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(54) HOT ROLLED Nb-CONTAINING FERRITIC STAINLESS STEEL SHEET AND METHOD FOR PRODUCING SAME, AND COLD ROLLED Nb-CONTAINING FERRITIC STAINLESS STEEL SHEET AND METHOD FOR PRODUCING SAME

(57) The hot-rolled Nb-containing ferritic stainless steel sheet of the present invention has a composition containing C: 0.030 mass% or less, Si: 2.00 mass% or less, Mn: 2.00 mass% or less, P: 0.050 mass% or less, S: 0.040 mass% or less, Cr: 10.00 mass% to 25.00 mass%, N: 0.030 mass% or less and Nb: 0.01 mass% to 0.80 mass%, with the balance being made up of Fe and unavoidable impurities. In this hot-rolled Nb-containing ferritic stainless steel sheet, the precipitation amount of Nb carbonitrides is 0.2 mass% or more, and the number of Laves phases having a grain size of 0.1 μm or less is 10 or fewer per 10 μm^2 of surface area.

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Description

TECHNICAL FIELD

[0001] The present invention relates to a hot-rolled Nb-containing ferritic stainless steel sheet and a method for producing same, and to a cold-rolled Nb-containing ferritic stainless steel sheet and a method for producing same. More particularly, the present invention relates to a hot-rolled Nb-containing ferritic stainless steel sheet and a method for producing same, and to a cold-rolled Nb-containing ferritic stainless steel sheet and a method for producing same, the stainless steel sheets being used in order to produce exhaust pipe flange parts and exhaust pipe parts.

BACKGROUND ART

[0002] Characteristics such as corrosion resistance, heat resistance, and strength are required for exhaust pipe flange parts and exhaust pipe parts, and accordingly stainless steel sheets, which are excellent in such characteristics, are used as a material of such parts. Herein, the term "exhaust pipe part" denotes parts through which exhaust gas can flow, in particular exhaust manifolds, front pipes, center pipes, catalytic converter barrels and the like used in automobiles. The term "exhaust pipe flange part" denotes a part that is welded to an end of the exhaust pipe part, and that constitutes a flange portion having the function of fastening the exhaust pipe part to other parts.
[0003] Stainless steel sheets generally used in conventional art are austenitic stainless steel sheets having good manufacturability, but these are being replaced by ferritic stainless steel sheets, which are advantageous from the viewpoint of coefficient of thermal expansion and cost. Examples of such ferritic stainless steel sheets include Nb-containing ferritic stainless steel sheets.
[0004] Exhaust pipe flange parts are produced through cold forging of a hot-rolled steel sheet. Exhaust pipe flange parts have a hole corresponding to an end of the exhaust pipe part, and a hole for bolt fastening, and ordinarily also undergo cutting work. Workability is accordingly required for a hot-rolled steel sheet that is used to produce exhaust pipe flange parts.
[0005] Exhaust pipe parts are generally produced through pressing of cold-rolled steel sheets and pipe processing of cold-rolled steel sheets, followed by various work processes. Workability is accordingly required for a cold-rolled steel sheet that is used to produce exhaust pipe parts. Better workability of cold-rolled steel sheets has come to be demanded in recent years as exhaust pipe parts (in particular, exhaust manifolds) have become smaller. The workability of cold-rolled steel sheets can be expressed using the Lankford value (hereafter "r-value") as an index. Increasing the cold rolling reduction ratio is effective herein in order to increase the r-value.
[0006] However, Nb-containing ferritic stainless steel sheets are prone to suffer from drops in toughness due to the generation of Laves phases (intermetallic compounds being mainly Fe_2Nb). To begin with, ferritic stainless steel sheets are prone to exhibit 475°C embrittlement. As a result, cracks occur readily and it is difficult to increase the cold rolling reduction ratio upon cold rolling of a produced hot-rolled Nb-containing ferritic stainless steel sheet of thick gauge (5 mm to 10 mm).
[0007] As a method for increasing the toughness of a hot-rolled Nb-containing ferritic stainless steel sheet, for instance Patent Document 1 proposes a method of suppressing generation of Laves phases, through control of the total amount of C and N so as to lie within a specific range.
[0008] As a method for increasing the workability of a cold-rolled Nb-containing ferritic stainless steel sheet, for instance Patent Document 2 proposes a method that involves controlling, among others, the starting temperature and end temperature of hot rolling finishing, as well as the annealing temperature of a hot-rolled sheet.
[0009]

Patent Document 1: Japanese Patent Application Laid-Open No. H10-237602
Patent Document 2: Japanese Patent Application Laid-Open No. 2002-30346

SUMMARY OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0010] However, the method of Patent Document 1 is aimed at hot-rolled Nb-containing ferritic stainless steel sheets having a sheet thickness of about 4.5 mm, and cannot sufficiently suppress generation of Laves phases in hot-rolled Nb-containing ferritic stainless steel sheets of thick gauge.
[0011] A further problem is that sufficient workability of a cold-rolled Nb-containing ferritic stainless steel sheet cannot be secured even when resorting to the method of Patent Document 2.
[0012] It is thus an object of the present invention, arrived at in order to solve the above problems, to provide a hot-

rolled Nb-containing ferritic stainless steel sheet having excellent toughness and workability, and a production method thereof.

