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(71) Applicant: **JFE Steel Corporation**
Tokyo 100-0011 (JP)

(72) Inventors:
- **YOSHINO Masataka**
  Tokyo 100-0011 (JP)
- **FUJISAWA Mitsuyuki**
  Tokyo 100-0011 (JP)

(74) Representative: **Hoffmann Eitle**
Patent- und Rechtsanwälte PartmbB
Arabellastraße 30
81925 München (DE)

(54) FERRITE STAINLESS HOT-ROLLED STEEL SHEET AND PRODUCTION METHOD THEREFOR

(57) Provided is a hot-rolled ferritic stainless steel sheet which has sufficient corrosion resistance and which can prevent the occurrence of cracking when subjected to blanking to be formed into a thick flange, and also provided is a method for manufacturing the hot-rolled ferritic stainless steel sheet. A hot-rolled ferritic stainless steel sheet having a chemical composition containing, in 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 0.50%, N: 0.001 to 0.020%, Cr: 11.0 to 24.0%, Ni: 0.01 to 2.00%, and Nb: 0.12 to 0.80%, with the balance being Fe and incidental impurities, wherein the hot-rolled ferritic stainless steel sheet has a threshold stress intensity factor K_{IC} of 25 $MPa \cdot m^{1/2}$ or more.

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Description

Technical Field

[0001] The present invention relates to a hot-rolled ferritic stainless steel sheet having excellent blanking workability and being suitable for use for a flange and the like and to a method for manufacturing the hot-rolled ferritic stainless steel sheet.

Background Art

[0002] In recent years, laws and regulations regarding exhaust gases from automobiles have been increasingly tightened, and improving fuel economy is an urgent need. Correspondingly, exhaust gas recirculation (EGR) systems, which are systems for reusing exhaust gases generated by an automobile engine as intake gases for the engine, are being increasingly employed. Exhaust gases that are generated by an engine pass through an EGR cooler, which is used to reduce the gas temperature, and are thereafter resupplied to the engine. For circulation of exhaust gases, individual exhaust system parts are joined together via flanges to prevent gas leakage. Flanges used for such exhaust system parts need to have sufficient rigidity. Accordingly, thick (e.g., 5 mm or more in sheet thickness) flanges are used for such exhaust system parts.

[0003] In the related art, ordinary steels have been used for thick flanges. However, flanges that are used for parts, for example, parts of an EGR system, through which high-temperature exhaust gases pass, are required to have sufficient corrosion resistance. Accordingly, studies are being conducted regarding using a stainless steel, which has higher corrosion resistance than ordinary steels, and particularly, using a ferritic stainless steel, which has a relatively low coefficient of thermal expansion and is less likely to generate thermal stress, and there is a strong need for a ferritic stainless steel sheet that has a large sheet thickness (e.g., 5 mm or more in sheet thickness) and can be used for thick flanges.

[0004] To meet such a market demand, Patent Literature 1, for example, discloses a hot-rolled Nb-containing ferritic stainless steel coil having a sheet thickness of 5.0 to 10.0 mm, the steel having a composition containing, in mass%, C: 0.030% or less, Si: 2.00% or less, Mn: 2.00% or less, P: 0.050% or less, S: 0.040% or less, Cr: 10.00 to 25.00%, N: 0.030% or less, and Nb: 0.01 to 0.80%, with the balance being Fe and incidental impurities. The coil has an adjusted hardness of 190 HV or less and an adjusted Charpy impact value at 25°C of 20 J/cm^2 or more.

Citation List

Patent Literature

[0005] PTL 1: Japanese Unexamined Patent Application Publication No. 2012-140688

Summary of Invention

Technical Problem

[0006] However, when the present inventors performed blanking using a crank press on a hot-rolled ferritic stainless steel coil such as disclosed in Patent Literature 1 to form a thick flange shape, noticeable cracking occurred in a central part in the sheet thickness of the blanked part and therefore the predetermined flange shape was not obtained in some cases although the coil had a sufficient Charpy impact value, and thus the coil was found to be insufficient to be used for thick flanges. Furthermore, when a hot-rolled coil such as disclosed in Patent Literature 1 is to be obtained, it is necessary to immerse the coil in water, after completion of hot rolling coiling, and keep the coil immersed for 15 minutes or more, which poses problems of manufacturability and productivity.

[0007] Objects of the present invention are to provide, in order to solve such problems, a hot-rolled ferritic stainless steel sheet which has sufficient corrosion resistance and which can prevented the occurrence of cracking when subjected to blanking in a crank press to be formed into a thick flange and to provide a method for manufacturing the hot-rolled ferritic stainless steel sheet. Solution to Problem

[0008] The present inventors performed detailed studies to solve the problems and consequently found that blanking for forming a thick flange by using a processing method with a relatively high processing speed, such as a method using a crank press, can be accomplished without causing cracking when the threshold stress intensity factor, K_{IC}, of the steel sheet is increased. Specifically, it was found that, by ensuring that the threshold stress intensity factor K_{IC} is 25 MPa·m$^{1/2}$ or more, the occurrence of cracking in the blanked edge surface when blanking for forming a thick flange is performed can be effectively prevented even if a processing method with a high processing speed, such as a method using a crank press, is used, and therefore practical use of the steel sheet for thick flanges can be sufficiently realized.

[0009] The present inventors conducted detailed studies to solve the problems. As a result, it was discovered that, in the case that a thick steel sheet of more than 5.0 mm sheet thickness is to be blanked to form a thick flange by using a processing method with a high processing speed, such as a method using a crank press, without causing cracking, the workability cannot be accurately evaluated by using the Charpy impact value, which has been used in the conventional technique, but can be accurately evaluated by using the threshold stress intensity factor K_{IC}, which is a toughness evaluation index in the field of thick steel plates. The reason for this is thought to be as follows. In the case of a thin steel sheet of less than 5.0 mm sheet thickness, the plastic deformation region in and near the blanked edge surface resulting from the processing is large with respect to the sheet thickness, and therefore the fracture phenomenon involved in the forming cannot be uniquely defined with an approach associated with the fracture mechanics, whereas, in the case of a thick steel sheet of 5.0 mm or more sheet thickness, the plastic deformation region in and near the blanked edge surface resulting from the processing is sufficiently small with respect to the sheet thickness and thus the small scale yielding state is sufficiently satisfied, and therefore the fracture phenomenon involved in a specific processing process can be handled with the stress intensity factor, which is a quantitative index associated with the fracture mechanics, and particularly can be accurately evaluated by using the threshold value, that is, the threshold stress intensity factor K_{IC}.

[0010] In view of the above, the present inventors closely investigated the relationship between the threshold stress intensity factor K_{IC} and the presence or absence of cracking that may occur when blanking, using a crank press, for forming a flange having a predetermined shape is performed. As a result, it was found that, by ensuring that the threshold stress intensity factor K_{IC} is 25 MPa·m$^{1/2}$ or more, the occurrence of cracking in the blanked edge surface when blanking for forming a thick flange is performed by using a crank press can be effectively prevented, and therefore practical use for thick flanges can be sufficiently realized.

