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

(11) EP 3 486 347 A1

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

(43) Date of publication:
**22.05.2019 Bulletin 2019/21**

(21) Application number: **17862905.1**

(22) Date of filing: **27.09.2017**

(51) Int Cl.:
***C22C 38/00*** *(2006.01)* ***C21D 8/02*** *(2006.01)*
***C21D 9/46*** *(2006.01)* ***C22C 38/50*** *(2006.01)*
***C22C 38/54*** *(2006.01)*

(86) International application number:
**PCT/JP2017/034949**

(87) International publication number:
**WO 2018/074164 (26.04.2018 Gazette 2018/17)**

(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:
**MA MD**

(30) Priority: **17.10.2016 JP 2016203348**

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

(57) Provided are a hot-rolled and annealed ferritic stainless steel sheet which has sufficient corrosion resistance and with which it is possible to inhibit a crack from occurring when punching work is performed to form a thick-walled flange and a method for manufacturing the steel sheet.

A hot-rolled and annealed ferritic stainless steel sheet having a chemical composition containing, 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 24.0%, Ni: 0.01% to 0.60%, Ti: 0.10% to 0.40%, N: 0.001% to 0.020%, and the balance being Fe and inevitable impurities, and

a threshold stress intensity factor $K_{IC}$ of 20 MPa $\cdot m^{1/2}$ or more.

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## Description

### Technical Field

**[0001]** The present invention relates to a hot-rolled and annealed ferritic stainless steel sheet excellent in terms of workability which can preferably be used for, for example, a flange and to a method for manufacturing the steel sheet.

### Background Art

**[0002]** Nowadays, since legislation and regulations regarding automobile exhaust gas are being strengthened, improving fuel efficiency is an urgent task. Therefore, there is a trend toward using an exhaust gas recirculation (EGR) system in which exhaust gas discharged from an automobile engine is reused as the intake gas of the engine. The exhaust gas discharged from an engine is passed through an EGR cooler, which is used for cooling the exhaust gas, and then charged again into the engine. When exhaust gas is recirculated, to prevent the exhaust gas from leaking, the parts of the exhaust system are connected with flanges being interposed between the parts. It is necessary that such flanges, which are used for parts of the exhaust system, have sufficient rigidity. Therefore, thick-walled flanges (for example, having a thickness of 5 mm or more) are used for such parts of the exhaust system.

**[0003]** Conventionally, plain carbon steel is used for such thick-walled flanges. However, flanges which are used for parts such as an EGR system, through which high-temperature exhaust gas passes, are required to have sufficient corrosion resistance. Therefore, consideration is being given to using stainless steel, which is superior to plain carbon steel in terms of corrosion resistance, in particular, ferritic stainless steel, with which thermal stress is less likely to be generated because of its comparatively low thermal expansion coefficient, and there is a strong demand for a ferritic stainless steel sheet having a large thickness (for example, a thickness of 5 mm or more) which can be used for thick-walled flanges.

**[0004]** In response to such a market demand, for example, Patent Literature 1 discloses a hot-rolled ferritic stainless steel sheet having a chemical composition containing, 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 18.0% (not inclusive), 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, B: 0.0002% to 0.0020%, and the balance being Fe and inevitable impurities, in which the contents of Nb, C, and N satisfy the relationship Nb/(C + N) ≥ 16, a Charpy impact value at a temperature of 0°C is 10 J/cm$^2$ or more, and a thickness is 5.0 mm to 9.0 mm.

### Citation List

### Patent Literature

**[0005]** PTL 1: International Publication No. WO2014/157576

### Summary of Invention

### Technical Problem

**[0006]** However, when the present inventors tried to form the hot-rolled ferritic stainless steel sheet according to Patent Literature 1 into a shape of a thick-walled flange having a portion subjected to burring work, it was clarified that the steel sheet is not good enough to be used for a thick-walled flange, because, despite the fact that the steel sheet had a sufficient Charpy impact value, a crack was generated in the portion subjected to burring work, in particular, in the central portion in the thickness direction, which made it impossible to obtain a specified flange shape in some cases.

**[0007]** An object of the present invention is, by solving the problems described above, to provide a hot-rolled and annealed ferritic stainless steel sheet which has sufficient corrosion resistance and with which it is possible to inhibit a crack from occurring when punching work is performed to form a thick-walled flange and to provide a method for manufacturing the steel sheet.

### Solution to Problem

**[0008]** The present inventors conducted detailed investigations to solve the problems and, as a result, found that, in the case where a steel sheet having a large thickness of more than 5.0 mm is formed into a thick-walled flange having a portion subjected to burring work without a crack being generated, although it is not possible to make accurate evaluations of workability on the basis of a Charpy impact value, which has been conventionally used, it is possible to make accurate evaluations of workability on the basis of the threshold stress intensity factor $K_{IC}$, which is the evaluation index of toughness in fields involving thick steel plates. This is because, while it is not possible to make unambiguous evaluations of a fracture phenomenon caused by forming work by using a fracture mechanics method in the case of a thin steel sheet having a thickness of less than 5.0 mm where a plastic deformation region in the vicinity of a punched end surface is too large in relation to the thickness when punching work is performed, it is possible to make accurate evaluations of a fracture phenomenon caused by a specified degree of work on the basis of the stress intensity factor, which is a fracture-mechanical quantitative index, in particular, on the basis of the threshold value of the factor, that is, the threshold stress intensity factor $K_{IC}$ in the case of a steel sheet having a large thickness of 5.0 mm or more where a plastic deformation region in the vicinity of a punched end surface is sufficiently small in relation to the thickness when punching work is performed, that is, a small-scale yielding condition is fully satisfied.

**[0009]** For the reasons described above, the present inventors conducted detailed investigations regarding the relationship between crack generation and the threshold stress intensity factor $K_{IC}$ when flange-forming work is performed to form a specified flange shape and, as a result, found that, by controlling the threshold stress intensity factor $K_{IC}$ to be 20 $MPa \cdot m^{1/2}$ or more, since it is possible to effectively inhibit a crack from occurring in a portion subjected to burring work when flange-forming work is performed to form a thick-walled flange having a portion subjected to burring work, it is possible to sufficiently put the thick steel sheet into practical use for a thick-walled flange having a portion subjected to burring work.

**[0010]** In addition, it was found that there is an improvement in the threshold stress intensity factor $K_{IC}$ as a result of performing hot-rolled-sheet annealing at an appropriate temperature on ferritic stainless steel having an appropriate chemical composition, in particular, on a hot-rolled steel sheet obtained by appropriately controlling the accumulated rolling reduction ratio in the final 3 passes (= 100 - (final thickness/thickness before rolling in final 3 passes is performed) × 100 [%]) in a multi-pass finish hot-rolling process composed of 3 passes or more.

**[0011]** The present invention has been completed on the basis of the knowledge described above, and the subject matter of the present invention is as follows.

[1] A hot-rolled and annealed ferritic stainless steel sheet having a chemical composition containing, 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 24.0%, Ni: 0.01% to 0.60%, Ti: 0.10% to 0.40%, N: 0.001% to 0.020%, and the balance being Fe and inevitable impurities, and
a threshold stress intensity factor $K_{IC}$ of 20 $MPa \cdot m^{1/2}$ or more.

[2] The hot-rolled and annealed ferritic stainless steel sheet according to item [1] above, in which the chemical composition further contains, by mass%, one, 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 item [1] or [2] above, in which the chemical composition further contains, by mass%, one, 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 items [1] to [3] above, the method including performing a hot-rolling process including finish rolling composed of 3 passes or more, in which rolling in final 3 passes of the finish rolling is performed in a temperature range of 800°C to 1100°C with an accumulated rolling reduction ratio of 25% or more to obtain a hot-rolled steel sheet and performing hot-rolled-sheet annealing on the hot-rolled steel sheet at a temperature of 800°C to 1100°C.