[0013] It is also an object of the present invention to provide a cold-rolled Nb-containing ferritic stainless steel sheet having excellent workability, and a production method thereof.

MEANS FOR SOLVING THE PROBLEMS

[0014] As a result of diligent and assiduous research aimed at solving the above problems, the inventors found that the amount of Nb carbonitrides and quantity of Laves phases can be controlled, so as to lie within proper ranges, by holding at a temperature of 1100°C to 1000°C for 60 seconds or longer and setting a finish hot rolling temperature to 850°C or higher, during hot rolling of a stainless steel slab having a specific composition, and, after hot rolling, performing coiling at a coiling temperature of 550°C or lower, as a result of which there is enhanced toughness of the resulting hot-rolled Nb-containing ferritic stainless steel sheet, and perfected the present invention on the basis of that finding.

[0015] Further, the inventors found that the r-value can be increased to 1.2 or more by, after annealing of the hot-rolled Nb-containing ferritic stainless steel sheet, performing cold rolling at a reduction ratio of 70% or higher, and then annealing the cold-rolled steel sheet, as a result of which there is enhanced workability of the cold-rolled Nb-containing ferritic stainless steel sheet, and perfected the present invention on the basis of that finding.

[0016] Specifically, the present invention is a hot-rolled Nb-containing ferritic stainless steel sheet having a composition containing C: 0.030 mass% or less, Si: 2.00 mass% or less, Mn: 2.00 mass% or less, P: 0.050 mass% or less, S: 0.040 mass% or less, Cr: 10.00 mass% to 25.00 mass%, N: 0.030 mass% or less and Nb: 0.01 mass% to 0.80 mass%, with the balance being made up of Fe and unavoidable impurities, wherein the precipitation amount of Nb carbonitrides is 0.2 mass% or more, and the number of Laves phases having a grain size of 0.1 μm or less is 10 or fewer per 10 μm^2 of surface area.

[0017] The present invention is also a method for producing a hot-rolled Nb-containing ferritic stainless steel sheet, the method including: holding at a temperature of 1000°C to 1100°C for 60 seconds or longer, and setting a finish hot rolling temperature to 850°C or higher, during hot rolling of a stainless steel slab having a composition containing C: 0.030 mass% or less, Si: 2.00 mass% or less, Mn: 2.00 mass% or less, P: 0.050 mass% or less, S: 0.040 mass% or less, Cr: 10.00 mass% to 25.00 mass%, N: 0.030 mass% or less and Nb: 0.01 mass% to 0.80 mass%, with the balance being made up of Fe and unavoidable impurities, and, after hot rolling, performing coiling at a coiling temperature of 550°C or lower.

[0018] The present invention is also a cold-rolled Nb-containing ferritic stainless steel sheet having a composition containing C: 0.030 mass% or less, Si: 2.00 mass% or less, Mn: 2.00 mass% or less, P: 0.050 mass% or less, S: 0.040 mass% or less, Cr: 10.00 mass% to 25.00 mass%, N: 0.030 mass% or less and Nb: 0.01 mass% to 0.80 mass%, with the balance being made up of Fe and unavoidable impurities, wherein the precipitation amount of Nb carbonitrides is 0.2 mass% or more, the number of Laves phases having a grain size of 0.1 μm or less is 10 or fewer per 10 μm^2 of surface area, and the r-value is 1.2 or greater.

[0019] The present invention is also a method for producing a cold-rolled Nb-containing ferritic stainless steel sheet, the method including annealing the above hot-rolled Nb-containing ferritic stainless steel sheet, and performing thereafter cold rolling at a reduction ratio of 70% or higher, and annealing the cold-rolled steel sheet.

ADVANTAGEOUS EFFECTS OF THE INVENTION

[0020] The present invention allows the provision of a hot-rolled Nb-containing ferritic stainless steel sheet having excellent toughness and workability, and a production method thereof.

[0021] Further, the present invention allows the provision of a cold-rolled Nb-containing ferritic stainless steel sheet having excellent workability, and a production method thereof.

DESCRIPTION OF EMBODIMENTS

<Hot-rolled Nb-containing ferritic stainless steel sheet>

[0022] The hot-rolled Nb-containing ferritic stainless steel sheet of the present invention (hereafter also referred to as "hot-rolled steel sheet" for short) has a composition containing C, Si, Mn, P, S, Cr, N and Nb, with the balance being made up of Fe and unavoidable impurities. The hot-rolled steel sheet of the present invention may have a composition further containing one or more from among Ni, Mo, Cu, Co, Al, W, V, Ti, Zr, B, rare earth elements and Ca.

[0023] The hot-rolled steel sheet of the present invention will be explained in detail next.

<C: 0.030 mass% or less>

[0024] Herein C causes steel hardening and drops in the toughness of the hot-rolled steel sheet. Accordingly, the content of C is limited to 0.030 mass% or less. However, there is no need to lower the content of C to the extreme, and generally it suffices to set a C content of 0.001 mass% to 0.030 mass%, preferably 0.003 mass% to 0.025 mass% and more preferably 0.005 mass% to 0.020 mass%.