[0011] Further, it was found that, when, for a ferritic stainless steel containing appropriate composition, the accumulated rolling reduction ratio (= 100 - (final sheet thickness/sheet thickness before start of rolling in final three passes) × 100 [%]) particularly in the final three passes of a finish hot rolling process including multiple (three or more) passes is appropriately controlled, the threshold stress intensity factor K_{IC} of the hot-rolled steel sheet is improved.

[0012] The present invention was made based on the above findings, and a summary of the present invention is as follows.

[1] A hot-rolled ferritic stainless steel sheet having a chemical composition containing, in 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 0.50%, N: 0.001 to 0.020%, Cr: 11.0 to 24.0%, Ni: 0.01 to 2.00%, and Nb: 0.12 to 0.80%, with the balance being Fe and incidental impurities, wherein the hot-rolled ferritic stainless steel sheet has a threshold stress intensity factor K_{IC} of 25 MPa·m$^{1/2}$ or more.

[2] A hot-rolled ferritic stainless steel sheet having a chemical composition containing, in 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 0.50%, N: 0.001 to 0.020%, Cr: 13.0 to 24.0%, Ni: 0.01 to 0.60%, and Nb: 0.12 to 0.80%, with the balance being Fe and incidental impurities, wherein the hot-rolled ferritic stainless steel sheet has a threshold stress intensity factor K_{IC} of 25 MPa·m$^{1/2}$ or more.

[3] The hot-rolled ferritic stainless steel sheet according to [1] or [2], wherein the chemical composition further contains, in mass%, one or more selected from Cu: 0.01 to 1.50%, Mo: 0.01 to 2.00%, W: 0.01 to 0.20%, and Co: 0.01 to 0.20%.

[4] The hot-rolled ferritic stainless steel sheet according to any one of [1] to [3], wherein the chemical composition further contains, in mass%, one or more selected from Ti: 0.01 to 0.30%, V: 0.01 to 0.20%, 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: 0.0005 to 0.0030%.

[5] A method for manufacturing the hot-rolled ferritic stainless steel sheet according to any one of [1] to [4], the method including hot rolling, the hot rolling including performing finish rolling including three or more passes, wherein a temperature range for final three passes of the finish rolling is 800 to 1100°C, and an accumulated rolling reduction ratio for the final three passes is 25% or more.

[0013] Here, the threshold stress intensity factor K_{IC} is a stress intensity factor determined by cutting a CT test piece in accordance with ASTM E399 from a sheet width central portion in such a manner 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 testing the test piece in accordance with ASTM E399.

Advantageous Effects of Invention

[0014] The present invention makes it possible to obtain a hot-rolled ferritic stainless steel sheet which has sufficient corrosion resistance and which has excellent toughness to prevent the occurrence of cracking when subjected to blanking in a crank press to be formed into a thick flange.

[0015] In the present invention, the phrase "sufficient corrosion resistance" means that the rust area ratio (= rust area/total area of steel sheet × 100 [%]) of the evaluation surface of a steel sheet is not more than 25% in the case where, after the surface to be evaluated is polished with #600 emery paper and the edge surface portions are sealed, the steel sheet is subjected to 5 cycles of a cyclic salt spray test as specified in JIS H 8502 (a test in which one cycle is as follows: salt spraying (5-mass% NaCl, 35°C, 2-hour spraying) → drying (60°C, 4 hours, 40% relative humidity) → exposure to humidity (50°C, 2 hours, relative humidity ≥ 95%).

[0016] Furthermore, the phrase "has excellent toughness to prevented the occurrence of cracking when subjected to blanking in a crank press to be formed into a thick flange" means that the threshold stress intensity factor K_{IC} is 25 MPa·$m^{1/2}$ or more, as determined by cutting a CT test piece in accordance with ASTM E399 from a sheet width central portion in such a manner 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 testing the test piece in accordance with ASTM E399.

Description of Embodiments

[0017] According to the present invention, a hot-rolled ferritic stainless steel sheet has a chemical composition containing, in 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 0.50%, N: 0.001 to 0.020%, Cr: 11.0 to 24.0%, Ni: 0.01 to 2.00%, and Nb: 0.12 to 0.80%, with the balance being Fe and incidental impurities, and the hot-rolled ferritic stainless steel sheet has a threshold stress intensity factor K_{IC} of 25 MPa·$m^{1/2}$ or more.

[0018] In a preferable embodiment, a hot-rolled ferritic stainless steel sheet of the present invention has a chemical composition containing, in 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 0.50%, N: 0.001 to 0.020%, Cr: 13.0 to 24.0%, Ni: 0.01 to 0.60%, and Nb: 0.12 to 0.80%, with the balance being Fe and incidental impurities, and the hot-rolled ferritic stainless steel sheet has a threshold stress intensity factor K_{IC} of 25 MPa·$m^{1/2}$ or more.

[0019] The threshold stress intensity factor K_{IC} is a stress intensity factor determined by cutting a CT test piece in accordance with ASTM E399 from a sheet width central portion in such a manner 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 testing the test piece in accordance with ASTM E399.

[0020] The present invention will now be described in detail.

[0021] The present inventors performed detailed studies on factors responsible for cracking that occurred when blanking was performed on various types of hot-rolled ferritic stainless steel sheets having a sheet thickness of 5.0 mm in a crank press to form a flange shaped with a hole having a diameter of 30 mm. As a result, it was found that, in the steel sheets in which cracking occurred, the cracking occurred in such a manner that microcracking generated in or near a central part in the sheet thickness of a blanked edge surface in a direction perpendicular to the blanking direction, and that the microcracks propagated.

[0022] The present inventors performed detailed studies on the relationship between the generation and propagation of microcracks and the material properties. As a result, it was found that there is a tendency for propagation of microcracks to occur more easily as the threshold stress intensity factor of a steel sheet decreases. Accordingly, blanking for forming a flange such as that described above was attempted by using various hot-rolled ferritic stainless steel sheets (5.0 mm in sheet thickness), and as a result, it was found that no cracking occurred in steel sheets having a threshold stress intensity factor of 25 MPa·$m^{1/2}$ or more and that cracking was more likely to occur in steel sheets in which the threshold stress intensity factor was less than 25 MPa·$m^{1/2}$, the threshold stress intensity factors being measured using a specified measurement method.

[0023] Accordingly, the present inventors conducted detailed research on composition of steel and conditions for hot rolling to perform studies on techniques for improving the threshold stress intensity factor of hot-rolled ferritic stainless steel sheets. As a result, the following was found. When, for a ferritic stainless steel containing appropriate composition, a hot rolling process, in which finish rolling including multiple passes is performed, is appropriately controlled particularly such that the temperature range for the final three passes is 800 to 1100°C and the accumulated rolling reduction ratio (= 100 - (final sheet thickness/sheet thickness before start of rolling in final three passes) × 100 [%]) for the final three passes is 25% or more, rolling strains are effectively introduced not only to the surface layer part but also to the central part in the sheet thickness. Consequently, the threshold stress intensity factor K_{IC} of 25 MPa·$m^{1/2}$ or more can be achieved.