**[0012]** Here, the term "threshold stress intensity factor $K_{IC}$" refers to the stress intensity factor obtained by performing a test in accordance with ASTM E 399 on a compact tension (CT) test piece in accordance with ASTM E 399 taken from the central portion in the width direction of a steel sheet so that the direction of a fatigue precrack is in a direction perpendicular to the rolling direction and the stress axis is in a direction parallel to the rolling direction. Advantageous Effects of Invention

**[0013]** According to the present invention, it is possible to obtain a hot-rolled and annealed ferritic stainless steel sheet having sufficient corrosion resistance and excellent workability with which it is possible to inhibit a crack from occurring when punching work is performed to form a thick-walled flange.

**[0014]** Here, the term "sufficient corrosion resistance" in the present invention refers to a case where a rust area ratio (= rust area/total area of a steel sheet × 100 [%]) is 25% or less after having performed a salt spray cyclic corrosion test prescribed in JIS H 8502 5 cycles, where the unit cycle consists of salt spraying (5 mass% NaCl, 35°C, 2-hour spraying), drying (60°C, 4 hours, relative humidity = 40%), and wetting (50°C, 2 hours, relative humidity ≥ 95%), on a steel sheet whose end surfaces are sealed after the surface to be evaluated thereof has been polished by using #600 emery paper.

**[0015]** In addition, the expression "excellent workability with which it is possible to inhibit a crack from occurring when punching work is performed to form a thick-walled flange" refers to a case where, when a test is performed in accordance with ASTM E 399 on a CT test piece in accordance with ASTM E 399 taken from the central portion in the width direction of a steel sheet so that the direction of a fatigue precrack is in a direction perpendicular to the rolling direction and the stress axis is in a direction parallel to the rolling direction to obtain the threshold stress intensity factor, the obtained threshold stress intensity factor $K_{IC}$ is 20 MPa·m$^{1/2}$ or more.

Description of Embodiments

**[0016]** The hot-rolled and annealed ferritic stainless steel sheet according to the present invention has a chemical composition containing, 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 24.0%, Ni: 0.01% to 0.60%, Ti: 0.10% to 0.40%, N: 0.001% to 0.020%, and the balance being Fe and inevitable impurities, and a threshold stress intensity factor $K_{IC}$ of 20 MPa·m$^{1/2}$ or more.

**[0017]** The term "threshold stress intensity factor $K_{IC}$" refers to the stress intensity factor obtained by performing a test in accordance with ASTM E 399 on a CT test piece in accordance with ASTM E 399 taken from the central portion in the width direction of a steel sheet so that the direction of a fatigue precrack is in a direction perpendicular to the rolling direction and the stress axis is in a direction parallel to the rolling direction.

**[0018]** Hereafter, the present invention will be described in detail.

**[0019]** The present inventors conducted detailed investigations regarding the reasons why a crack was generated when flange-forming work was performed on each of various kinds of ferritic stainless steel sheets having a thickness of 5.0 mm to form a flange having a portion subjected to burring work so that the periphery of a flange hole having a diameter of 30 mmϕ was raised to a height of 10 mm with respect to the surface of a blank steel sheet (in the punched state) and, as a result, found that, in the case of the steel sheet in which a crack was generated, the crack was generated due to a microcrack, which had been generated in the vicinity of the central portion in the thickness direction of the steel sheet in a punched end surface, and had grown significantly when burring work was performed.

**[0020]** The present inventors conducted detailed investigations regarding the relationship between the significant growth of a microcrack and material properties and, as a result, found that, the smaller the threshold stress intensity factor $K_{IC}$ of a steel sheet, the more likely the microcrack is to grow significantly. Therefore, the present inventors tried to perform the above-described flange-forming work on various kinds of hot-rolled and annealed ferritic stainless steel sheets (having a thickness of 5.0 mm) and, as a result, found that a crack caused by the growth of a microcrack tends to occur in the case of a steel sheet having a threshold stress intensity factor $K_{IC}$ of less than 20 MPa·m$^{1/2}$, where the threshold stress intensity factor $K_{IC}$ is obtained by using the specified determination method.

**[0021]** Moreover, the present inventors conducted detailed investigations regarding the cracks of the steel sheets described above to clarify the reasons why the threshold stress intensity factors $K_{IC}$ of the steel sheets, in which cracks were generated when the above-described flange-forming work was performed, was small and, as a result, found that, in the case of a steel sheet in which a crack is generated, a microcrack generated in the vicinity of the central portion in the thickness direction in a punched end surface grows significantly at grain boundaries of the crystal grains in the vicinity of the central portion in the thickness direction.

**[0022]** In addition, from the results of investigations regarding the microstructure of a steel sheet involving analysis utilizing a scanning electron microscopy/electron backscatter diffraction (SEM/EBSD) method, it was found that crystal grains in a portion, in which a microcrack grows significantly, have crystal orientations almost identical to those of the adjacent crystal grains, that is, form a so-called colony (group of crystal grains having similar crystal orientations), although these crystal grains exist independently of each other. Generally, a crystal grain has an orientation different from the orientations of the adjacent crystal grains, and the boundaries of grains having different orientations have a function of obstructing the growth of a microcrack when the microcrack grows through the grain boundaries. However, since the crystal orientations of crystal grains adjacent to each other in a colony are almost identical, there is a decrease in the effect of inhibiting the growth of a microcrack at the grain boundaries of the crystal grains in the colony. That is, it was found that, in the case of a steel sheet in which a colony is formed, since there is a decrease in the threshold stress intensity factor $K_{IC}$, a crack was generated when the above-described flange-forming work is performed.

**[0023]** Therefore, the present inventors diligently conducted investigations regarding a method for improving the threshold stress intensity factor $K_{IC}$ of a hot-rolled and annealed ferritic stainless steel sheet and, as a result, found that it is possible to break colonies effectively and achieve a threshold stress intensity factor $K_{IC}$ of 20 MPa·m$^{1/2}$ or more by performing hot-rolled-sheet annealing at a temperature of 800°C to 1100°C on ferritic stainless steel having an appropriate chemical composition, in particular, on a hot-rolled steel sheet obtained by performing rolling in the final 3 passes of a hot-rolling process involving multi-pass finish rolling in a temperature range of 800°C to 1100°C with an accumulated rolling reduction ratio (= 100 - (final thickness/thickness before rolling in final 3 passes is performed) $\times$ 100 [%]) which is appropriately controlled to be 25% or more.

**[0024]** Here, although there is no particular limitation on the thickness of the hot-rolled and annealed ferritic stainless steel sheet according to the present invention, since it is preferable that the thickness be that of the steel sheet to be used for a thick-walled flange, it is preferable that the thickness be 5.0 mm or more or more preferably 7.0 mm or more. In addition, although there is no particular limitation on the thickness described above, it is preferable that the thickness be 15.0 mm or less or more preferably 10.0 mm or less.

**[0025]** The reasons why the breaking of a colony is promoted by using the method described above will be described hereafter.

**[0026]** In the central portion in the thickness direction of a slab of ferritic stainless steel which has yet to be subjected to hot-rolling, coarse and elongated colonies (groups of crystal grains having similar crystal orientations) are linearly distributed in the casting direction. On the other hand, when a steel sheet is rolled, the steel sheet is elongated in such a manner that deformation spreads from the surface layer thereof. Therefore, in the case where the rolling reduction ratio is small, since the amount of deformation is small in the central portion in the thickness direction, rolling strain is hardly applied to the central portion in the thickness direction.

**[0027]** Therefore, in the case of hot-rolling according to conventional techniques, since a sufficient amount of rolling strain is not applied to elongated grains in the central portion in the thickness direction of a steel sheet, there is an insufficient number of recrystallization sites when subsequent hot-rolled-sheet annealing is performed. Therefore, although recrystallization occurs to some extent in the vicinity of the central portion in the thickness direction when hot-rolled-sheet annealing is performed, colonies tend to be retained without being broken, which makes it impossible to achieve a threshold stress intensity factor $K_{IC}$ of 20 MPa·m$^{1/2}$ or more, which is required in the present invention.