<Si: 2.00 mass% or less; Mn: 2.00 mass% or less>

[0025] Herein Si and Mn are effective as deoxidizers, and moreover elicit the effect of increasing resistance to oxidation at high temperature. In particular when resistance to oxidation at high temperature is emphasized, it is effective to secure a content of 0.05 mass% or more of Si, and 0.05 mass% or more of Mn. However, an excessively high content of these elements gives rise to steel embrittlement. As a result of various studies, the content of both Si and Mn is limited to 2.00 mass% or less. The content of both Si and Mn may be managed to be 1.00 mass% or less, or 0.50 mass% or less. The lower limit of the content of Si and Mn is not particularly restricted, and is generally 0.05 mass%, preferably 0.1 mass% and more preferably 0.15 mass%.

<P: 0.050 mass% or less; S: 0.040 mass% or less>

[0026] Herein P and S give rise to, for example, drops in corrosion resistance when present in large amounts. Accordingly, the content of P is limited to 0.050 mass% or less, and the content of S is limited to 0.040 mass% or less. Ordinarily it suffices to set the content of P to lie in the range of 0.010 mass% to 0.050 mass%, and the content of S to lie in the range of 0.0005 mass% to 0.040 mass%. The preferred content of P is 0.020 mass% to 0.040 mass% while the preferred content of S is 0.001 mass% to 0.010 mass%. In particular where corrosion resistance is emphasized, it is effective to limit the content of S to 0.005 mass% or less.

<Cr: 10.00 mass% to 25.00 mass%>

[0027] Herein Cr is an important element in order to secure corrosion resistance in stainless steel, and is also effective in terms of enhancing resistance to oxidation at high temperature. In order to bring about these effects, the content of Cr must be 10.00 mass% or more. The content of Cr is preferably 13.50 mass% or more, more preferably 17.00 mass% or more. This is effective in terms of eliciting the above effect. When the content of Cr is high, on the other hand, manufacturability of thick-gauge hot-rolled steel sheet is impaired on account of the resulting steel hardening and drop in toughness. As a result of various studies, the content of Cr is limited to 25.00 mass% or less, preferably to 22.00 mass% or less and more preferably to 20.00 mass% or less.

<N: 0.030 mass% or less>

[0028] Herein N causes a decrease in toughness. Accordingly, the content of N is limited to 0.030 mass% or less. However, there is no need to lower the content of N to the extreme, and generally it suffices to set the content of N to 0.001 mass% to 0.030 mass%, preferably to 0.005 mass% to 0.025 mass%.

<Nb: 0.01 mass% to 0.80 mass%>

[0029] Herein Nb is an element effective for suppressing boundary segregation of Cr carbonitrides (carbides / nitrides), through fixing of C and N, and for preserving high corrosion resistance, and high resistance to oxidation at high temperature, in steel. Accordingly, the content of Nb must be set to 0.01 mass% or more. It is effective to set the content of Nb to 0.05 mass% or more, and more effective to set the content of Nb to 0.20 mass% or more. An excessively high content of Nb, however, promotes drops in the toughness of the hot-rolled steel sheet, and is therefore undesirable. As a result of various studies, the content of Nb is limited to 0.80 mass% or less, preferably to 0.60 mass% or less.

<Ni: 2.00 mass% or less>

[0030] Herein Ni has the effect of inhibiting the progress of corrosion, and can be added as needed. In this case it is effective to secure a Ni content of 0.01 mass% or more. However, a high Ni content has an adverse impact on workability, and hence the content of Ni that is added, if any, must be 2.00 mass% or less, preferably 1.00 mass% or less.

<Mo: 2.50 mass% or less>

[0031] Herein Mo is an effective element in terms of enhancing corrosion resistance, and can be added as needed. In this case it is effective to set the content of Mo to 0.02 mass% or more, and more effective to set the content of Mo to 0.50 mass% or more. A high content of Mo, however, affects toughness adversely, and hence the content of Mo that is added, if any, must be 2.50 mass% or less, preferably 1.50 mass% or less.

<Cu: 1.80 mass% or less>

[0032] Herein Cu is an element effective in terms of enhancing low-temperature toughness, and in terms of enhancing also high-temperature strength. Accordingly, Cu can be added as needed. In this case it is effective to secure a Cu content of 0.02 mass% or more. However, workability rather decreases when Cu is added in large amounts. The content of Cu that is added, if any, must be 1.80 mass% or less, preferably 0.80 mass% or less.

<Co: 0.50 mass% or less>

[0033] Herein, Co is an element that contributes to low-temperature toughness, and can be added as needed. In this case it is effective to secure a Co content of 0.010 mass% or more. However, excessive addition of Co results in a loss of ductility, and hence the content of Co that is added, if any, must be 0.50 mass% or less.

<Al: 0.50 mass% or less>

[0034] Herein Al is an effective element as a deoxidizer, and can be added as needed. In this case, it is effective to set an Al content of 0.005 mass% or more. However, a high Al content is one factor underlying drops in toughness. Therefore, if Al is contained, the content thereof is limited to 0.50 mass% or less, and is preferably limited to 0.20 mass% or less.