[0024] The sheet thickness of hot-rolled ferritic stainless steel sheets of the present invention is not particularly limited but preferably not less than 5.0 mm because a sheet thickness suitable for a thick flange is desirable. Furthermore, the sheet thickness is not particularly limited but preferably not more than 15.0 mm and more preferably not more than 10.0 mm.

[0025] The following description describes reasons that, with the above-described technique, a steel sheet after hot rolling has rolling strains effectively introduced also to the central part in the sheet thickness and therefore has an increased threshold stress intensity factor K_{IC} over the entire thickness of the steel sheet.

[0026] When a steel sheet is subjected to rolling, the steel sheet is elongated with the surface layer being deformed first. Accordingly, if the rolling reduction ratio is low, the amount of deformation in the central part in the sheet thickness is small, and therefore almost no rolling strain is introduced to the central part in the sheet thickness. In addition to this, in ferritic stainless steels, recovery of work strain tends to occur during hot rolling. Consequently, hot rolling of the related art cannot effectively introduced work strains to the central part in the sheet thickness because the rolling reduction ratio is insufficient. In addition, introduced rolling strains are eliminated and reduced by excessive recovery during hot rolling. As a result, with hot rolling of the related art, the predetermined threshold stress intensity factor K_{IC} cannot be achieved.

[0027] In view of the above, the present inventors diligently performed studies on techniques for effectively and sufficiently introducing rolling strains to the central part in the sheet thickness in a hot rolling process, from the standpoints of both steel components and the method of hot rolling.

[0028] As a result, from the perspective of the method of hot rolling, it was found that rolling strains are sufficiently and effectively introduced to the central part in the sheet thickness when the temperature range for the final three passes of finish hot rolling is controlled to be appropriate and, in such a state, rolling is performed at a high accumulated rolling reduction ratio.

[0029] However, from the perspective of steel components, it was found that, with a ferritic stainless steel containing substantially no Nb, recovery during hot rolling tends to occur, and therefore, even if the method of hot rolling proposed by the present inventors is used, the rolling strain density that can be obtained is insufficient and the predetermined threshold stress intensity factor cannot be achieved.

[0030] On the other hand, it was found that, with a ferritic stainless steel containing an appropriate amount of Nb, fine Nb carbonitrides precipitate during hot rolling, and such fine Nb carbonitrides suppress the movement of dislocations, and therefore, using the method of hot rolling proposed by the present inventors makes it possible to obtain a high rolling strain density and ensures that the hot-rolled steel sheet has the predetermined threshold stress intensity factor.

[0031] That is, the following was found. In the present invention, with a ferritic stainless steel containing an appropriate amount of Nb, the temperature range for the final three passes of finish hot rolling is controlled to be appropriate and, in such a state, rolling is performed at a high accumulated rolling reduction ratio, and as a result, rolling strains are sufficiently and effectively introduced to the central part in the sheet thickness while recovery of rolling strains is suppressed, and therefore the predetermined threshold stress intensity factor K_{IC} can be achieved.

[0032] Specifically, performing hot rolling in the following manner was devised. For a ferritic stainless steel containing Nb in an amount of 0.12% or more, a finish hot rolling process including three or more passes is to be appropriately controlled such that the temperature range for the final three passes is 800 to 1100°C and the accumulated rolling reduction ratio (= 100 - (final sheet thickness/sheet thickness before start of rolling in final three passes) × 100 [%]) for the final three passes is 25% or more.

[0033] The chemical composition of the hot-rolled ferritic stainless steel sheet of the present invention will now be described. In the following description, "%" used to indicate the chemical composition means "mass%" unless otherwise specified.

C: 0.001 to 0.020%

[0034] If C is contained in an amount more than 0.020%, workability and corrosion resistance in the weld zone noticeably deteriorate. A C content as low as possible is preferable from the perspectives of corrosion resistance and workability but is not preferable from the standpoint of manufacturing because obtaining a C content of less than 0.001% requires that refining be performed for a long period of time. Accordingly, the C content is within the range of 0.001 to 0.020%. The C content is preferably not less than 0.003% and more preferably not less than 0.004%. Furthermore, the C content is preferably not more than 0.015% and more preferably not more than 0.012%.

Si: 0.05 to 1.00%

[0035] Si has an effect of improving corrosion resistance in the weld zone by being concentrated in the oxide layer formed during welding. Si is an element also useful as a deoxidizing element in the steelmaking process. These effects are obtained when Si is contained in an amount of 0.05% or more. The effects increase as the content increases. However, the presence of Si in an amount more than 1.00% is not preferable because, in the hot rolling process, the rolling load increases and the formation of scale is noticeable, and in the annealing process, pickling properties are deteriorated because of the formation of a Si-rich layer in the surface layer of the steel sheet, and consequently, an increase in surface defects and an increase in manufacturing cost are induced. Accordingly, the Si content is 0.05 to 1.00%. It is preferable that the Si content not be less than 0.10%. Furthermore, the Si content is preferably not more than 0.60% and more preferably not more than 0.40%.

Mn: 0.05 to 1.00%

[0036] Mn has an effect of increasing the strength of steel and also acts as a deoxidizer. To obtain the effects, Mn need to be contained in an amount of 0.05% or more. If the Mn content is more than 1.00%, however, precipitation of MnS, which acts as a corrosion initiation site, is promoted, which deteriorates corrosion resistance. Accordingly, the Mn content is 0.05 to 1.00%. It is preferable that the Mn content not be less than 0.10%. Furthermore, the Mn content is preferably not more than 0.50% and more preferably not more than 0.30%.

P: 0.04% or less

[0037] P is an element inevitably present in steel, but, since P is an element harmful to corrosion resistance and workability, it is preferable that the P content be as low as possible. In particular, if the P content is more than 0.04%, workability noticeably deteriorates because of solid solution strengthening. Accordingly, the P content is not more than 0.04%. It is preferable that the P content not be more than 0.03%.

S: 0.01% or less

[0038] Similarly to P, S is an element inevitably present in steel, but, since S is an element harmful to corrosion resistance and workability, it is preferable that the P content be as low as possible. In particular, if the S content is more than 0.01%, corrosion resistance noticeably deteriorates. Accordingly, the S content is not more than 0.01%. It is preferable that the S content not be more than 0.008%. It is more preferable that the S content not be more than 0.003%.

Al: 0.001 to 0.50%

[0039] Al is an effective deoxidizer. In addition, Al has a higher affinity for N than does Cr and therefore has an effect of, if N penetrates into a weld, causing N to precipitate as an Al nitride rather than as a Cr nitride, thereby suppressing sensitization. These effects are obtained when Al is contained in an amount of 0.001% or more. However, the presence of Al in an amount more than 0.50% deteriorates the penetration characteristics for welding, which deteriorates welding workability, and is therefore not preferable. Accordingly, the Al content is within the range of 0.001 to 0.50%. The Al content is preferably not more than 0.20% and more preferably not more than 0.10%.

