steel symbol	Chemical composition (mass%)											Remarks
	C	Si	Mn	P	S	Al	Cr	Ni	Ti	N	Others	
A25	0.010	0.27	0.25	0.02	0.004	0.03	16.4	1.09	0.16	0.009	B:0.0009	Example
A26	0.007	0.26	0.26	0.03	0.005	0.02	16.2	1.33	0.19	0.010	Mg:0.0006, Ca:0.0008	Example
A27	0.009	0.19	0.24	0.03	0.003	0.03	11.3	0.78	0.25	0.010	-	Example
B1	0.006	0.26	0.29	0.04	0.003	0.04	10.9	<u>0.16</u>	0.26	0.006	-	Comparative Example
B2	0.007	0.30	0.19	0.03	0.004	0.03	11.1	<u>0.61</u>	0.24	0.006	-	Comparative Example
B3	0.005	0.12	0.27	0.02	0.006	0.02	17.5	<u>0.24</u>	0.33	0.008	-	Comparative Example
B4	0.007	0.16	0.21	0.04	0.002	0.03	17.1	<u>0.60</u>	0.31	0.007	-	Comparative Example
B5	0.008	0.21	0.22	0.04	0.004	0.04	<u>19.7</u>	<u>1.49</u>	0.24	0.006	-	Comparative Example
B6	0.006	0.23	0.21	0.03	0.004	0.03	16.4	0.68	<u>0.06</u>	0.009	-	Comparative Example
B7	0.009	0.19	0.26	0.04	0.003	0.03	16.2	0.77	<u>0.47</u>	0.010	-	Comparative Example
The balance other than the elements in the chemical composition described above consists of Fe and unavoidable impurities. Underlined items are outside the range of the present invention.												

[Table 2]

No.	Steel symbol	Rough rolling end thickness [mm]	5th pass start thickness [mm]	5th pass start temperature [°C]	6th pass start temperature [°C]	7th pass end temperature [°C]	7th pass end thickness [mm]	Accumulated rolling reduction of final three passes [%]	Hot-rolled sheet annealing temperature [°C]	K _{IC} [MPa·m ^{1/2}]	Corrosion resistance	Remarks
1	A1	40.3	13.2	965	935	895	9.7	27	803	43	○	Example
2	A2	39.8	13.2	995	960	904	9.7	27	806	41	○	Example
3	A3	40.2	13.5	987	947	913	10.0	26	814	38	○	Example
4	A4	40.4	13.4	984	951	922	9.8	27	828	35	○	Example
5	A5	39.9	13.7	972	937	909	10.2	26	801	42	○	Example
6	A6	40.0	13.4	980	942	918	9.7	28	805	45	○	Example
7	A7	40.4	13.5	971	938	900	9.9	27	866	39	○	Example
8	A8	39.5	13.2	962	939	894	9.9	25	833	40	○	Example
9	A9	39.7	14.1	1016	980	930	10.2	28	881	37	○	Example
10	A10	40.2	13.0	959	934	885	9.7	25	830	35	○	Example
11	A11	40.1	13.3	997	970	928	9.9	26	832	37	○	Example
12	A12	39.6	13.2	986	950	897	9.7	27	839	42	○	Example
13	A13	40.5	12.9	973	935	888	9.6	26	727	38	○	Example
14	A14	39.8	13.3	992	956	898	9.8	26	894	36	○	Example
15	A15	39.6	13.5	969	946	890	9.8	27	816	45	○	Example
16	A16	40.0	13.4	1014	977	921	10.0	25	877	39	○	Example
17	A17	39.8	13.1	966	933	879	9.7	26	835	39	○	Example
18	A18	40.2	13.2	965	927	883	9.7	27	829	41	○	Example
19	A19	40.2	13.1	973	945	898	9.5	27	830	39	○	Example
20	A20	39.5	13.4	966	936	887	9.7	28	830	40	○	Example
21	A21	39.7	13.4	995	961	913	9.7	28	756	40	○	Example
22	A22	40.2	13.2	969	939	881	9.9	25	703	41	○	Example

(continued)