<W: 1.80 mass% or less; V: 0.30 mass% or less>

[0035] Herein W and V are effective elements in terms of increasing high-temperature strength, and one or more of the foregoing can be added as needed. In this case it is effective to secure a content of 0.10 mass% or more of W and a content of 0.10 mass% or more of V. However, steel becomes hard, which may give rise to cracks, when the foregoing elements are added in large amounts. The content of W that is added, if any, must be 1.80 mass% or less, preferably 0.50 mass% or less. The content of V that is added, if any, must be 0.30 mass% or less, preferably 0.15 mass% or less.

<Ti: 0.50 mass% or less; Zr: 0.20 mass% or less>

[0036] Herein Ti and Zr have the effect of fixing C and N, and are effective elements in terms of preserving high corrosion resistance, and high resistance to oxidation at high temperature, in steel. Accordingly, one or both of Ti and Zr can be added as needed. In this case it is effective to secure a content of 0.01 mass% or more of Ti, and a content of 0.02 mass% or more of Zr. However, an excessive content of Ti promotes loss of toughness in hot-rolled coils, and accordingly the content of Ti that is added, if any, must be 0.50 mass% or less. Further, a high content of Zr constitutes a hindrance to workability, and hence the content of Zr that is added, if any, must be 0.20 mass% or less.

<B: 0.0050 mass% or less>

[0037] Herein B is an element that improves corrosion resistance and workability by being added in small amounts, and can be added as needed in the form of one or more types. In this case it is effective to secure a B content of 0.0001 mass% or more. However, an excessive B content affects hot workability adversely, and accordingly the content of B that is added, if any, must be 0.0050 mass% or less.

<Rare earth elements: 0.100 mass% or less; Ca: 0.0050 mass% or less>

[0038] Rare earth elements and Ca are effective elements in terms of enhancing resistance to oxidation at high temperature, and one or more of the foregoing can be added as needed. In this case it is effective to secure a content of 0.001 mass% or more of rare earth elements and a content of 0.0005 mass% or more of Ca. However, toughness decreases when these elements are added in large amounts, and hence the content of the rare earth elements that are added, if any, must be 0.100 mass% or less, and that of Ca that is added, if any, must be 0.0050 mass% or less.

<Balance: Fe and unavoidable impurities>

[0039] The balance, being components other than those above, is made up of Fe and unavoidable impurities. The term "unavoidable impurities" denotes herein impurity elements that cannot be prevented from being mixed into the materials during the production process. The unavoidable impurities are not particularly limited.

<Precipitation amount of Nb carbonitrides: 0.2 mass% or more; Number of Laves phases having a grain size of 0.1 μm or less, per 10 μm^2 of surface area: 10 or fewer>

[0040] Herein Nb carbonitrides (carbides / nitrides) and Laves phases are precipitates generated as a result of a hot rolling process. The toughness of the hot-rolled steel sheet decreases when C and N are present in the form of a solid solution in steel, and thus the presence of such a solid solution is accordingly effective in allowing C and N to precipitate in the form of Nb carbonitrides. Through precipitation of Nb carbonitrides, moreover, the amount of Nb in solid solution within the steel decreases, and it becomes possible to reduce the precipitation quantity of Laves phases that reduce the toughness of the hot-rolled steel sheet. The precipitation amount of Nb carbonitrides must be set to 0.2 mass% or more in order to increase the toughness of the hot-rolled steel sheet through a reduction in the amount of C and N in solid solution within the steel. Further, the number of Laves phases having a grain size of 0.1 μm or less must be 10 or fewer per 10 μm^2 of surface area.

[0041] To calculate the precipitation amount (mass%) of Nb carbonitrides, there was used a mixed solution of 10 mass% acetylacetone + 1 mass% tetramethylammonium chloride + 89 mass% methyl alcohol, with electrolytic extraction of a precipitate residue at a SCE potential of -100 mV to 400 mV with respect to a saturated calomel electrode, followed by filtration of the extracted residue, using a 0.2 μm micropore filter. The precipitation amount was calculated on the basis of the ratio between the weight of the filtered residue and total dissolution weight.

[0042] A scanning electron microscope (SEM) was used to capture surface micrographs and measure the size of Laves phases, and also measure the number of Laves phases having a grain size of 0.1 μm or less, per 10 μm^2 of surface area. The average value of the number of Laves phases, measured at least in five points, was taken herein as the number of Laves phases.

<Thickness>

[0043] The thickness of the hot-rolled steel sheet of the present invention is not particularly limited and may be set as appropriate depending on the intended application. In a case for instance where the hot-rolled steel sheet of the present invention is used to produce exhaust pipe flange parts for automobiles, the thickness of the hot-rolled steel sheet is ordinarily 5.0 mm to 11.0 mm preferably 5.5 mm to 9.0 mm. In a case where the hot-rolled steel sheet of the present invention is used to produce automotive exhaust pipe parts, the reduction ratio must be increased at the time of cold rolling of the hot-rolled steel sheet of the present invention, in order to increase the r-value, which is an index of the workability of a cold-rolled Nb-containing ferritic stainless steel sheet (hereafter also referred to as "cold-rolled steel sheet" for short). Therefore, the thickness of the hot-rolled steel sheet is ordinarily set to be larger than 4.5 mm, but no larger than 10.00 mm, taking into consideration the thickness and cold rolling reduction ratio of the cold-rolled steel sheet that is used in order to produce automotive exhaust pipe parts. The thickness of the hot-rolled steel sheet is preferably 5.0 mm to 9.0 mm, more preferably 5.5 mm to 8.0 mm.