N: 0.001 to 0.020%

[0040] If the N content is more than 0.020%, workability and corrosion resistance in the weld zone noticeably deteriorate. A N content as low as possible is preferable from the perspective of corrosion resistance, but reducing the N content to less than 0.001% requires long-time refining, which results in an increase in the manufacturing cost and a deterioration in productivity, and is therefore not preferable. Accordingly, the N content is within the range of 0.001 to 0.020%. The N content is preferably not less than 0.003% and more preferably not less than 0.005%. Furthermore, the N content is preferably not more than 0.015% and more preferably not more than 0.012%.

Cr: 11.0 to 24.0%

[0041] Cr is the most important element for ensuring the corrosion resistance of stainless steel. If the Cr content is less than 11.0%, sufficient corrosion resistance is not exhibited in an automobile exhaust gas atmosphere. On the other hand, if Cr is present in an amount more than 24.0%, toughness significantly deteriorates because of formation of the σ (sigma) phase, and, in the present invention, the predetermined threshold stress intensity factor cannot be achieved. Accordingly, the Cr content is within the range of 11.0 to 24.0%. The Cr content is preferably not less than 13.0%, more preferably not less than 14.0%, even more preferably not less than 16.0%, and still more preferably not less than 17.0%. Furthermore, the Cr content is preferably not more than 21.5%, more preferably not more than 20.0%, and even more preferably not more than 18.5%.

Ni: 0.01 to 2.00%

[0042] Ni is an element that improves the corrosion resistance of stainless steel and an element that suppresses the progression of corrosion in a corrosive environment in which the passivation film is not formed and active dissolution occurs. Furthermore, Ni is a strong austenite-forming element and has an effect of reducing the formation of ferrite in a weld, thereby suppressing sensitization due to precipitation of Cr carbonitrides. This effect is obtained when Ni is contained in an amount of 0.01% or more. The effect increases as the Ni content increases. If the Ni content is more than 2.00%, however, workability deteriorates, and in addition, stress corrosion cracking tends to occur. In addition, since Ni is an expensive element, increasing the Ni content increases the manufacturing cost and is therefore not preferable. Accordingly, the Ni content is 0.01 to 2.00%. The Ni content is preferably not less than 0.05% and more preferably not less than 0.10%. Furthermore, the Ni content is preferably not more than 1.00%, more preferably not more than 0.60%, even more preferably not more than 0.50%, and still more preferably not more than 0.45%.

Nb: 0.12 to 0.80%

[0043] In a hot rolling process, Nb combines with C and N and precipitates as Nb carbonitrides. Precipitated Nb carbonitrides have an effect of pinning the movement of dislocations and thus preventing rolling strains introduced by hot rolling from being eliminated through recovery. Consequently, recovery during hot rolling is retarded, and a decrease in the rolling strain density due to the occurrence of excessive recovery can be prevented. The effect described above is produced when Nb is contained in an amount of 0.12% or more. However, if the Nb content is more than 0.80%, toughness, on the contrary, may deteriorate because of the formation of a Laves phase, and a significant increase in the rolling load in hot rolling makes it difficult to employ the method of hot rolling provided by the present invention. Accordingly, the Nb content is within the range of 0.12 to 0.80%. The Nb content is preferably not less than 0.15% and more preferably not less than 0.20%. Furthermore, the Nb content is preferably not more than 0.75% and more preferably not more than 0.60%.

[0044] The present invention is a ferritic stainless steel containing the above-described essential elements, with the balance being Fe and incidental impurities. In addition, optionally, one or more selected from Cu, Mo, W, and Co may be contained, or alternatively or additionally, one or more selected from Ti, V, Zr, REM, B, Mg, and Ca may be contained. The ranges of the contents are as follows.

Cu: 0.01 to 1.50%

[0045] Cu is an element particularly effective for improving the corrosion resistance of the base metal and a weld when it is in an aqueous solution or when drops of weakly acidic water adhere thereto. This effect is obtained when Cu is contained in an amount of 0.01% or more. The effect increases as the Cu content increases. If Cu is contained in an amount more than 1.50%, however, a deterioration in hot workability may induce surface defects. In addition, in some cases, descaling after annealing is difficult. Accordingly, when Cu is to be contained, it is preferable that the Cu content be within the range of 0.01 to 1.50%. The Cu content is more preferably not less than 0.10% and even more preferably not less than 0.30%. Furthermore, the Cu content is more preferably not more than 0.60% and even more preferably not more than 0.45%.

Mo: 0.01 to 2.00%

[0046] Mo is an element that noticeably improves the corrosion resistance of stainless steel. This effect is obtained when Mo is contained in an amount of 0.01% or more. The effect improves as the content increases. If the Mo content is more than 2.00%, however, an increase in the rolling load in hot rolling may deteriorate manufacturability, and the strength of the steel sheet may increase excessively. Furthermore, since Mo is an expensive element, the presence of Mo in large amounts increases the manufacturing cost. Accordingly, when Mo is to be contained, it is preferable that the Mo content be 0.01 to 2.00%. It is more preferable that the Mo content not be less than 0.10%. Furthermore, it is more preferable that the Mo content not be more than 1.40%. However, in a Ti-containing steel, Mo also has an effect of deteriorating toughness, and it is therefore preferable, when Ti is contained in an amount of 0.15% or more, that the Mo content be 0.30 to not more than 1.40%. When Ti is contained in an amount of 0.15% or more, it is more preferable that the Mo content not be less than 0.40%. Furthermore, when Ti is contained in an amount of 0.15% or more, it is more preferable that the Mo content not be more than 0.90%.

W: 0.01 to 0.20%

[0047] Similarly to Mo, W has an effect of improving corrosion resistance. This effect is obtained when W is contained in an amount of 0.01% or more. If W is contained in an amount more than 0.20%, however, strength increases, and an increase in rolling load, for example, may deteriorate manufacturability. Accordingly, when W is to be contained, it is preferable that the W content be within the range of 0.01 to 0.20%. It is more preferable that the W content not be less than 0.05%. Furthermore, it is more preferable that the W content not be more than 0.15%.

Co: 0.01 to 0.20%

[0048] Co is an element that improves toughness. This effect is obtained when Co is contained in an amount of 0.01% or more. On the other hand, if the Co content is more than 0.20%, workability may deteriorate. Accordingly, when Co is to be contained, it is preferable that the Co content be within the range of 0.01 to 0.20%.

Ti: 0.01 to 0.30%

[0049] Ti is an element having a higher affinity for C and N than does Cr and has an effect of, by precipitating as carbides or nitrides, suppressing sensitization caused by precipitation of Cr carbonitrides. To obtain this effect, Ti needs to be contained in an amount of 0.01% or more. If the Ti content is more than 0.30%, however, TiN may precipitate excessively, and consequently, good surface properties may not be obtained. Accordingly, when Ti is to be contained, it is preferable that the Ti content be within the range of 0.01 to 0.30%. The Ti content is more preferably not less than 0.03% and even more preferably not less than 0.10%. Furthermore, the Ti content is more preferably not more than 0.20% and even more preferably not more than 0.15%.