**[0028]** Moreover, in the case of ferritic stainless steel, since dynamic recrystallization (refers to recrystallization occurring along with deformation due to work) hardly occurs when hot-rolling is performed, the recovery of strain due to work applied by performing rolling tends to occur. Therefore, in the case of hot-rolling according to conventional techniques, since the recovery of strain due to work applied by performing rolling occurs to an excessive degree, it is not possible to effectively maintain the strain due to work until after hot-rolling has been performed. As a result, since the number of recrystallization sites is insufficient, colonies are not effectively broken in a subsequent hot-rolled-sheet annealing process, which makes it impossible to achieve the specified threshold stress intensity factor $K_{IC}$.

**[0029]** Therefore, the present inventors diligently conducted investigations regarding a method for effectively and sufficiently applying strain due to rolling work across the entire thickness of a steel sheet in a hot-rolling process and, as a result, found that, by performing rolling in the final 3 passes of finish hot-rolling in an appropriately controlled temperature range with a large accumulated rolling reduction ratio, since strain due to rolling work is sufficiently and effectively applied to the central portion in the thickness direction while the recovery of strain due to rolling work is suppressed, it is possible to form a hot-rolled steel sheet microstructure retaining sufficient strain due to rolling work which functions as recrystallization sites in a subsequent hot-rolled-sheet annealing process, resulting in colonies being effectively broken in the subsequent hot-rolled-sheet annealing process.

**[0030]** Specifically, a method, in which rolling in the final 3 passes of a finish hot-rolling process composed of 3 passes or more is performed at a temperature of 800°C to 1100°C with an accumulated rolling reduction ratio (= 100 - (final thickness/thickness before rolling in final 3 passes is performed) × 100 [%]) which is appropriately controlled to be 25% or more, has been devised.

**[0031]** In addition, the present inventors also diligently conducted investigations regarding preferable conditions to be applied in a subsequent hot-rolled-sheet annealing. A hot-rolled-sheet annealing process is a process in which a worked microstructure formed by performing hot-rolling is recrystallized. Therefore, it is necessary that annealing be performed at a temperature at which sufficient recrystallization occurs. However, in the case where hot-rolled-sheet annealing is performed at an excessively high temperature, there is a significant coarsening of recrystallized grains, although recrystallization occurs. It was found that, although such significantly coarse recrystallized grains are individual crystal grains which exist independently of each other, since such grains have significantly long grain boundaries, there is a decrease in the effect of inhibiting the growth of a microcrack at the boundaries of the crystal grains having different orientations as in the case where colonies exist, which makes it impossible to achieve the specified threshold stress intensity factor $K_{IC}$.

**[0032]** Therefore, the present inventors conducted detailed investigations regarding the relationship between the grain diameter of a recrystallized crystal grain and an annealing temperature and, as a result, found that, by controlling a hot-rolled-sheet annealing temperature to be 1100°C or lower, it is possible to suppress the formation of such coarse recrystallized grains that there is a significant decrease in the threshold stress intensity factor $K_{IC}$.

**[0033]** Hereafter, the chemical composition of hot-rolled and annealed ferritic stainless steel sheet according to the present invention will be described.

**[0034]** Hereafter, "%" used when describing a chemical composition refers to "mass%", unless otherwise noted.

C: 0.001% to 0.020%

**[0035]** In the case where the C content is more than 0.020%, there is a significant deterioration in workability and in the corrosion resistance of a weld. Although it is preferable that the C content be as small as possible from the viewpoint of corrosion resistance and workability, it is not preferable that the C content be less than 0.001% from the viewpoint of manufacturing conditions, because this results in an increase in the time taken to perform refining. Therefore, the C content is set to be in the range of 0.001% to 0.020%. It is preferable that the C content be 0.003% or more or more preferably 0.004% or more. In addition, it is preferable that the C content be 0.015% or less or more preferably 0.012% or less.

Si: 0.05% to 1.00%

**[0036]** S is an element which is effective for improving the corrosion resistance of a weld as a result of being concentrated in an oxide layer formed when welding is performed and which is also effective as a deoxidizing agent in a steel-making process. Such effects are obtained in the case where the Si content is 0.05% or more, and such effects increase with an increase in Si content. However, it is not preferable that the Si content be more than 1.00%, because this results in an increase in the degree of surface defects and an increase in manufacturing costs, since there is an increase in rolling load and a significant increase in the amount of scale generated in a hot-rolling process, and since there is a deterioration in pickling performance due to Si being concentrated in the surface layer of a steel sheet in an annealing process. Therefore, the Si content is set to be 0.05% to 1.00%. It is preferable that the Si content be 0.10% or more. In addition, it is preferable that the Si content be 0.60% or less or more preferably 0.40% or less.

Mn: 0.05% to 1.00%

**[0037]** Mn is effective for improving the strength of steel and has a function as a deoxidizing agent. It is necessary that the Mn content be 0.05% or more to obtain such effects. However, in the case where the Mn content is more than 1.00%, since the formation of MnS, which becomes a starting point at which corrosion occurs, is promoted, there is a deterioration in corrosion resistance. Therefore, the Mn content is set to be 0.05% to 1.00%. It is preferable that the Mn content be 0.10% or more. In addition, it is preferable that the Mn content be 0.60% or less or more preferably 0.30% or less.

P: 0.04% or less

**[0038]** Although P is an element which is inevitably contained in steel, since P has a negative effect on corrosion resistance and workability, it is preferable that the P content be as small as possible. In particular, in the case where the P content is more than 0.04%, there is a significant deterioration in workability through solid solution strengthening. Therefore, the P content is set to be 0.04% or less or preferably 0.03% or less.

S: 0.01% or less

**[0039]** Although S is an element which is inevitably contained in steel like P, since S has a negative effect on corrosion resistance and workability, it is preferable that the S content be as small as possible. In particular, in the case where the S content is more than 0.01%, there is a significant deterioration in corrosion resistance.
Therefore, the S content is set to be 0.01% or less, preferably 0.008% or less, or more preferably 0.003% or less.

Al: 0.001% to 0.100%

**[0040]** Al is an effective deoxidizing agent. Moreover, since Al has a higher affinity for nitrogen than Cr does, nitrogen is precipitated in the form of Al nitrides instead of Cr nitrides when nitrogen enters a weld, which results in sensitization being effectively inhibited. Such effects are obtained in the case where the Al content is 0.001% or more. However, it is not preferable that the Al content be more than 0.100%, because this results in deterioration in welding workability due to a deterioration in weld penetration capability when welding is performed. Therefore, the Al content is set to be in the range of 0.001% to 0.100%. It is preferable that the Al content be 0.005% or more or more preferably 0.010% or more. In addition, it is preferable that the Al content be 0.060% or less or more preferably 0.040% or less.

Cr: 10.0% to 24.0%

**[0041]** Cr is an element which is most important for achieving the corrosion resistance of stainless steel. In the case where the Cr content is less than 10.0%, it is not possible to achieve sufficient corrosion resistance in an automobile exhaust gas atmosphere. On the other hand, in the case where the Cr content is more than 24.0%, since there is a significant deterioration in toughness due to the formation of a $\sigma$ (sigma) phase, it is not possible to achieve the specified threshold stress intensity factor $K_{IC}$ in the present invention. Therefore, the Cr content is set to be in the range of 10.0% to 24.0%. It is preferable that the Cr content be 14.0% or more, more preferably 16.0% or more, or even more preferably 17.0% or more. In addition, it is preferable that the Cr content be 21.5% or less, more preferably 19.5% or less, or even more preferably 18.5% or less.

Ni: 0.01% to 0.60%

**[0042]** Ni is an element which improves the corrosion resistance of stainless steel and which inhibits the progress of corrosion in a corrosive environment in which active dissolution occurs due to a passivation film not being formed. In addition, since Ni is such a strong austenite-forming element as to suppress the formation of ferrite in a weld, Ni is effective for inhibiting sensitization from occurring due to the precipitation of Cr carbonitrides. Such effects are obtained in the case where the Ni content is 0.01% or more, and such effects increase with an increase in Ni content. However, in the case where the Ni content is more than 0.60%, there is a deterioration in workability, and stress corrosion cracking tends to occur. Moreover, since Ni is an expensive element, it is not preferable that the Ni content be increased, because this results in an increase in manufacturing costs. Therefore, the Ni content is set to be 0.01% to 0.60%. It is preferable that the Ni content be 0.10% or more. In addition, it is preferable that the Ni content be 0.50% or less or more preferably 0.40% or less.