<Method for producing a hot-rolled Nb-containing ferritic stainless steel sheet>

[0044] The hot-rolled Nb-containing ferritic stainless steel sheet of the present invention having the above features can be produced through hot rolling of a stainless steel slab having a composition identical to that of the above hot-rolled Nb-containing ferritic stainless steel sheet, such that during hot rolling the slab is held at a temperature of 1000°C to 1100°C for 60 seconds or longer and a finish hot rolling temperature is set to 850°C or higher, and after hot rolling, coiling is performed at a coiling temperature of 550°C or lower.

[0045] The stainless steel slab is ordinarily heated prior to hot rolling. The heating temperature of the stainless steel slab is not particularly limited, but is preferably 1200°C to 1300°C. When the heating temperature of the stainless steel slab is lower than 1200°C, excessive strain derived from hot rolling is introduced, and it is difficult to control thereafter the structure of the steel, and moreover surface scratches become problematic. On the other hand, a heating temperature of the stainless steel slab in excess of 1300°C results in structure coarsening, and there may be a failure to obtain a hot-rolled steel sheet having the desired characteristics.

[0046] As described above, hot rolling is carried out after heating of the stainless steel slab. Hot rolling ordinarily includes a plurality of rough rolling passes and a plurality of finish hot rolling passes. Holding at a temperature of 1000°C to 1100°C for 60 seconds or longer is necessary, and the finish hot rolling temperature must be set to 850°C or higher, in order to reduce precipitation of Laves phases during hot rolling while efficiently promoting precipitation of Nb carbonitrides. The reason for setting the holding temperature to be 1000°C to 1100°C is that precipitation of Nb carbonitrides can be promoted with good efficiency by a precipitation temperature of Nb carbonitrides of 1100°C or lower, and in particular by setting such a holding temperature. Precipitation of Nb carbonitrides is insufficient when the holding temperature and the hold time lie outside the above ranges. When the finish hot rolling temperature is lower than 850°C, moreover, the precipitation temperature of the Laves phases is about 800°C, and accordingly precipitation of Laves phases cannot be reduced sufficiently.

[0047] The method for holding at a temperature of 1000°C to 1100°C for 60 seconds or longer is not particularly limited, and may involve lowering a passing speed, and/or introducing a delay before finish rolling.

[0048] The timing for the holding at a temperature of 1000°C to 1100°C for 60 seconds or longer is not particularly limited, so long as it lies within the hot rolling process, but preferably lasts from the end of rough rolling up to the beginning of finish hot rolling.

[0049] The finish hot rolling time is not particularly limited, and can be set in accordance with known hot rolling methods in the relevant technical field. The finish hot rolling time is generally established taking into consideration a balance with respect to the total duration of the hot rolling process, but the longer the finish hot rolling time, the greater the precipitation amount of Nb carbonitrides is.

[0050] Hot rolling is followed by coiling into coils at a coiling temperature of 550°C or lower. A coiling temperature in excess of 550°C may result in precipitation of Laves phases and in reduced toughness.

[0051] The precipitation amount of Nb carbonitrides in the hot-rolled steel sheet obtained as described above is sufficiently increased during the hot rolling process, and accordingly Laves phases do not precipitate readily even at the precipitation temperature of the Laves phases (around 800°C). Accordingly, there is little need for a method of quenching the hot-rolled steel sheet by water cooling or the like before coiling, to shorten the transit time of the Laves phases at the precipitation temperature.

<Cold-rolled Nb-containing ferritic stainless steel sheet and production method thereof>

[0052] In addition to the characterizing features of the above hot-rolled steel sheet, a further characterizing feature of the cold-rolled steel sheet of the present invention is that the r-value of the sheet is 1.2 or greater. As a result the cold-rolled steel sheet of the present invention boasts excellent workability, and, by being worked in various ways, allows the production of automotive exhaust pipe parts such as exhaust manifolds, front pipes, center pipes and catalyst converter barrels.

[0053] The cold-rolled steel sheet of the present invention having the above characterizing features can be produced through annealing of the above hot-rolled steel sheet, followed by cold rolling at a reduction ratio of 70% or higher, and annealing the cold-rolled steel sheet.

[0054] The hot-rolled steel sheet is annealed prior to cold rolling. Annealing is carried out at a temperature such that a recrystallized structure is obtained. The annealing temperature is not particularly limited and may be set as appropriate depending on the composition of the hot-rolled steel sheet, but is ordinarily 950°C to 1150°C. There may be a failure to obtain a recrystallized structure in some instances when the annealing temperature is lower than 950°C. On the other hand, crystal grains become coarser when the annealing temperature exceeds 1150°C.

[0055] Cold rolling is carried out at a reduction ratio of 70% or more, in order to increase the r-value of the cold-rolled steel sheet to 1.2 or more. The r-value of the cold-rolled steel sheet is smaller than 1.2 when the reduction ratio is lower than 70%.