V: 0.01 to 0.20%

[0050] V forms carbonitrides with C and N and suppresses sensitization during welding and thus improves corrosion resistance in the weld zone. This effect is obtained when the V content is 0.01% or more. On the other hand, if the V content is more than 0.20%, workability and toughness may noticeably deteriorate. Accordingly, it is preferable that the V content be 0.01 to 0.20%. It is more preferable that the V content not be less than 0.05%. Furthermore, it is more preferable that the V content not be more than 0.15%.

Zr: 0.01 to 0.20%

[0051] Zr has an effect of, by combining with C and N, suppressing sensitization. This effect is obtained when Zr is contained in an amount of 0.01% or more. On the other hand, if Zr is contained in an amount more than 0.20%, workability may noticeably deteriorate. Accordingly, when Zr is to be contained, it is preferable that the Zr content be within the range of 0.01 to 0.20%. It is more preferable that the Zr content not be more than 0.10%.

REM: 0.001 to 0.100%

[0052] REM (rare earth metal) has an effect of improving oxidation resistance and inhibits the formation of a weld oxide layer (welding temper color) and thus suppresses the formation of a Cr depletion zone immediately below the oxide layer. This effect is obtained when one or more REM is contained in an amount of 0.001% or more. On the other hand, if one or more REM is contained in an amount more than 0.100%, manufacturability, such as pickling properties for cold rolling-annealing, may deteriorate. Accordingly, when one or more REM is to be contained, it is preferable that the REM content be within the range of 0.001 to 0.100%. It is more preferable that the REM content not be more than 0.050%.

B: 0.0002 to 0.0025%

[0053] B is an element effective for improving secondary working embrittlement resistance after deep drawing. This effect is obtained when the B content is 0.0002% or more. On the other hand, if B is contained in an amount more than 0.0025%, workability and toughness may deteriorate. Accordingly, when B is to be contained, it is preferable that the B content be within the range of 0.0002 to 0.0025%. It is more preferable that the B content not be less than 0.0003%. Furthermore, it is more preferable that the B content not be more than 0.0006%.

Mg: 0.0005 to 0.0030%

[0054] Mg is an element that improves the equiaxed crystal ratio of a slab and is effective for improving workability and toughness. This effect is obtained when Mg is contained in an amount of 0.0005% or more. On the other hand, if the Mg content is more than 0.0030%, surface properties of the steel may deteriorate. Accordingly, when Mg is to be contained, it is preferable that the Mg content be within the range of 0.0005 to 0.0030%. It is more preferable that the Mg content not be less than 0.0010%. Furthermore, it is more preferable that the Mg content not be more than 0.0020%.

Ca: 0.0005 to 0.0030%

[0055] Ca has an effect of refining inclusions formed during steelmaking and continuous casting and is a component particularly effective for preventing nozzle blockage in continuous casting. The effect is obtained when Ca is contained in an amount of 0.0005% or more. If Ca is contained in an amount more than 0.0030%, however, formation of CaS may decrease corrosion resistance. Accordingly, when Ca is to be contained, it is preferable that the Ca content be within the range of 0.0005 to 0.0030%. The Ca content is more preferably not more than 0.0015% and even more preferably not more than 0.0010%.

Threshold stress intensity factor K_{IC}: 25 MPa·m$^{1/2}$ or more

[0056] Hot-rolled ferritic stainless steel sheets of the present invention have a threshold stress intensity factor K_{IC} of 25 MPa·m$^{1/2}$ or more, and as a result, when subjected to blanking in a crank press to be formed into a thick flange, the occurrence of cracking can be prevented. The threshold stress intensity factor K_{IC} is preferably not less than 30 MPa·m$^{1/2}$, more preferably not less than 35 MPa·m$^{1/2}$, and even more preferably not less than 40 MPa·m$^{1/2}$. The "thick flange" is not particularly limited but may be, for example, a flange of 5.0 mm or more sheet thickness. For example, the flange is preferably a flange of 5.0 to 15.0 mm sheet thickness and more preferably a flange of 5.0 to 10.0 mm sheet thickness.

[0057] A method for manufacturing the hot-rolled ferritic stainless steel sheet of the present invention will now be described. In the following description, the temperature is the surface temperature of a steel slab, a hot-rolled steel sheet, or the like measured with a surface thermometer or the like unless otherwise specified.

[0058] The hot-rolled ferritic stainless steel sheet of the present invention can be obtained by using a steel slab having a chemical composition as described above and ensuring that, in hot rolling including rough rolling and finish rolling that includes three or more passes, the temperature range for rolling in the final three passes of the finish rolling is 800 to 1100°C and the accumulated rolling reduction ratio for the final three passes is 25% or more.

[0059] First, a molten steel with a chemical composition as described above is prepared using a steelmaking process known in the art, using, for example, a converter, an electric furnace, or a vacuum melting furnace. The steel is subjected to a continuous casting process or an ingot casting-slabbing process to form a steel starting material (slab) .

[0060] The slab is subjected to hot rolling after being heated at 1100 to 1250°C for 1 to 24 hours, or the as-cast slab is directly subjected to hot rolling without being heated. In the present invention, although the rough rolling is not particularly limited, effectively destroying the casting structure prior to the finish hot rolling provides an advantage for grain refining in the subsequent finish hot rolling, and therefore, further improvement in toughness due to refinement of the metallurgical structure after hot rolling can be expected, and accordingly, it is preferable that the accumulated rolling reduction ratio for the rough rolling not be less than 65%. Subsequently, rolling is performed in the finish hot rolling to obtain a predetermined sheet thickness. In the final three passes of the finish rolling, rolling is performed within the temperature range of 800 to 1100°C and at the accumulated rolling reduction ratio of 25% or more.

Rolling temperature range for final three passes of finish hot rolling: 800 to 1100°C

Accumulated rolling reduction ratio for final three passes of finish hot rolling: 25% or more

[0061] To ensure that the threshold stress intensity factor after hot rolling is the predetermined threshold stress intensity factor, it is necessary to appropriately control the temperature and the accumulated rolling reduction ratio for rolling in the final three passes of the finish hot rolling, thereby effectively introducing rolling strains also to the central part in the sheet thickness while suppressing excessive recovery during rolling.

[0062] To introduce sufficient rolling strains also to the central part in the sheet thickness, it is necessary that, in the finish hot rolling, the rolling temperatures for the final three passes be within the range of 800 to 1100°C and the accumulated rolling reduction ratio (= 100 - (final sheet thickness/sheet thickness before start of rolling in final three passes) $\times$ 100 [%]) for the final three passes be 25% or more, so that rolling strains can be effectively introduced also to the central part in the sheet thickness while preventing the rolling strains introduced in the final three passes from being eliminated through recovery.