Ti: 0.10% to 0.40%

**[0043]** In the present invention, Ti is a very important element. Since Ti is more likely than other elements to combine with C and N such that the precipitation of Cr carbonitrides is inhibited, Ti is effective for decreasing a recrystallization temperature and for inhibiting a deterioration in corrosion resistance caused by sensitization due to the precipitation of Cr carbonitrides. It is necessary that the Ti content be 0.10% or more to obtain such effects. However, in the case where the Ti content is more than 0.40%, since there is an excessive increase in the amount of solid solution Ti, there is conversely an increase in recrystallization temperature, which makes it impossible to use the technique according to the present invention. In addition, it is not preferable that the Ti content be more than 0.40% from the viewpoint of manufacturing conditions, because this results in surface defects due to the formation of coarse Ti carbonitrides in a casting process. Therefore, the Ti content is set to be 0.10% to 0.40%. It is preferable that the Ti content be 0.15% or more or more preferably 0.20% or more. In addition, it is preferable that the Ti content be 0.35% or less or more preferably 0.30% or less. Here, from the viewpoint of the corrosion resistance of a weld, it is preferable that the Ti content satisfy the relational expression $Ti/(C+N) \geq 8$ (where, in the relational expression, Ti, C, and N respectively denote the content (mass%) of the corresponding elements).

N: 0.001% to 0.020%

**[0044]** In the case where the N content is more than 0.020%, there is a significant deterioration in workability and in the corrosion resistance of a weld. Although it is preferable that the N content be as small as possible from the viewpoint of corrosion resistance, it is not preferable that the N content be decreased to less than 0.001%, because this results in an increase in manufacturing costs and in a decrease in productivity due to an increase in the time taken to perform refining. Therefore, the N content is set to be in the range of 0.001% to 0.020%. It is preferable that the N content be 0.005% or more or more preferably 0.007% or more. In addition, it is preferable that the N content be 0.015% or less or more preferably 0.012% or less.

**[0045]** The present invention provides ferritic stainless steel having a chemical composition containing the essential elements describe above and the balance being Fe and inevitable impurities. Moreover, one, two, or more selected from Cu, Mo, W and Co and/or one, two, or more of V, Nb, Zr, REM, B, Mg, and Ca may be optionally contained within the ranges described below.

Cu: 0.01% to 1.00%

**[0046]** Cu is an element which is particularly effective for improving the corrosion resistance of a base metal and a weld in an aqueous solution or in the case where weakly acidic water drops stick to them. Such an effect is obtained in the case where the Cu content is 0.01% or more, and such an effect increases with an increase in Cu content. However, in the case where the Cu content is more than 1.00%, there is a deterioration in hot workability, which may result in surface defects. Moreover, there may be a case where it is difficult to perform descaling after annealing has been performed. Therefore, in the case where Cu is contained, it is preferable that the Cu content be in the range of 0.01% to 1.00%. It is more preferable that the Cu content be 0.10% or more or even more preferably 0.30% or more. In addition, it is more preferable that the Cu content be 0.60% or less or even more preferably 0.45% or less.

Mo: 0.01% to 2.00%

**[0047]** Mo is an element which significantly improves the corrosion resistance of stainless steel. Such an effect is obtained in the case where the Mo content is 0.01% or more, and such an effect increases with an increase in Mo content. However, in the case where the Mo content is more than 2.00%, there may be a deterioration in manufacturability due to an increase in rolling load when hot-rolling is performed, and there may be an excessive increase in the strength of a steel sheet. In addition, since Mo is an expensive element, there is an increase in manufacturing costs in the case where the Mo content is high. Therefore, in the case where Mo is contained, it is preferable that the Mo content be 0.01% to 2.00%. It is more preferable that the Mo content be 0.10% or more or even more preferably 0.30% or more. In addition, it is more preferable that the Mo content be 1.40% or less or even more preferably 0.90% or less.

W: 0.01% to 0.20%

**[0048]** W is effective for improving corrosion resistance like Mo. Such an effect is obtained in the case where the W content is 0.01% or more. However, in the case where the W content is more than 0.20%, since there is an increase in strength, there may be a deterioration in manufacturability due to, for example, an increase in rolling load. Therefore, in the case where W is contained, it is preferable that the W content be in the range of 0.01% to 0.20%. It is more preferable that the W content be 0.05% or more. In addition, it is more preferable that the W content be 0.15% or less.

Co: 0.01% to 0.20%

**[0049]** Co is an element which improves toughness. Such an effect is obtained in the case where the Co content is 0.01% or more. On the other hand, in the case where the Co content is more than 0.20%, there may be a deterioration in workability. Therefore, in the case where Co is contained, it is preferable that the Co content be in the range of 0.01% to 0.20%. It is more preferable that the Co content be 0.10% or less.

V: 0.01% to 0.20%

**[0050]** V improves the corrosion resistance of a weld by inhibiting sensitization from occurring when welding is performed as a result of combining with C and N to form carbonitrides. Such an effect is obtained in the case where the V content is 0.01% or more. On the other hand, in the case where the V content is more than 0.20%, there may be a significant deterioration in workability and toughness. Therefore, it is preferable that the V content be 0.01% to 0.20%. It is more preferable that the V content be 0.03% or more. In addition, it is more preferable that the V content be 0.10% or less or even more preferably 0.05% or less.

Nb: 0.01% to 0.10%

**[0051]** Nb is effective for refining crystal grains and for improving the toughness of a steel sheet by forming a solid solution in a parent phase. Such effects are obtained in the case where the Nb content is 0.01% or more. On the other hand, since Nb is also effective for increasing a recrystallization temperature, there is an excessive increase in annealing temperature at which sufficient recrystallization occurs in hot-rolled-sheet annealing in the case where the Nb content is more than 0.10% such that there is significant coarsening of recrystallized grains to a maximum of 300 $\mu$m or more during annealing, which may make it impossible to achieve the specified threshold stress intensity factor $K_{IC}$. Therefore, in the case where Nb is contained, it is preferable that the Nb content be in the range of 0.01% to 0.10%. It is more preferable that the Nb content be 0.02% or more. In addition, it is more preferable that the Nb content be 0.05% or less.

Zr: 0.01% to 0.20%

**[0052]** Zr is effective for inhibiting sensitization by combining with C and N. Such an effect is obtained in the case where the Zr content is 0.01% or more. On the other hand, in the case where the Zr content is more than 0.20%, there may be a significant deterioration in workability. Therefore, in the case where Zr is contained, it is preferable that the Zr content be in the range of 0.01% to 0.20%. It is more preferable that the Zr content be 0.02% or more. In addition, it is more preferable that the Zr content be 0.10% or less or even more preferably 0.05% or less.

REM: 0.001% to 0.100%

**[0053]** Since rare earth metals (REM) is effective for improving oxidation resistance, REM inhibits the formation of a Cr-depleted zone directly underneath an oxide layer (welding temper color) in a weld by inhibiting the formation of the oxide layer. Such an effect is obtained in the case where the REM content is 0.001% or more. On the other hand, in the case where the REM content is more than 0.100%, there may be a deterioration in manufacturability such as pickling performance when cold-rolled-sheet annealing is performed. Therefore, in the case where REM is contained, it is preferable that the REM content be in the range of 0.001% to 0.100%. It is more preferable that the REM content be 0.010% or more. In addition, it is more preferable that the REM content be 0.050% or less.

B: 0.0002% to 0.0025%

**[0054]** B is an element which is effective for improving secondary work brittleness resistance after forming has been performed. Such an effect is obtained in the case where the B content is 0.0002% or more. On the other hand, in the case where the B content is more than 0.0025%, there may be a deterioration in workability and toughness. Therefore, in the case where B is contained, it is preferable that the B content be in the range of 0.0002% to 0.0025%. It is more preferable that the B content be 0.0003% or more. In addition, it is more preferable that the B content be 0.0006% or less.