[0056] The cold-rolled steel sheet is annealed after cold rolling. Annealing is carried out at a temperature such that a recrystallized structure is obtained. The annealing temperature is not particularly limited and may be set as appropriate depending on the composition of the cold-rolled steel sheet, but is ordinarily 1000°C to 1100°C. There may be a failure to obtain a recrystallized structure in some instances when the annealing temperature is lower than 1000°C. Crystal grains become coarser and rough skin arises during working, which may give rise to cracks, when the annealing temperature exceeds 1100°C.

EXAMPLES

[0057] The present invention will be further explained next by way of examples, but the invention is not meant to be limited to these examples.

[0058] Stainless steel slabs were produced through smelting of steels having the component compositions given in Table 1, and the slabs were hot rolled in accordance with the conditions given in Table 1, to yield respective hot-rolled Nb-containing ferritic stainless steel sheets having a predetermined thickness.

No.	Chemical composition (mass%)													Hot rolling condition					Classification
	C	Si	Mn	P	S	Ni	Cu	Cr	Mo	N	Nb	Ti	Al	Slab heating temp. (°C)	Hold time (sec)*1	Finish rolling temp. (°C)	Coiling temp. (°C)	Thickness (mm)	
1	0.012	0.24	0.27	0.027	0.002	--	--	18.4	1.24	0.02	0.39	--	0.02	1205	61	860	440	5.0	Example of the invention
2	0.010	0.78	0.30	0.025	0.006	0.12	--	14.2	0.04	0.01	0.43	--	0.01	1253	63	870	400	6.0	
3	0.013	0.41	0.31	0.029	0.003	--	--	19.8	--	0.01	0.41	--	--	1240	64	862	540	5.0	
4	0.015	0.54	0.28	0.028	0.004	0.32	--	22.5	--	0.01	0.52	--	--	1234	70	856	500	5.1	
5	0.014	0.56	0.21	0.030	0.001	--	--	18.5	0.05	0.01	0.42	--	--	1221	63	900	490	5.6	
6	0.014	0.56	0.21	0.030	0.001	--	--	18.5	0.05	0.01	0.42	--	--	1213	61	897	480	4.3	
7	0.019	0.79	0.43	0.290	0.003	0.24	0.49	18.9	0.06	0.01	0.46	--	--	1225	62	887	485	5.2	
8	0.007	0.09	0.25	0.330	0.001	0.11	--	16.5	0.01	0.01	0.25	0.19	0.03	1201	71	901	450	8.1	
9	0.007	0.54	0.26	0.020	0.005	--	--	18.2	0.54	0.02	0.42	--	--	1260	<u>49</u>	960	530	5.0	Comparative example
10	0.023	0.38	0.34	0.034	0.007	--	0.21	18	0.06	0.01	0.42	--	0.03	1243	<u>40</u>	860	460	5.0	
11	0.016	0.57	0.37	0.032	0.005	--	--	13.9	--	0.01	0.44	--	0.04	1246	<u>51</u>	855	480	5.0	
12	0.015	0.28	0.32	0.027	0.004	0.11	--	18.6	0.04	0.01	0.38	0.11	0.03	1231	<u>49</u>	865	500	5.0	

(Remarks)
*1) Hold time at a temperature of 1000°C to 1100°C.
The balance other than the above components of the chemical composition is Fe and unavoidable impurities. Underline denotes values outside the condition range of the present invention.

[0059] Next, specimens were sampled from the obtained hot-rolled Nb-containing ferritic stainless steel sheets, and were evaluated for precipitation amount of Nb carbonitrides, size of Laves phases, quantity of Laves phases having a grain size of 0.1 μm or less, per 10 μm^2 of surface area, and toughness.

[0060] The precipitation amount of Nb carbonitrides and the size and quantity of Laves phases were measured in accordance with the methods described above. The SCE potential in the measurement of the precipitation amount of Nb carbonitrides was set to 400 mV. Toughness was evaluated on the basis of a Charpy impact test of U-notch specimens. The admissibility of toughness was evaluated on the basis of observable toughness (good: ○) at a ductile-brittle transition temperature (DBTT) of 20°C or lower.

[0061] The various evaluation results are given in Table 2.

No.	Precipitation amount of Nb carbonitrides (mass%)	Size of Laves phases (μm)	Number of Laves phases *1(phases)	Toughness	Classification
1	0.21	0.08	9	○	Example of the invention
2	0.22	0.09	7	○	
3	0.22	0.08	6	○	
4	0.26	0.06	4	○	
5	0.21	0.05	7	○	
6	0.21	0.05	7	○	
7	0.23	0.09	8	○	
8	0.21	0.03	5	○	
9	<u>0.12</u>	0.09	<u>14</u>	×	Comparative example
10	<u>0.05</u>	0.06	<u>14</u>	×	
11	<u>0.12</u>	<u>0.12</u>	8	×	
12	<u>0.09</u>	<u>0.11</u>	<u>11</u>	×	

(Remarks)
*1) Number of Laves phases having a grain size of 0.1 μm or less, per 10 μm^2 of surface area.
Underline denotes values outside the condition range of the present invention.