[0063] If the accumulated rolling reduction ratio for the final three passes of the finish hot rolling is less than 25%, rolling strains are not effectively introduced to the central part in the sheet thickness, and as a result, the predetermined threshold stress intensity factor cannot be achieved. Accordingly, the accumulated rolling reduction ratio for the final three passes is 25% or more. It is preferable that the accumulated rolling reduction ratio not be less than 30%. It is more preferable that the accumulated rolling reduction ratio not be less than 35%. The upper limit of the accumulated rolling reduction ratio is not particularly limited but is preferably not more than 60% because, if the accumulated rolling reduction ratio is excessively high, an increase in the rolling load may deteriorate manufacturability.

[0064] If the rolling temperatures for the final three passes of the finish hot rolling are lower than 800°C, the rolling load significantly increases with a decrease in the temperature of the steel sheet, and therefore such temperatures are not preferable from the standpoint of manufacturing. On the other hand, if the rolling temperatures for the final three passes are higher than 1100°C, rolling strains introduced by the rolling are eliminated through excessive recovery, and the predetermined threshold stress intensity factor cannot be achieved. Accordingly, the rolling temperatures for the final three passes are within the range of 800 to 1100°C. It is preferable that the rolling temperatures for the final three passes be within a range of 800 to 1050°C. It is more preferable that the rolling temperatures for the final three passes be within a range of 850 to 1000°C.

[0065] To prevent an excessive rolling load from being applied in a specific pass of the final three passes of the finish hot rolling, it is preferable that, in the final three passes, the rolling temperature range for the first pass be 950 to 1100°C, the rolling temperature range for the second pass, which follows the first pass, be 925 to 1075°C, and the rolling temperature range for the third pass, which follows the second pass, be 875 to 1050°C.

[0066] In the method for manufacturing the hot-rolled ferritic stainless steel sheet of the present invention, in the final three passes of finish hot rolling including three or more passes, high-reduction rolling is applied with the temperature range being controlled. If rolling in which high-reduction rolling is applied is performed over the final four or more passes, strains cannot be sufficiently introduced to the central part in the sheet thickness even when the accumulated rolling reduction ratio is unchanged because the reduction ratio is distributed among the passes, and in addition, since the accumulated interval time between passes increases, recovery during transfer between passes is promoted, which reduces the strain introducing effect, and as a result, achieving the predetermined threshold stress intensity factor is difficult. On the other hand, it is not preferable that the control of the rolling temperature and the accumulated rolling reduction ratio of the finish rolling be performed in the final two or less passes because, in such a case, since the high-reduction rolling at the accumulated rolling reduction ratio of 25% or more is performed in two passes, the rolling load significantly increases, which may decrease manufacturability. Accordingly, in the method for manufacturing the hot-rolled ferritic stainless steel sheet of the present invention, the rolling temperature and the accumulated rolling reduction ratio of the final three passes of the finish rolling are controlled.

[0067] In the method for manufacturing the hot-rolled ferritic stainless steel sheet of the present invention, it is important to control the rolling temperature and the accumulated rolling reduction ratio of the final three passes of the finish hot rolling, and any number of passes may be performed in the finish hot rolling provided that the finish hot rolling includes three or more passes; however, it is preferable that the maximum number of passes not be more than 15 passes because, if the maximum number of passes is more than 15 passes, a decrease in the temperature of the steel sheet due to increased number of contact with the rolling rolls is more likely to occur, and consequently, for example, heating of the steel sheet from the outside becomes necessary to maintain the temperature to be within the predetermined temperature range, and as a result, manufacturability may deteriorate or the manufacturing cost may increase. It is more preferable that the maximum number of passes not be more than 10 passes.

[0068] After the finish hot rolling, the steel sheet is cooled, and subsequently the steel sheet is coiled to form a hot-rolled steel strip. In the present invention, the coiling temperature is not particularly limited, but, if the coiling temperature is between higher than 450°C and lower than 500°C, embrittlement due to 475°C embrittlement may occur. Accordingly, it is preferable that the coiling temperature not be higher than 450°C or not be lower than 500°C. Coiling may be performed at a temperature not higher than 450°C after accelerated cooling using water mist cooling or the like is performed following the final rolling. This is more preferable because elimination of rolling strains due to recovery after coiling can be further suppressed.

[0069] The hot-rolled steel sheet obtained in accordance with the present invention may be subjected to hot-rolled-sheet annealing to form a hot-rolled and annealed steel sheet. The hot-rolled steel sheet provided by the present invention has excellent toughness and therefore can be subjected to hot-rolled-sheet annealing in a continuous annealing line, which is avoided in the related art because of concern over failure due to low toughness. Furthermore, the resulting hot-rolled and annealed steel sheet may be subsequently subjected to cold rolling and cold-rolled-sheet annealing.

EXAMPLE

[0070] The present invention will now be described in more detail with reference to examples.

[0071] Molten stainless steels each having the chemical composition shown in Table 1 were prepared by steelmaking using a 150-ton capacity converter and involving refining using a strong-stirring vacuum oxygen decarburization process (SS-VOD). The molten stainless steel was continuously cast to form a steel slab of 1000 mm width and 200 mm thickness. The slab was heated at 1200°C for 1 hour and thereafter subjected to hot rolling. In the hot rolling, the slab was subjected to reverse rough rolling using three stands to form a steel sheet of approximately 40 mm in thickness, which was subsequently subjected to finish rolling including seven passes to form a hot-rolled steel sheet. The final three passes (fifth pass, sixth pass, and seventh pass) of the finish rolling were performed under the conditions listed in Table 2.

[0072] The resulting hot-rolled steel sheet was evaluated as follows.

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

[0073] A CT test piece in accordance with ASTM E399 was cut from a sheet width central portion in such a manner that a fatigue pre-crack was introduced 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 E399. Threshold stress intensity factors equal to or more than 25 $MPa{\cdot}m^{1/2}$ were rated as "pass", and threshold stress intensity factors less than 25 $MPa{\cdot}m^{1/2}$ were rated as "fail".

(2) Evaluation of corrosion resistance

[0074] A test piece of 60 × 100 mm was cut from the resulting hot-rolled steel sheet. The surface to be evaluated was polished with #600 emery paper, and thereafter the edge surface were sealed to prepare such a test piece, which was subjected to a cyclic salt spray test as specified in JIS H 8502. In the cyclic salt spray test, five cycles were conducted, with one cycle being as follows: salt spraying (5-mass% NaCl, 35°C, 2-hour spraying) → drying (60°C, 4 hours, relative humidity of 40%) → exposure to humidity (50°C, 2 hours, relative humidity ≥ 95%). The evaluation surface of the test piece after conducting five cycles of the cyclic salt spray test was photographed, the rust area of the evaluation surface of the test piece was measured by image analysis, and, from the ratio of the rust area to the total area of the test piece, the rust ratio (rust area of test piece/total area of test piece) × 100 [%]) was calculated. Rust ratios equal to or less than 10% were rated as "pass" (⊙), as being particularly good in corrosion resistance, rust ratios more than 10% and not more than 25% were rated as "pass" (○), and rust ratios more than 25% were rated as "fail" (×).

[0075] The test results together with the hot rolling conditions are shown in Table 2.