Mg: 0.0005% to 0.0030%

**[0055]** Mg is an element which is effective for improving workability and toughness by improving the equiaxial crystal ratio of a slab. Moreover, although there is a deterioration in toughness when there is coarsening of Ti carbonitrides in the case of steel containing Ti as in the case of the present invention, Mg is also effective for inhibiting coarsening of Ti carbonitrides. Such effects are obtained in the case where the Mg content is 0.0005% or more. On the other hand, in the case where the Mg content is more than 0.0030%, there may be a deterioration in the surface quality of steel. Therefore, in the case where Mg is contained, it is preferable that the Mg content be in the range of 0.0005% to 0.0030%. It is more preferable that the Mg content be 0.0010% or more. In addition, it is more preferable that the Mg content be 0.0020% or less.

Ca: 0.0003% to 0.0030%

**[0056]** Ca is an element which is effective for preventing nozzle clogging, which tends to occur due to Ti-based inclusions being crystallized when continuous casting is performed. Such an effect is obtained in the case where the Ca content is 0.0003% or more. However, in the case where the Ca content is more than 0.0030%, there may be a deterioration in corrosion resistance due to the formation of CaS. Therefore, in the case where Ca is contained, it is preferable that the Ca content be in the range of 0.0003% to 0.0030%. It is more preferable that the Ca content be 0.0005% or more. In addition, it is more preferable that the Ca content be 0.0015% or less or even more preferably 0.0010% or less.

Threshold stress intensity factor $K_{IC}$: 20 MPa·m$^{1/2}$ or more

**[0057]** In the case of the hot-rolled and annealed ferritic stainless steel sheet according to the present invention, by controlling the threshold stress intensity factor $K_{IC}$ to be 20 MPa·m$^{1/2}$ or more, it is possible to inhibit a crack from occurring when punching work is performed to form a thick-walled flange. It is preferable that the threshold stress intensity factor $K_{IC}$ be 25 MPa·m$^{1/2}$ or more or more preferably 30 MPa·m$^{1/2}$ or more. Here, the meaning of the term "thick-walled flange" includes, for example, a flange having a wall thickness of 5.0 mm or more, although there is no particular limitation on the thickness. It is preferable that the above-described flange have a wall thickness of, for example, 5.0 mm to 15.0 mm or more preferably 5.0 mm to 10.0 mm.

**[0058]** Hereafter, the method for manufacturing the hot-rolled and annealed ferritic stainless steel sheet according to the present invention will be described. Hereinafter, the term "temperature" refers to the surface temperature of, for example, a steel slab or a hot-rolled steel sheet, which is determined by using, for example, a surface pyrometer, unless otherwise noted.

**[0059]** It is possible to obtain the hot-rolled and annealed ferritic stainless steel sheet according to the present invention by performing a hot-rolling process involving rough rolling and finish rolling which is composed of 3 passes or more on a steel slab having the chemical composition described above, in which rolling in the final 3 passes of finish rolling is performed in a temperature range of 800°C to 1100°C with an accumulated rolling reduction ratio of 25% or more to obtain a hot-rolled steel sheet, and by further performing hot-rolled-sheet annealing in a temperature range of 800°C to 1100°C on the hot-rolled steel sheet.

**[0060]** First, molten steel having the chemical composition described above is prepared by using a known method such as one which utilizes, for example, a converter, an electric furnace, or a vacuum melting furnace and made into steel (slab) by using a continuous casting method or an ingot casting-slabbing method.

**[0061]** This slab is subjected to the hot-rolling after having been heated at a temperature of 1100°C to 1250°C for 1 hour to 24 hours or when the slab has a temperature of 1100°C to 1250°C without having been heated after casting has been performed. In the present invention, although there is no particular limitation on the rough rolling, it is preferable that an accumulated rolling reduction ratio in the rough rolling be 65% or more to effectively break a cast structure before the finish hot-rolling is performed, because this is effective for refining of crystal grains in the subsequent finish hot-rolling. When the finish hot-rolling is subsequently performed to obtain a specified thickness, rolling in the final 3 passes of the finish rolling is performed in a temperature range of 800°C to 1100°C with an accumulated rolling reduction ratio of 25% or more.

Rolling temperature range in final 3 passes of finish hot-rolling: 800°C to 1100°C

Accumulated rolling reduction ratio in final 3 passes of finish hot-rolling: 25% or more

**[0062]** Although the coarse cast structure has been broken when the rough rolling is performed before the finish rolling is performed, the crystal grains in such a broken structure is significantly coarse. To achieve the specified threshold stress intensity factor $K_{IC}$ after the hot-rolled-sheet annealing has been performed, it is necessary to effectively apply rolling strain to, in particular, the central portion in the thickness direction while inhibiting excessive recovery from occurring during rolling by appropriately controlling rolling temperature and accumulated rolling reduction ratio in the final 3 passes of the finish hot-rolling.

**[0063]** To form a sufficient number of recrystallization sites for forming the specified microstructure in the subsequent hot-rolled-sheet annealing process, by controlling rolling temperature in the final 3 passes of the finish hot-rolling to be 800°C to 1100°C, and by controlling accumulated rolling reduction ratio in the final 3 passes (= 100 - (final thickness/thickness before rolling in final 3 passes is performed) $\times$ 100 [%]) to be 25% or more, it is necessary to effectively apply rolling strain to the central portion in the thickness direction while preventing the rolling strain applied in the final 3 passes from being eliminated through recovery.

**[0064]** In the case where the accumulated rolling reduction ratio in the final 3 passes of the finish hot-rolling is less than 25%, since it is not possible to effectively apply rolling strain to the central portion in the thickness direction, colonies are retained in the subsequent hot-rolled-sheet annealing process, which makes it impossible to achieve the specified threshold stress intensity factor $K_{IC}$. Therefore, the accumulated rolling reduction ratio in the final 3 passes is set to be 25% or more, preferably 30% or more, or even more preferably 35% or more. Here, although there is no particular limitation on the upper limit of the accumulated rolling reduction ratio, in the case where the accumulated rolling reduction ratio is excessively high, there is a deterioration in manufacturability due to an increase in rolling load, and rough surface may occur after the rolling has been performed. Therefore, it is preferable that the accumulated rolling reduction ratio be 60% or less.

**[0065]** It is not preferable that the rolling temperature in the final 3 passes of the finish hot-rolling be lower than 800°C from the viewpoint of manufacturing conditions, because this results in a significant increase in rolling load due to a decrease in the temperature of a steel sheet. In addition, there may be a deterioration in surface quality due to rough surface occurring on the surface of a steel sheet as a result of rolling at a low temperature. On the other hand, in the case where the rolling temperature in the final 3 passes of the finish hot-rolling is higher than 1100°C, since the recovery of strain applied by performing rolling occurs, there is an insufficient number of recrystallization sites after the subsequent hot-rolled-sheet annealing has been performed, which makes it impossible to achieve the specified threshold stress intensity factor $K_{IC}$ due to colonies being retained after the hot-rolled-sheet annealing has been performed. Therefore, the rolling temperature in the final 3 passes is set to be 800°C to 1100°C, preferably 800°C to 1050°C, or more preferably 850°C to 1000°C.

**[0066]** Here, to prevent rolling load from excessively increasing in a specific pass in the final 3 passes of the finish hot-rolling, it is preferable that the rolling temperature range of the first pass of the final 3 passes be 950°C to 1100°C, that the rolling temperature range of the second pass to be performed following the first pass be 925°C to 1075°C, and that the rolling temperature range of the third pass to be performed following the second pass be 875°C to 1050°C.

**[0067]** In addition, the method for manufacturing the hot-rolled and annealed ferritic stainless steel sheet according to the present invention is characterized by performing rolling with large rolling reduction in the final 3 passes of the finish hot-rolling composed of 3 passes or more while controlling the rolling temperature range. In the case where such rolling with large rolling reduction is performed in the final 4 passes or more, there is a decrease in the effect of applying strain, because insufficient strain is applied to the central portion in the thickness direction due to the accumulated rolling reduction ratio being divided into each of the passes even with the same accumulated rolling reduction ratio, and because recovery in the interval time between the passes is promoted due to an increase in accumulated transporting time between the passes. In addition, it is not preferable that the rolling temperature and the accumulated rolling reduction ratio of the finish rolling be controlled in the final 2 passes or less, because this may result in a deterioration in manufacturability due to a significant increase in rolling load as a result of rolling being performed with such large rolling reduction as an accumulated rolling reduction ratio of 25% or more in 2 passes. 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 ratio are controlled in the final 3 passes of the finish rolling.