[0062] Table 2 reveals that hot-rolled Nb-containing ferritic stainless steel sheets Nos. 1 to 8, produced by holding at a temperature of 1000°C to 1100°C for 60 seconds or longer, with the finish hot rolling temperature set to 850°C or higher, during hot rolling of the stainless steel slab, and, after hot rolling, by coiling at a coiling temperature of 550°C or lower, exhibited a precipitation amount of Nb carbonitrides of 0.2 mass% or more, 10 or fewer Laves phases having a grain size of 0.1 μm or less, per 10 μm^2 of surface area, and excellent toughness.

[0063] By contrast, it was found that in hot-rolled Nb-containing ferritic stainless steel sheets Nos. 9 to 12, in which the hold time at a temperature of 1000°C to 1100°C during hot rolling of the stainless steel slab was too short, the precipitation amount of Nb carbonitrides was small, the quantity of Laves phases substantial, and toughness insufficient.

[0064] A cold forging test, a press drilling test and a cutting test for simulation of working of an exhaust pipe flange part were carried out on each hot-rolled Nb-containing ferritic stainless steel sheet that was obtained. The results revealed that hot-rolled Nb-containing ferritic stainless steel sheets Nos. 1 to 8 exhibited good workability to a desired shape, without occurrence of cracks or the like caused by lack of toughness. By contrast, hot-rolled Nb-containing ferritic stainless steel sheets Nos. 9 to 12 exhibited cracks caused by lack of toughness.

[0065] Next, the obtained hot-rolled Nb-containing ferritic stainless steel sheets Nos. 1 to 7 were annealed and were thereafter cold rolled, with further annealing to yield respective cold-rolled Nb-containing ferritic stainless steel sheets. The production conditions involved are given in Table 3. Hot-rolled Nb-containing ferritic stainless steel sheets Nos. 9 to 12 had low toughness and could not be cold rolled.

[0066] The r-value of the obtained cold-rolled Nb-containing ferritic stainless steel sheets was worked out next. The r-value was calculated in the form of an average r-value, in accordance with Expression (1) and Expression (2) below, after application of 14.4% strain to a JIS 13B tensile specimen of each cold-rolled Nb-containing ferritic stainless steel sheet.

$$r = \ln(W_0/W)/\ln(t_0/t) \quad (1)$$

where W_0 denotes sheet width before tension, W denotes sheet width after tension, to denotes sheet thickness before tension and t denotes sheet thickness after tension.

$$\text{Average r-value} = (r_0 + 2r_{45} + r_{90})/4 \quad (2)$$

where r_0 denotes the r-value in the rolling direction, r_{45} denotes the r-value in a 45° direction with respect to the rolling direction, and r_{90} denotes the r-value in a direction perpendicular to the rolling direction.

[0067] An average r-value of 1.2 or greater translates into a characteristic of enabling sufficient working of automotive exhaust pipe parts, for which complex shapes are required. Accordingly, it can be concluded that workability is excellent if the average r-value is 1.2 or greater.

[0068] The evaluation results are given in Table 3.

No.	Annealing temp. after hot rolling (°C)	Cold rolling reduction ratio (%)	Annealing temp. after cold rolling (°C)	$\bar{r}$ value	Classification
1	1002	70	1003	1.4	Example of the invention
2	985	75	1010	1.5	
3	1050	70	1043	1.4	
4	1103	71	1085	1.3	
5	1030	73	1045	1.4	
6	1024	65	1053	1.1	Comparative example
7	1028	71	1048	1.3	Example of the invention
(Remarks) Underline denotes values outside the condition range of the present invention.					

[0069] As Table 3 reveals, cold-rolled Nb-containing ferritic stainless steel sheets Nos. 1 to 5 and 7, having been cold rolled at a reduction ratio of 70% or higher, had an r-value of 1.2 or greater and exhibited excellent workability.

[0070] By contrast, it was found that cold-rolled Nb-containing ferritic stainless steel sheet No. 6, having been cold rolled at a reduction ratio lower than 70%, had an r-value smaller than 1.2 and exhibited insufficient workability.

[0071] The above results indicate that the present invention allows the provision of a hot-rolled Nb-containing ferritic stainless steel sheet having excellent toughness and workability, and a production method thereof. Further, the present invention allows the provision of a cold-rolled Nb-containing ferritic stainless steel sheet having excellent workability, and a production method thereof.

[0072] The present application claims the right of priority based on Japanese Patent Application No. 2016-017883, filed on February 2nd, 2016, the entire contents thereof are incorporated herein by reference.

Claims

1. A hot-rolled Nb-containing ferritic stainless steel sheet having a composition containing C: 0.030 mass% or less, Si: 2.00 mass% or less, Mn: 2.00 mass% or less, P: 0.050 mass% or less, S: 0.040 mass% or less, Cr: 10.00 mass% to 25.00 mass%, N: 0.030 mass% or less and Nb: 0.01 mass% to 0.80 mass%, with the balance being made up of Fe and unavoidable impurities,
wherein the precipitation amount of Nb carbonitrides is 0.2 mass% or more, and the number of Laves phases having a grain size of 0.1 μm or less is 10 or fewer per 10 μm^2 of surface area.

2. The hot-rolled Nb-containing ferritic stainless steel sheet of claim 1, having a composition further containing one or more from among Ni: 2.00 mass% or less, Mo: 2.50 mass% or less, Cu: 1.80 mass% or less, Co: 0.50 mass% or less, Al: 0.50 mass% or less, W: 1.80 mass% or less, V: 0.30 mass% or less, Ti: 0.50 mass% or less, Zr: 0.20 mass% or less, B: 0.0050 mass% or less, rare earth elements: 0.100 mass% or less and Ca: 0.0050 mass% or less.