[Table 1]

No.	Chemical composition (mass%)											Notes
	C	Si	Mn	P	S	Al	N	Cr	Ni	Nb	Others	
A	0.005	0.11	0.29	0.03	0.005	0.004	0.007	16.4	0.12	0.23	-	Invention example
B	0.013	0.24	0.46	0.02	0.006	0.003	0.015	17.3	0.14	0.35	Mo: 0.46	Invention example
C	0.012	0.30	0.44	0.02	0.003	0.002	0.013	17.6	0.12	0.41	-	Invention example
D	0.005	0.27	0.17	0.03	0.002	0.016	0.008	18.9	0.20	0.34	Mo: 1.91	Invention example
E	0.017	0.58	0.14	0.03	0.004	0.004	0.018	19.5	0.44	0.46	Cu: 0.54, V: 0.12	Invention example
F	0.005	0.39	0.18	0.02	0.001	0.009	0.006	22.6	0.16	0.29	Mo: 1.14, B: 0.0009	Invention example
G	0.009	0.90	0.36	0.03	0.002	0.014	0.012	14.5	0.23	0.50	Mo: 0.05, Co: 0.04	Invention example
H	0.007	0.81	0.23	0.03	0.001	0.377	0.007	16.9	0.18	0.47	Cu: 1.22	Invention example
I	0.004	0.33	0.21	0.02	0.003	0.026	0.006	14.7	0.36	0.52	Mo: 1.53, Co: 0.04	Invention example
J	0.012	0.19	0.20	0.02	0.004	0.039	0.015	15.2	0.11	0.36	Zr: 0.17	Invention example
K	0.018	0.13	0.20	0.01	0.006	0.023	0.006	15.2	0.26	0.31	W: 0.15	Invention example
L	0.006	0.11	0.25	0.02	0.007	0.016	0.012	16.3	0.12	0.35	Ti: 0.14	Invention example
M	0.018	0.16	0.21	0.02	0.005	0.046	0.014	23.8	0.13	0.39	-	Invention example
N	0.016	0.19	0.27	0.01	0.003	0.023	0.009	21.4	0.16	0.37	REM: 0.07	Invention example
O	0.007	0.19	0.18	0.03	0.002	0.033	0.017	22.0	0.14	0.38	Ca: 0.0009, Mg: 0.0028	Invention example
P	0.014	0.20	0.26	0.03	0.003	0.024	0.007	13.3	0.19	0.76	-	Invention example
Q	0.011	0.17	0.21	0.04	0.004	0.020	0.013	15.2	0.20	0.12	-	Invention example
R	0.019	0.14	0.27	0.03	0.004	0.023	0.006	18.3	0.11	0.83	-	Comparative example
S	0.013	0.15	0.31	0.04	0.005	0.032	0.014	18.4	0.17	0.08	-	Comparative example
T	0.010	0.22	0.36	0.03	0.003	0.037	0.012	17.9	0.13	0.26	Cu: 0.33	Invention example
U	0.008	0.19	0.33	0.03	0.004	0.008	0.009	11.2	0.54	0.24	-	Invention example
V	0.009	0.17	0.32	0.04	0.005	0.007	0.010	16.3	0.98	0.25	-	Invention example
W	0.007	0.21	0.30	0.02	0.002	0.005	0.008	16.5	1.83	0.25	-	Invention example
X	0.011	0.18	0.31	0.04	0.004	0.006	0.012	11.4	1.98	0.23	-	Invention example

(continued)

No.	Chemical composition (mass%)											Notes
	C	Si	Mn	P	S	Al	N	Cr	Ni	Nb	Others	
Y	0.009	0.20	0.31	0.02	0.003	0.008	0.009	9.8	0.15	0.23	-	Comparative example
Z	0.012	0.19	0.32	0.03	0.004	0.009	0.013	24.6	0.23	0.26	-	Comparative example

• Balance, other than above components, is Fe and incidental impurities.
• Underline indicates the value is outside range of present invention.

[Table 2]

No.	Steel symbol	Rough rolling end sheet thickness [mm]	5th pass start sheet thickness [mm]	5th pass start temperature [°C]	6th pass start temperature [°C]	7th pass end temperature [°C]	7th pass end sheet thickness [mm]	Accumulated rolling reduction ratio for final 3 passes [%]	K_{IC} [$MPa \cdot m^{1/2}$]	Corrosion resistance	Notes
1	A	40.6	14.2	969	932	895	9.8	31	34	○	Invention example
2	B	40.1	14.8	985	944	902	10.4	30	34	⊙	Invention example
3	C	40.9	14.3	966	927	890	10.3	28	31	○	Invention example
4	D	40.6	14.2	989	941	908	9.8	31	29	⊙	Invention example
5	E	40.2	15.4	977	941	903	10.4	32	30	⊙	Invention example
6	F	40.5	15.9	969	930	890	10.2	36	29	⊙	Invention example
7	G	39.8	14.5	985	941	903	10.3	29	32	⊙	Invention example
8	H	40.3	14.5	998	948	907	10.3	29	32	⊙	Invention example
9	I	40.8	15.1	979	939	904	10.2	32	36	⊙	Invention example
10	J	39.9	14.7	983	937	899	10.5	29	34	○	Invention example
11	K	40.4	15.8	980	941	901	10.5	34	33	○	Invention example
12	L	40.7	14.5	983	936	897	9.8	32	28	○	Invention example
13	M	40.8	15.4	984	947	911	10.1	34	29	⊙	Invention example

(continued)

No.	Steel symbol	Rough rolling end sheet thickness [mm]	5th pass start sheet thickness [mm]	5th pass start temperature [°C]	6th pass start temperature [°C]	7th pass end temperature [°C]	7th pass end sheet thickness [mm]	Accumulated rolling reduction ratio for final 3 passes [%]	K_{IC} [$MPa \cdot m^{1/2}$]	Corrosion resistance	Notes
14	N	40.7	15.0	972	934	900	9.9	34	28	⊙	Invention example
15	O	40.2	15.2	956	920	889	10.2	33	36	⊙	Invention example
16	P	39.9	14.7	972	924	891	10.1	31	35	○	Invention example
17	Q	39.9	14.8	971	923	888	10.3	30	32	○	Invention example
18	O	40.2	9.4	964	921	888	5.3	44	34	○	Invention example
19	A	40.6	11.4	975	935	899	8.4	26	28	○	Invention example
20	C	39.8	19.3	990	947	909	13.0	33	34	○	Invention example
21	C	40.5	16.1	1097	1072	1048	10.2	37	33	○	Invention example
22	C	39.8	15.8	953	925	877	10.3	35	36	○	Invention example
23	C	40.2	14.0	1113	1072	1043	10.4	26	18	○	Comparative example
24	F	40.4	12.7	986	948	907	10.4	18	17	⊙	Comparative example
25	F	40.4	17.7	1134	1101	1079	12.6	29	14	⊙	Comparative example
26	F	39.9	17.9	794	765	Not evaluated because excessive load resulted in incomplete rolling					Comparative example