**[0068]** Here, in the method for manufacturing the hot-rolled ferritic stainless steel sheet according to the present invention, since it is important that the rolling temperature and the accumulated rolling reduction ratio be controlled in the final 3 passes of the finish hot-rolling, there is no particular limitation on the number of passes in the finish rolling as long as the number of passes is 3 or more. However, in the case where the maximum number of passes is more than 15, since the temperature of a steel sheet tends to be decreased due to an increase in the number of contacts with rolling rolls, it is necessary to perform, for example, external heating to keep the temperature of a steel sheet within a specified temperature range, which may result in a deterioration in manufacturability or an increase in manufacturing costs. Therefore, it is preferable that the maximum number of passes be 15 or less or more preferably 10 or less.

**[0069]** After the finish hot-rolling has been performed, cooling followed by coiling is performed on the steel sheet to obtain a hot-rolled steel strip. In the present invention, although there is no particular limitation on the coiling temperature, there may be a case where embrittlement occurs due to 475°C embrittlement in the case where the coiling temperature is more than 450°C to less than 500°C. Therefore, it is preferable that the coiling temperature be 450°C or lower or 500°C or higher.

Hot-rolled-sheet annealing temperature: 800°C to 1100°C

**[0070]** In the present invention, hot-rolled-sheet annealing is performed after the above-described hot-rolling process has been performed. In the hot-rolled-sheet annealing, a microstructure formed by performing rolling work in the hot-rolling process is recrystallized. In the present invention, by effectively applying rolling strain to a steel sheet in the hot-rolling process to increase the number of recrystallization sites, the breaking of colonies in the hot-rolled-sheet annealing is promoted. It is necessary that the hot-rolled-sheet annealing be performed at a temperature of in the range of 800°C to 1100°C to obtain such an effect. In the case where the annealing temperature is lower than 800°C, since sufficient recrystallization does not occur, it is not possible to achieve the specified threshold stress intensity factor $K_{IC}$. On the other hand, in the case where the annealing temperature is higher than 1100°C, since there is a significant coarsening of recrystallized grains to a maximum of 300 μm or more, which makes it impossible to achieve the specified threshold stress intensity factor $K_{IC}$. Therefore, the hot-rolled-sheet annealing temperature is set to be 800°C to 1100°C. A hot-rolled steel sheet which has been subjected to such hot-rolled-sheet annealing described above has the chemical composition described above and a threshold stress intensity factor $K_{IC}$ of 20 MPa·m$^{1/2}$ or more. It is preferable that the hot-rolled-sheet annealing temperature be 800°C to 1050°C or more preferably 850°C to 1000°C. Here, there is no particular limitation on the holding time or the method used for hot-rolled-sheet annealing, any one of box annealing (batch annealing) and continuous annealing may be used.

**[0071]** The obtained hot-rolled and annealed steel sheet may be subjected to a descaling treatment such as shot blasting or pickling as needed. Moreover, grinding, polishing, or the like may be performed to improve surface quality. In addition, the hot-rolled and annealed steel sheet provided by the present invention may further be subjected to cold rolling and cold-rolled-sheet annealing.

EXAMPLES

**[0072]** Hereafter, the present invention will be described in detail on the basis of examples.

**[0073]** Molten stainless steels having the chemical compositions given in Table 1 were prepared by performing refining which utilized a converter having a capacity of 150 tons and a strong stirring-vacuum oxygen decarburization

**[0074]** (SS-VOD) method, and steel slabs having a width of 1000 mm and a thickness of 200 mm were then manufactured by using a continuous casting method. The obtained slabs other than No. 31 were heated at a temperature of 1200°C for one hour and then subjected to hot-rolling in which reverse-type rough rolling was performed by using 3 rolling stands to obtain steel plates having a thickness of about 40 mm and in which the final 3 passes of finish rolling composed of 7 passes (the fifth pass, the sixth path, and the seventh pass) were then performed under the conditions given in Table 2 to obtain hot-rolled steel sheets. The slab of No. 31 was subjected to heating at a temperature of 1300°C for one hour followed by the hot-rolling. The obtained hot-rolled steel sheets were similarly subjected to hot-rolled-sheet annealing using a box annealing method under the conditions given in Table 2 to obtain hot-rolled and annealed steel sheets.

**[0075]** The obtained hot-rolled and annealed steel sheets were evaluated as described below.

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

**[0076]** A CT test piece in accordance with ASTM E 399 was taken from the central portion in the width direction of the steel sheet so that the direction of a fatigue precrack was in a direction perpendicular to the rolling direction and the stress axis was in a direction parallel to the rolling direction. The threshold stress intensity factor $K_{IC}$ of the test piece was determined in accordance with ASTM E 399. A case where the threshold stress intensity factor $K_{IC}$ was 20 MPa·$m^{1/2}$ or more was judged as passed, and a case where the threshold stress intensity factor $K_{IC}$ was less than 20 MPa·$m^{1/2}$ was judged as failed.

(2) Evaluation of corrosion resistance

**[0077]** A test piece was prepared by taking a test piece having a size of 60 mm × 100 mm from the hot-rolled and annealed steel sheet, by polishing the evaluation surface thereof by using #600 emery paper, and by sealing the end surfaces thereof and subjected to a salt spray cyclic corrosion test prescribed in JIS H 8502. The salt spray cyclic corrosion test was performed in such a manner that a unit cycle was repeated 5 times, where the unit cycle consists of salt spraying (5 mass% NaCl, 35°C, 2-hour spraying), drying (60°C, 4 hours, relative humidity = 40%), and wetting (50°C, 2 hours, relative humidity ≥ 95%). The rust area on the evaluation surface of the test piece was determined by performing image analysis on a photograph of the evaluation surface of the test piece which had been subjected to 5 cycles of the salt spray cyclic corrosion test, and a rust area ratio ((rust area of test piece/total area of test piece) × 100 [%]) was calculated as the ratio of the rust area to the total area of the test piece. A case where the rust area ratio was 10% or less was judged as a case of particularly excellent corrosion resistance, that is, judged as passed (⊙), a case where the rust area ratio was more than 10% and 25% or less was judged as passed (○), and a case where the rust area ratio was more than 25% was judged as failed (×).

**[0078]** The test results are given along with the hot-rolling conditions and the hot-rolled-sheet annealing conditions in Table 2.

[Table 1]