3. The hot-rolled Nb-containing ferritic stainless steel sheet of claim 1 or 2, used for producing an exhaust pipe flange part.

4. A method for producing a hot-rolled Nb-containing ferritic stainless steel sheet, the method comprising: holding at a temperature of 1000°C to 1100°C for 60 seconds or longer, and setting a finish hot rolling temperature to 850°C or higher, during hot rolling of a stainless steel slab having a composition containing C: 0.030 mass% or less, Si: 2.00 mass% or less, Mn: 2.00 mass% or less, P: 0.050 mass% or less, S: 0.040 mass% or less, Cr: 10.00 mass% to 25.00 mass%, N: 0.030 mass% or less and Nb: 0.01 mass% to 0.80 mass%, with the balance being made up of Fe and unavoidable impurities, and, after hot rolling, performing coiling at a coiling temperature of 550°C or lower.

5. The method for producing a hot-rolled Nb-containing ferritic stainless steel sheet of claim 4, wherein the stainless steel slab has a composition further containing one or more from among Ni: 2.00 mass% or less, Mo: 2.50 mass% or less, Cu: 1.80 mass% or less, Co: 0.50 mass% or less, Al: 0.50 mass% or less, W: 1.80 mass% or less, V: 0.30 mass% or less, Ti: 0.50 mass% or less, Zr: 0.20 mass% or less, B: 0.0050 mass% or less, rare earth elements: 0.100 mass% or less and Ca: 0.0050 mass% or less.

6. A cold-rolled Nb-containing ferritic stainless steel sheet having a composition containing C: 0.030 mass% or less, Si: 2.00 mass% or less, Mn: 2.00 mass% or less, P: 0.050 mass% or less, S: 0.040 mass% or less, Cr: 10.00 mass% to 25.00 mass%, N: 0.030 mass% or less and Nb: 0.01 mass% to 0.80 mass%, with the balance being made up of Fe and unavoidable impurities,
wherein the precipitation amount of Nb carbonitrides is 0.2 mass% or more, the number of Laves phases having a grain size of 0.1 μm or less is 10 or fewer per 10 μm^2 of surface area, and the r-value is 1.2 or greater.

7. The cold-rolled Nb-containing ferritic stainless steel sheet of claim 6, having a composition further containing one or more from among Ni: 2.00 mass% or less, Mo: 2.50 mass% or less, Cu: 1.80 mass% or less, Co: 0.50 mass% or less, Al: 0.50 mass% or less, W: 1.80 mass% or less, V: 0.30 mass% or less, Ti: 0.50 mass% or less, Zr: 0.20 mass% or less, B: 0.0050 mass% or less, rare earth elements: 0.100 mass% or less and Ca: 0.0050 mass% or less.

8. The cold-rolled Nb-containing ferritic stainless steel sheet of claim 6 or 7, used for producing an exhaust pipe part.

9. A method for producing a cold-rolled Nb-containing ferritic stainless steel sheet, the method comprising annealing the hot-rolled Nb-containing ferritic stainless steel sheet of claim 1 or 2, and performing thereafter cold rolling at a reduction ratio of 70% or higher, and annealing the cold-rolled steel sheet.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/003379

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00(2006.01)i, *C21D8/02*(2006.01)i, *C21D9/46*(2006.01)i, *C22C38/38*(2006.01)i, *C22C38/58*(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00, C21D8/02, C21D9/46, C22C38/38, C22C38/58

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2017
Kokai Jitsuyo Shinan Koho	1971-2017	Toroku Jitsuyo Shinan Koho	1994-2017

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2009-120893 A (Nisshin Steel Co., Ltd.), 04 June 2009 (04.06.2009), (Family: none)	1-9
A	JP 2015-187290 A (Nippon Steel & Sumikin Stainless Steel Corp.), 29 October 2015 (29.10.2015), & WO 2015/147211 A1 & EP 3124635 A1 & CN 106133166 A & KR 10-2016-0123371 A	1-9
A	JP 2011-190468 A (Nippon Steel & Sumikin Stainless Steel Corp.), 29 September 2011 (29.09.2011), & US 2013/0004360 A1 & WO 2011/111871 A1 & EP 2546378 A1 & KR 10-2012-0099152 A & CN 102791897 A	1-9

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 April 2017 (26.04.17)	16 May 2017 (16.05.17)

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No.
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 8-199237 A (Nisshin Steel Co., Ltd.), 06 August 1996 (06.08.1996), (Family: none)	1-9
A	JP 2015-190025 A (Nippon Steel & Sumikin Stainless Steel Corp.), 02 November 2015 (02.11.2015), (Family: none)	1-9
A	JP 2014-148722 A (Independent Administrative Institution National Institute for Materials Science), 21 August 2014 (21.08.2014), (Family: none)	1-9

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

REFERENCES CITED IN THE DESCRIPTION

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- JP H10237602 B **[0009]**
- JP 2002030346 A **[0009]**
- JP 2016017883 A **[0072]**