No.	Steel symbol	Rough rolling end thickness [mm]	5th pass start thickness [mm]	5th pass start temperature [°C]	6th pass start temperature [°C]	7th pass end temperature [°C]	7th pass end thickness [mm]	Accumulated rolling reduction of final three passes [%]	Hot-rolled sheet annealing temperature [°C]	K_{IC} [MPa·m ^{1/2}]	Corrosion resistance	Remarks
23	A23	40.5	13.3	984	963	907	9.5	29	833	40	○	Example
24	A24	40.1	13.4	991	955	903	9.5	29	826	41	○	Example
25	A25	39.6	13.4	991	961	909	9.6	28	827	39	○	Example
26	A26	39.7	13.3	969	947	890	9.6	28	836	40	○	Example
27	A2	40.5	15.4	1004	966	925	11.4	26	836	39	○	Example
28	A2	40.0	17.6	966	942	901	13.1	26	823	38	○	Example
29	A2	40.3	20.3	987	962	907	14.8	27	830	35	○	Example
30	A2	40.3	13.1	1098	1072	1044	9.4	28	823	35	○	Example
31	A2	39.9	13.6	959	933	877	9.7	29	829	47	○	Example
45	A27	40.1	7.6	956	931	898	5.2	32	603	44	○	Example
46	A27	40.2	14.5	979	943	914	10.3	29	605	40	○	Example
47	A27	40.1	14.4	972	939	909	10.3	28	671	42	○	Example
48	A27	39.9	14.4	965	932	899	10.2	29	898	38	○	Example
49	A27	40.0	14.6	976	944	917	10.3	29	1067	36	○	Example
32	A2	40.4	13.8	1123	1071	1038	9.8	29	827	28	○	Comparative Example
33	A2	39.7	12.7	961	934	902	10.6	17	835	20	○	Comparative Example
34	A2	40.3	13.4	998	965	929	9.9	26	1126	19	○	Comparative Example
36	A2	39.7	13.5	1179	1141	1112	10.0	26	830	17	○	Comparative Example
37	A2	40.1	13.8	794	776	Rolling was not able to be completed because of excessive load and evaluation was not possible						Comparative Example

(continued)

No.	Steel symbol	Rough rolling end thickness [mm]	5th pass start thickness [mm]	5th pass start temperature [°C]	6th pass start temperature [°C]	7th pass end temperature [°C]	7th pass end thickness [mm]	Accumulated rolling reduction of final three passes [%]	Hot-rolled sheet annealing temperature [°C]	K_{IC} [MPa m ^{1/2}]	Corrosion resistance	Remarks
38	<u>B1</u>	39.6	13.4	965	928	891	9.7	28	839	<u>22</u>	○	Comparative Example
42	<u>B2</u>	40.4	13.6	982	948	903	9.4	31	817	<u>21</u>	○	Comparative Example
39	<u>B3</u>	39.6	14.4	964	939	908	10.3	28	874	<u>22</u>	○	Comparative Example
40	<u>B4</u>	40.2	14.2	985	955	921	10.5	26	882	<u>23</u>	○	Comparative Example
41	<u>B5</u>	40.3	13.8	952	917	886	9.9	28	985	<u>16</u>	○	Comparative Example
43	<u>B6</u>	39.8	14.0	968	937	907	10.2	27	821	36	×	Comparative Example
44	<u>B7</u>	40.1	13.3	977	952	922	9.5	29	826	<u>16</u>	○	Comparative Example
50	<u>A27</u>	40.2	14.3	970	938	912	10.1	29	571	<u>18</u>	○	Comparative Example
Underlined items are outside the range of the present invention.												

[0075] In Nos. 1 to 31 and Nos. 45 to 49 of Table 2 in which the steel composition, hot rolling conditions, and hot-rolled sheet annealing conditions are within the ranges of the present invention, colonies were effectively destroyed by predetermined hot rolling and hot-rolled sheet annealing, and consequently, aimed values of threshold stress intensity factors were obtained. Furthermore, as a result of evaluation of corrosion resistance of the resulting hot-rolled and annealed sheets, it is confirmed that the hot-rolled and annealed sheets each have a rust area ratio of 25% or less, indicating sufficient corrosion resistance.

[0076] In particular, in Nos. 7, 9, and 14 which used steels A7, A9, and A14 with a Cr content of more than 17%, in No. 17 which used steel A17 containing Cu, and in No. 18 which used steel A18 containing Mo, the rust area ratio was 10% or less, indicating particularly excellent corrosion resistance.

[0077] In No. 32 in which the rolling temperature of final three passes was higher than the range of the present invention, although rolling was performed with a predetermined accumulated rolling reduction, since the rolling temperature was excessively high, recovery of working strain occurred and introduction of recrystallization sites was insufficient. Therefore, the effect of destroying colonies in hot-rolled sheet annealing was insufficient. Consequently, many colonies remained even after hot-rolled sheet annealing, and an aimed threshold stress intensity factor was not obtained.

[0078] In No. 33 in which the accumulated rolling reduction of final three passes was less than the range of the present invention, the effect of destroying colonies in the hot-rolled sheet annealing step was not obtained sufficiently. Consequently, many colonies remained in the central part in the sheet thickness direction even after hot-rolled sheet annealing, and a predetermined threshold stress intensity factor was not obtained.

[0079] In No. 34 in which the hot-rolled sheet annealing temperature was higher than the range of the present invention, formed recrystallized grains were markedly coarsened, and consequently, a predetermined threshold stress intensity factor was not obtained.

[0080] No. 36 is an example in which the slab was heated at 1,300°C for one hour, and then subjected to hot rolling, in which the rolling temperature ranges of final three passes of finish hot-rolling each exceeded 1,100°C. In No. 36, recovery of working strain occurred during rolling of final three-passes, and introduction of recrystallization sites became insufficient. Therefore, the effect of destroying colonies by hot-rolled sheet annealing was insufficient. Consequently, a predetermined threshold stress intensity factor was not obtained.