| Steel Code | Chemical Composition (mass%) | | | | | | | | | | | Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | P | S | Al | Cr | Ni | Ti | N | Other | |
| A | 0.006 | 0.24 | 0.33 | 0.01 | 0.001 | 0.029 | 11.3 | 0.15 | 0.28 | 0.006 | - | Example |
| B | 0.004 | 0.13 | 0.29 | 0.02 | 0.001 | 0.042 | 16.2 | 0.11 | 0.10 | 0.008 | B:0.0007 | Example |
| C | 0.008 | 0.47 | 0.53 | 0.03 | 0.004 | 0.008 | 16.6 | 0.42 | 0.19 | 0.007 | V:0.03 | Example |
| D | 0.007 | 0.16 | 0.22 | 0.03 | 0.002 | 0.027 | 17.3 | 0.12 | 0.31 | 0.009 | - | Example |
| E | 0.010 | 0.06 | 0.15 | 0.04 | 0.006 | 0.031 | 17.4 | 0.06 | 0.27 | 0.011 | Mo:0.4, V:0.03, Ca:0.0005 | Example |
| F | 0.002 | 0.08 | 0.07 | 0.02 | 0.006 | 0.020 | 18.1 | 0.08 | 0.11 | 0.005 | Mo:1.53 | Example |
| G | 0.007 | 0.09 | 0.18 | 0.03 | 0.007 | 0.033 | 18.1 | 0.13 | 0.29 | 0.012 | Mo:1.12 | Example |
| H | 0.005 | 0.26 | 0.31 | 0.04 | 0.001 | 0.034 | 18.4 | 0.17 | 0.13 | 0.008 | Cu:0.36, Ca:0.0006 | Example |
| I | 0.013 | 0.19 | 0.20 | 0.03 | 0.003 | 0.029 | 20.7 | 0.25 | 0.34 | 0.011 | Cu:0.44 | Example |
| J | 0.006 | 0.12 | 0.17 | 0.02 | 0.005 | 0.036 | 22.3 | 0.09 | 0.16 | 0.006 | Mo:1.68 | Example |
| K | 0.012 | 0.97 | 0.94 | 0.04 | 0.007 | 0.043 | 17.8 | 0.18 | 0.38 | 0.017 | - | Example |
| L | 0.009 | 0.21 | 0.26 | 0.03 | 0.004 | 0.035 | 17.5 | 0.07 | 0.24 | 0.013 | Zr:0.06, REM:0.005 | Example |
| M | 0.011 | 0.18 | 0.23 | 0.02 | 0.002 | 0.038 | 18.8 | 0.13 | 0.33 | 0.009 | - | Example |
| N | 0.011 | 0.20 | 0.26 | 0.04 | 0.004 | 0.036 | 18.7 | 0.10 | 0.23 | 0.015 | W:0.04, Co:0.06 | Example |
| O | 0.008 | 0.19 | 0.24 | 0.03 | 0.008 | 0.031 | 18.4 | 0.16 | 0.25 | 0.013 | - | Example |
| P | 0.010 | 0.21 | 0.22 | 0.04 | 0.007 | 0.040 | 17.2 | 0.11 | 0.21 | 0.015 | V:0.04, Mg:0.0007 | Example |
| Q | 0.009 | 0.18 | 0.30 | 0.01 | 0.002 | 0.058 | 17.9 | 0.09 | 0.22 | 0.012 | Nb:0.03 | Example |
| R | 0.010 | 0.17 | 0.31 | 0.02 | 0.004 | 0.029 | 18.3 | 0.10 | 0.16 | 0.011 | Zr:0.03 | Example |
| S | 0.007 | 0.24 | 0.27 | 0.02 | 0.003 | 0.032 | 17.6 | 0.13 | 0.20 | 0.008 | - | Example |
| T | 0.010 | 0.18 | 0.25 | 0.03 | 0.001 | 0.092 | 18.0 | 0.11 | 0.21 | 0.009 | - | Example |
| U | 0.009 | 0.18 | 0.26 | 0.02 | 0.004 | 0.037 | 14.6 | 0.09 | 0.18 | 0.012 | - | Example |
| V | 0.011 | 0.19 | 0.23 | 0.04 | 0.006 | 0.039 | 17.7 | 0.18 | <u>0.47</u> | 0.014 | - | Comparative Example |
| W | 0.004 | 0.18 | 0.17 | 0.01 | 0.002 | 0.028 | 17.5 | 0.05 | <u>0.05</u> | 0.002 | - | Comparative Example |

(continued)

| Steel Code | Chemical Composition (mass%) | | | | | | | | | | | Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | P | S | Al | Cr | Ni | Ti | N | Other | |
| Z | 0.007 | 0.22 | 0.39 | 0.02 | 0.003 | 0.036 | 17.1 | 0.14 | <u>0.03</u> | 0.008 | Nb:<u>0.34</u>, B:0.0012 | Comparative Example |

•The balance other than the constituents described above is Fe and inevitable impurities.
•Underlined portions indicate items out of the range of the present invention.

[Table 2]

| No. | Steel Code | Finishing Thickness of Rough Rolling [mm] | Starting Thickness of 5th Pass [mm] | Starting Temperature of 5th Pass [°C] | Starting Temperature of 6th Pass [°C] | Finishing Temperature of 7th Pass [°C] | Finishing Thickness of 7th Pass [mm] | Accumulated Rolling Reduction Ratio of Final 3 Passes [%] | Hot-rolled-sheet Annealing Temperature [°C] | $K_{IC}$ [$MPa \cdot m^{1/2}$] | Corrosion Resistance | Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | 41.1 | 19.6 | 1006 | 969 | 903 | 13.2 | 33 | 862 | 28 | ○ | Example |
| 2 | B | 39.9 | 12.1 | 996 | 946 | 882 | 8.0 | 34 | 886 | 23 | ○ | Example |
| 3 | C | 40.4 | 10.9 | 978 | 955 | 894 | 8.1 | 26 | 885 | 24 | ○ | Example |
| 4 | D | 40.5 | 11.6 | 977 | 941 | 904 | 7.8 | 33 | 908 | 24 | ○ | Example |
| 5 | E | 39.4 | 11.5 | 1027 | 959 | 882 | 8.3 | 28 | 887 | 25 | ⊙ | Example |
| 6 | F | 40.8 | 11.6 | 1025 | 969 | 902 | 8.3 | 28 | 888 | 24 | ⊙ | Example |
| 7 | G | 39.9 | 10.9 | 1029 | 960 | 917 | 8.1 | 26 | 902 | 22 | ⊙ | Example |
| 8 | H | 40.0 | 10.9 | 1004 | 949 | 910 | 7.8 | 28 | 884 | 25 | ⊙ | Example |
| 9 | I | 39.3 | 11.2 | 1029 | 960 | 893 | 7.9 | 29 | 1016 | 25 | ⊙ | Example |
| 10 | J | 39.1 | 11.7 | 989 | 959 | 915 | 8.5 | 27 | 1087 | 23 | ⊙ | Example |
| 11 | K | 40.6 | 11.5 | 996 | 955 | 911 | 8.4 | 27 | 902 | 24 | ○ | Example |
| 12 | L | 39.4 | 11.8 | 994 | 969 | 901 | 7.8 | 34 | 911 | 26 | ○ | Example |
| 13 | M | 39.5 | 12.1 | 991 | 956 | 904 | 8.2 | 32 | 893 | 26 | ○ | Example |
| 14 | N | 40.5 | 11.2 | 994 | 966 | 882 | 8.1 | 28 | 898 | 24 | ○ | Example |
| 15 | O | 40.7 | 10.9 | 985 | 953 | 888 | 7.9 | 28 | 902 | 24 | ○ | Example |
| 16 | P | 39.7 | 11.9 | 1014 | 966 | 880 | 8.3 | 30 | 896 | 24 | ○ | Example |
| 17 | Q | 40.2 | 13.2 | 1088 | 1012 | 939 | 9.4 | 29 | 1053 | 30 | ○ | Example |
| 18 | R | 40.1 | 13.3 | 1034 | 968 | 906 | 9.5 | 29 | 1052 | 31 | ○ | Example |
| 19 | S | 39.9 | 13.3 | 1040 | 974 | 910 | 9.7 | 27 | 1029 | 26 | ○ | Example |
| 20 | T | 40.8 | 13.1 | 1031 | 973 | 897 | 9.4 | 28 | 1055 | 31 | ○ | Example |
| 21 | U | 37.9 | 12.9 | 1035 | 978 | 906 | 9.5 | 26 | 1074 | 32 | ○ | Example |
| 22 | C | 39.5 | 15.5 | 986 | 969 | 889 | 10.3 | 34 | 890 | 25 | ○ | Example |