(continued)

No.	Steel symbol	Rough rolling end sheet thickness [mm]	5th pass start sheet thickness [mm]	5th pass start temperature [°C]	6th pass start temperature [°C]	7th pass end temperature [°C]	7th pass end sheet thickness [mm]	Accumulated rolling reduction ratio for final 3 passes [%]	K_{IC} [$MPa\cdot m^{1/2}$]	Corrosion resistance	Notes
27	R	40.7	17.5	983	941	908	12.6	28	$\underline{15}$	○	Comparative example
28	S	40.4	17.2	982	944	906	12.3	28	$\underline{18}$	○	Comparative example
29	T	40.7	14.7	959	933	894	10.3	30	32	○	Invention example
30	U	40.5	14.6	971	939	903	10.2	30	38	○	Invention example
31	V	40.6	14.4	979	946	905	9.9	31	31	○	Invention example
32	W	40.5	14.5	983	937	899	10.4	28	35	○	Invention example
33	X	40.8	14.7	976	943	902	10.0	32	43	○	Invention example
34	Y	40.7	14.6	972	929	888	10.2	30	31	×	Comparative example
35	Z	40.7	14.6	984	948	895	10.1	31	$\underline{16}$	⊙	Comparative example

Underline indicates the value is outside range of present invention.

[0076] In Nos. 1 to 22 and 29 to 33, in each of which the steel composition and the hot rolling conditions satisfied the ranges of the present invention, rolling strains were sufficiently introduced into the steel sheet by the predetermined hot rolling, and as a result, the predetermined threshold stress intensity factor was achieved. In addition, the corrosion resistance of each of the resulting hot-rolled steel sheets was evaluated, and as a result, it was found that all of the hot-rolled steel sheets had a rust ratio not more than 25% and therefore had sufficient corrosion resistance.

[0077] In particular, in Nos. 2, 4, 6, 7, and 9, in which Mo-containing steels B, D, F, G, and I were used, in Nos. 5 and 8, in which Cu-containing steels E and H were used, and in Nos. 13 to 15, in which high-Cr-content steels M, N, and O were used, higher corrosion resistance was achieved, each with a rust ratio not more than 10%.

[0078] In No. 23, in which the rolling temperature of the fifth pass (third pass from the final pass) was above the range of the present invention, and in No. 25, in which the rolling temperatures of the fifth pass and the sixth pass (second pass form the final pass) were above the range of the present invention, rolling was performed at a predetermined accumulated rolling reduction ratio, but, because of the excessively high rolling temperature, excessive recovery of work strains introduced by rolling occurred, and as a result, the threshold stress intensity factor after hot rolling was not the predetermined threshold stress intensity factor. In No. 24, in which the accumulated rolling reduction ratio for the final three passes was below the range of the present invention, rolling strains were not sufficiently introduced, and as a result, the threshold stress intensity factor after hot rolling was not the predetermined threshold stress intensity factor.

[0079] In No. 26, in which the rolling temperatures of the fifth pass and the sixth pass were below the range of the present invention, because of the excessively low rolling temperatures, the rolling load significantly increased, and, while rolling was performed in the final seventh pass, the load exceeded the acceptable range of the machine, and as a result, rolling could not be completed, and the predetermined evaluation could not be conducted.

[0080] In No. 27, in which steel R, which had a Nb content above the range of the present invention, was used, toughness significantly deteriorated because of precipitation of Laves phase during hot rolling, and therefore the predetermined threshold stress intensity factor was not achieved.

[0081] In No. 28, in which steel S, which had a Nb content below the range of the present invention, was used, excessive recovery occurred during hot rolling because the amount of Nb carbonitrides precipitated was insufficient, and therefore the predetermined threshold stress intensity factor was not achieved.

[0082] In No. 34, in which steel Y, which had a Cr content below the range of the present invention, was used, desired corrosion resistance was not achieved because of the insufficient Cr content.

[0083] In No. 35, in which steel Z, which had a Cr content above the range of the present invention, was used, σ phase precipitated because of the excessive Cr content, and as a result, toughness significantly deteriorated, and the predetermined threshold stress intensity factor was not achieved.

Industrial Applicability

[0084] Hot-rolled ferritic stainless steel sheets that can be obtained in accordance with the present invention have, in particular, excellent blanking workability for crank press and are, in particular, suitable for use in, for example, forming a thick flange that is manufactured by, for example, blanking using a crank press or another technique and which needs to have high workability and corrosion resistance.

Claims

1. A hot-rolled ferritic stainless steel sheet having a chemical composition comprising, in 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 0.50%,
N: 0.001 to 0.020%,
Cr: 11.0 to 24.0%,
Ni: 0.01 to 2.00%, and
Nb: 0.12 to 0.80%, with a balance of Fe and incidental impurities,
wherein the hot-rolled ferritic stainless steel sheet has a threshold stress intensity factor K_{IC} of 25 MPa·$m^{1/2}$ or more.

2. A hot-rolled ferritic stainless steel sheet having a chemical composition comprising, in 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 0.50%,
N: 0.001 to 0.020%,
Cr: 13.0 to 24.0%,
Ni: 0.01 to 0.60%, and
Nb: 0.12 to 0.80%, with a balance of Fe and incidental impurities,
wherein the hot-rolled ferritic stainless steel sheet has a threshold stress intensity factor K_{IC} of 25 MPa·$m^{1/2}$ or more.

3. The hot-rolled ferritic stainless steel sheet according to Claim 1 or 2, wherein the chemical composition further comprises, in mass%, one or more selected from
Cu: 0.01 to 1.50%,
Mo: 0.01 to 2.00%,
W: 0.01 to 0.20%, and
Co: 0.01 to 0.20%.

4. The hot-rolled ferritic stainless steel sheet according to any one of Claims 1 to 3, wherein the chemical composition further comprises, in mass%, one or more selected from
Ti: 0.01 to 0.30%,
V: 0.01 to 0.20%,
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: 0.0005 to 0.0030%.

5. A method for manufacturing the hot-rolled ferritic stainless steel sheet according to any one of Claims 1 to 4, the method comprising hot rolling, the hot rolling including performing finish rolling including three or more passes, wherein a temperature range for final three passes of the finish rolling is 800 to 1100°C, and an accumulated rolling reduction ratio for the final three passes is 25% or more.

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2018/000559

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. C22C38/00(2006.01)i, C21D8/02(2006.01)i, C21D9/46(2006.01)i, C22C38/48(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, C22C38/48, 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 2001-181798 A (KAWASAKI STEEL CORP.) 03 July 2001 (Family: none)	1-5
A	JP 2008-208412 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORPORATION) 11 September 2008 & KR 10-2008-0079178 A & CN 101255532 A	1-5
A	JP 2004-243354 A (JFE STEEL CORPORATION) 02 September 2004 (Family: none)	1-5

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

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

Date of the actual completion of the international search	Date of mailing of the international search report
02 April 2018 (02.04.2018)	17 April 2018 (17.04.2018)

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

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

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2012140688 A **[0005]**