[0081] In No. 37 in which the rolling temperature ranges of final three passes were each lower than the range of the present invention, the rolling load was markedly increased, and during rolling at the final third pass, the load exceeded the permissible range of the device. Therefore, it was not possible to complete rolling, and predetermined evaluations were not possible.

[0082] In Nos. 38 to 41 which used steels B1 to B4 with a Ni content lower than the range of the present invention, although predetermined hot rolling and hot-rolled sheet annealing were performed, as a result of decrease in the austenite phase formation capability, the effect of destroying colonies in the hot rolling step was insufficient, and a predetermined threshold stress intensity factor was not obtained.

[0083] In No. 42 which used steel B5 with a Cr content higher than the range of the present invention, although a predetermined amount of Ni was contained, because of the excessive Cr content, the austenite phase formation capability was decreased. As a result, the effect of destroying colonies in the hot rolling step was insufficient, and a predetermined threshold stress intensity factor was not obtained.

[0084] In No. 43 which used steel B6 with a Ti content lower than the range of the present invention, sensitization occurred due to precipitation of a large amount of Cr carbonitrides during hot-rolled sheet annealing, and it was not possible to obtain a predetermined corrosion resistance. On the other hand, in No. 44 which used steel B7 with a Ti content higher than the range of the present invention, the recrystallization temperature was increased owing to the excessive Ti content, and even when predetermined hot-rolled sheet annealing was performed, colonies remained since sufficient recrystallization did not occur. As a result, a predetermined threshold stress intensity factor was not obtained.

[0085] In No. 50 in which the hot-rolled sheet annealing temperature was lower than the range of the present invention, because of insufficient recrystallization, a sufficient effect of destroying colonies was not obtained, and a predetermined threshold stress intensity factor was not obtained.

Industrial Applicability

[0086] The hot-rolled and annealed ferritic stainless steel sheet obtained in the present invention is suitable for application requiring high workability and corrosion resistance, for example, particularly suitable for use in a flange having a burring working part or the like.

Claims

1. A hot-rolled and annealed ferritic stainless steel sheet having a chemical composition containing, in percent by mass,

C: 0.001% to 0.020%,
 Si: 0.05% to 1.00%,
 Mn: 0.05% to 1.00%,
 P: 0.04% or less,
 S: 0.01% or less,
 Al: 0.001% to 0.100%,
 Cr: 10.0% to 19.0%,
 Ni: 0.65% to 1.50%,
 Ti: 0.10% to 0.40%, and
 N: 0.001% to 0.020%, with the balance being Fe and
 unavoidable impurities; and
 having a threshold stress intensity factor K_{IC} of 35 MPa · m^{1/2} or more.

2. The hot-rolled and annealed ferritic stainless steel sheet according to Claim 1, wherein the chemical composition further contains, in percent by mass, one or two or more selected from Cu: 0.01% to 1.00%,
 Mo: 0.01% to 2.00%,
 W: 0.01% to 0.20%, and
 Co: 0.01% to 0.20%.

3. The hot-rolled and annealed ferritic stainless steel sheet according to Claim 1 or 2, wherein the chemical composition further contains, in percent by mass, one or two or more selected from V: 0.01% to 0.20%,
 Nb: 0.01% to 0.10%,
 Zr: 0.01% to 0.20%,
 REM: 0.001% to 0.100%,
 B: 0.0002% to 0.0025%,
 Mg: 0.0005% to 0.0030%, and
 Ca: 0.0003% to 0.0030%.

4. A method for manufacturing the hot-rolled and annealed ferritic stainless steel sheet according to any one of Claims 1 to 3, comprising:

a hot rolling step of performing finish rolling with three or more passes; and
 a hot-rolled sheet annealing step of performing hot-rolled sheet annealing at 600°C to 1,100°C on a hot-rolled steel sheet obtained in the hot rolling step,
 wherein, in the hot rolling step, the temperature of final three passes of finish rolling is set at 800°C to 1,100°C,
 and the accumulated rolling reduction of the final three passes is set at 25% or more.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2018/016545

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. C22C38/00 (2006.01) i, C21D9/46 (2006.01) i, C22C38/50 (2006.01) i,
C22C38/54 (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. C22C38/00, C21D9/46, C22C38/50, C22C38/54

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

Published examined utility model applications of Japan 1922-1996

Published unexamined utility model applications of Japan 1971-2018

Registered utility model specifications of Japan 1996-2018

Published registered utility model applications of Japan 1994-2018

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 8-283913 A (NIPPON STEEL CORP.) 29 October 1996, claim 1, paragraph [0018], table 1 (Family: none)	1-4
A	JP 2001-181742 A (KAWASAKI STEEL CORP.) 03 July 2001, claim 2, paragraphs [0011], [0016], table 2 (Family: none)	1-4
E, A	WO 2018/074164 A1 (JFE STEEL CORPORATION) 26 April 2018, claim 1, paragraphs [0007], [0063], [0064], [0071], table 2 & JP 6304469 B1	4

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
09 July 2018 (09.07.2018)

Date of mailing of the international search report
24 July 2018 (24.07.2018)

Name and mailing address of the ISA/
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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2014157576 A [0005]