(continued)

| No. | Steel Code | Finishing Thickness of Rough Rolling [mm] | Starting Thickness of 5th Pass [mm] | Starting Temperature of 5th Pass [°C] | Starting Temperature of 6th Pass [°C] | Finishing Temperature of 7th Pass [°C] | Finishing Thickness of 7th Pass [mm] | Accumulated Rolling Reduction Ratio of Final 3 Passes [%] | Hot-rolled-sheet Annealing Temperature [°C] | $K_{IC}$ [MPa·m$^{1/2}$] | Corrosion Resistance | Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | C | 40.9 | 18.1 | 990 | 952 | 908 | 12.1 | 33 | 910 | 25 | ○ | Example |
| 24 | G | 39.9 | 22.3 | 994 | 950 | 887 | 15.2 | 32 | 912 | 25 | ○ | Example |
| 25 | D | 39.8 | 15.6 | 1097 | 1079 | 1046 | 11.0 | 29 | 901 | 25 | ○ | Example |
| 26 | D | 40.6 | 15.4 | 953 | 926 | 878 | 11.2 | 27 | 899 | 23 | ○ | Example |
| 27 | D | 40.5 | 10.9 | $\underline{1113}$ | 1083 | 1057 | 8.1 | 26 | 908 | $\underline{11}$ | ○ | Comparative Example |
| 28 | D | 40.3 | 12.4 | 965 | 929 | 886 | 10.3 | $\underline{17}$ | 889 | $\underline{16}$ | ○ | Comparative Example |
| 29 | D | 40.8 | 11.3 | 979 | 954 | 911 | 8.1 | 28 | $\underline{1139}$ | $\underline{10}$ | ○ | Comparative Example |
| 30 | D | 39.8 | 12.1 | 969 | 935 | 893 | 8.1 | 33 | $\underline{774}$ | $\underline{15}$ | ○ | Comparative Example |
| 31 | D | 40.2 | 12.5 | $\underline{1187}$ | $\underline{1139}$ | $\underline{1101}$ | 8.3 | 34 | 904 | $\underline{14}$ | ○ | Comparative Example |
| 32 | D | 40.5 | 12.2 | 788 | 751 | $\underline{\text{Evaluation was abandoned because of incomplete rolling due to excessive rolling load}}$ | | | | | | Comparative Example |
| 33 | $\underline{V}$ | 39.1 | 11.6 | 978 | 951 | 909 | 8.5 | 27 | 1087 | $\underline{18}$ | ○ | Comparative Example |
| 34 | $\underline{W}$ | 39.5 | 11.7 | 982 | 954 | 903 | 7.8 | 33 | 890 | 23 | × | Comparative Example |
| 35 | $\underline{Z}$ | 39.9 | 11.5 | 989 | 963 | 909 | 8.1 | 30 | $\underline{1148}$ | $\underline{11}$ | × | Comparative Example |

Underlined portions indicate items out of the range of the present invention.

**[0079]** In the case of Nos. 1 through 26 where the chemical composition of steel, the hot-rolling conditions, and the hot-rolled-sheet annealing conditions were within the ranges according to the present invention, as a result of colonies being effectively broken by performing the specified hot-rolling and hot-rolled-sheet annealing, the specified threshold stress intensity factor $K_{IC}$ was achieved. Moreover, the corrosion resistance of the obtained hot-rolled and annealed steel sheets was evaluated and, as a result, it was clarified that any of such steel sheets had sufficient corrosion resistance represented by a rust area ratio of 25%.

**[0080]** In particular, in the case of Nos. 5 through 7 and 10 where steels E, F, G, and J containing Mo were respectively used, and in the case of Nos. 8 and 9 where steels H and I containing Cu were respectively used, particularly excellent corrosion resistance represented by a rust area ratio of 10% or less (⊙) was achieved.

**[0081]** In the case of No. 27 where the rolling temperature in the final 3 passes was higher than the range according to the present invention, although rolling was performed with the specific accumulated rolling reduction ratio, since the recovery of strain due to work occurred as a result of the rolling temperature being excessively high, colonies were retained after the hot-rolled-sheet annealing had been performed due to an insufficient number of recrystallization sites, which resulted in the specific threshold stress intensity factor $K_{IC}$ not being achieved.

**[0082]** In the case of No. 28 where the accumulated rolling reduction ratio in the final 3 passes was less than the range according to the present invention, since sufficient strain due to rolling work was not applied to the central portion in the thickness direction, colonies were retained in the central portion in the thickness direction after the hot-rolled-sheet annealing had been performed, which resulted in the specific threshold stress intensity factor $K_{IC}$ not being achieved.

**[0083]** In the case of No. 29 where the hot-rolled-sheet annealing temperature was higher than the range according to the present invention, there was a significant coarsening of recrystallized grains formed, which resulted in the specific threshold stress intensity factor $K_{IC}$ not being achieved.

**[0084]** In the case of No. 30 where the hot-rolled-sheet annealing temperature was lower than the range according to the present invention, since sufficient recrystallization did not occur, colonies were retained without being broken, which resulted in the specific threshold stress intensity factor $K_{IC}$ not being achieved.

**[0085]** No. 31 is an example in which a slab was subjected to hot-rolling following heating at a temperature of 1300°C for one hour and in which the rolling temperature of the each of the final 3 passes of the finish hot-rolling was higher than 1100°C. In the case of No. 31, since the recovery of strain due to work excessively occurred during rolling in the final 3 passes, colonies were retained after the hot-rolled-sheet annealing had been performed due to insufficient number of recrystallization sites, which resulted in the specific threshold stress intensity factor $K_{IC}$ not being achieved.

**[0086]** In the case of No. 32 where the rolling temperature range of the each of the final 3 passes was lower than the range according to the present invention, since it was not possible to complete rolling in the final pass as a result of rolling load exceeding the acceptable load limit of the equipment due to a significant increase in rolling load, it was not possible to conduct the specified evaluations.

**[0087]** In the case of No. 33 where steel V, whose Ti content was more than the range according to the present invention, was used, since there was an increase in recrystallization temperature due to excessive Ti content such that sufficient recrystallization did not occur even though the specific hot-rolled-sheet annealing was performed, colonies were retained, which resulted in the specific threshold stress intensity factor $K_{IC}$ not being achieved. On the other hand, in the case of No. 34 where steel W, whose Ti content was less than the range according to the present invention, was used, since a large amount of Cr carbonitrides were precipitated when the hot-rolled-sheet annealing was performed, sensitization occurred, which resulted in the specified corrosion resistance not being achieved. In addition, in the case of No. 35 where steel Z, whose Ti content was less than the range according to the present invention, and whose Nb content was more than the range according to the present invention, was used, since it was necessary to perform annealing at an excessively high temperature in response to the excessively large Nb content to form a sufficient amount of recrystallized microstructure when the hot-rolled-sheet annealing is performed, there was a significant deterioration in toughness due to a significant coarsening of the recrystallized grains formed by performing the hot-rolled-sheet annealing, which resulted in the specific threshold stress intensity factor $K_{IC}$ not being achieved. Moreover, since a large amount of Cr carbonitrides was precipitated due to insufficient Ti content when hot-rolled-sheet annealing was performed, sensitization occurred, which resulted in the specified corrosion resistance not being achieved.

## Industrial Applicability

**[0088]** The hot-rolled and annealed ferritic stainless steel sheet obtained in the present invention can preferably be used in applications in which high workability and corrosion resistance are required, in particular, used for, for example, a flange having a portion subjected to burring work.

## Claims

1. A hot-rolled and annealed ferritic stainless steel sheet having
a chemical composition containing, 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 24.0%,
Ni: 0.01% to 0.60%,
Ti: 0.10% to 0.40%,
N: 0.001% to 0.020%, and the balance being Fe and inevitable impurities, and
a threshold stress intensity factor $K_{IC}$ of 20 $MPa{\cdot}m^{1/2}$ or more.

2. The hot-rolled and annealed ferritic stainless steel sheet according to Claim 1, wherein the chemical composition further contains, by mass%,
one, 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, by mass%,
one, 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, the method comprising
performing a hot-rolling process including finish rolling composed of 3 passes or more, in which rolling in final 3 passes of the finish rolling is performed in a temperature range of 800°C to 1100°C with an accumulated rolling reduction ratio of 25% or more to obtain a hot-rolled steel sheet and
performing hot-rolled-sheet annealing on the hot-rolled steel sheet at a temperature of 800°C to 1100°C.

## INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/034949

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. C22C38/00(2006.01)i, C21D8/02(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, C21D8/02, 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 | 1971-2017 |
| Registered utility model specifications of Japan | 1996-2017 |
| Published registered utility model applications of Japan | 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

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

☐ See patent family annex.

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"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 08 December 2017 (08.12.2017) | 19 December 2017 (19.12.2017) |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| Japan Patent Office<br>3-4-3, Kasumigaseki, Chiyoda-ku,<br>Tokyo 100-8915, Japan | Telephone No. |

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**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/JP2017/034949

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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## REFERENCES CITED IN THE DESCRIPTION

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