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(54) **FERRITIC STAINLESS STEEL**

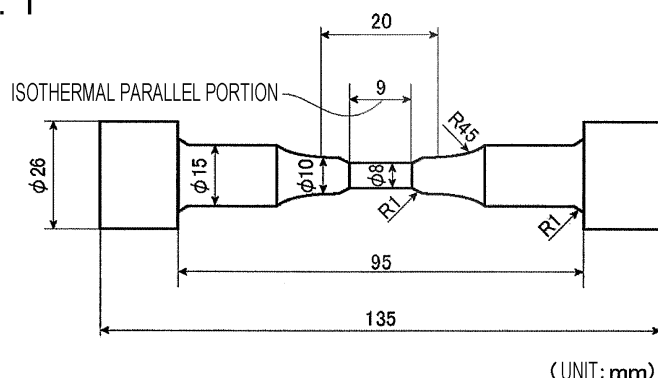
(57) Provided is a ferritic stainless steel sheet excellent not only in adhesion of scale and thermal fatigue resistance but also in corrosion resistance to condensed water.

The steel sheet has a chemical composition containing, by mass%, C: 0.010% or less, Si: 1.0% or less, Mn: 1.0% or less, P: 0.040% or less, S: 0.030% or less, Cr: 17.0% or more and 18.5% or less, N: 0.015% or less, Nb: 0.40% or more and 0.80% or less, Ti: 0.10% or more and 0.40% or less, Al: 0.20% or less, Ni: 0.05% or more and 0.40% or less, Co: 0.01% or more and 0.30% or less, Mo: 0.02% or more and 0.30% or less, Cu: 0.02% or more and 0.40% or less, and the balance being Fe and inevitable impurities, in which expression (1) below is satisfied.

$$C\% + N\%: 0.018\% \text{ or less} \quad \cdots (1)$$

In expression (1), C% and N% respectively denote the contents (mass%) of C and N.

FIG. 1



Description

Technical Field

- 5 **[0001]** The present invention relates to ferritic stainless steel excellent in adhesion of scale, thermal fatigue resistance, and corrosion resistance to condensed water.

Background Art

- 10 **[0002]** Of the exhaust system members of automobiles, an exhaust manifold, which is disposed on the upstream side and also directly connected to an engine, is used in a severe environment in which the maximum operating temperature reaches 800°C to 900°C. Therefore, since a material for such a member is required to have excellent thermal fatigue resistance, ferritic stainless steel containing Nb is mainly used.

- 15 **[0003]** Nb which is added to ferritic stainless steel improves thermal fatigue resistance by improving high-temperature strength by solid solution in the steel. However, since Nb tends to combine with C and N in the steel to form carbonitrides, there may be a deterioration in thermal fatigue resistance due to a decrease in the amount of solid solution Nb. As an example of a countermeasure for such a problem, the formation of Nb carbonitrides is prevented by adding Ti, which is more likely than Nb to combine with C and N, in combination with Nb so that C and N are used to form Ti carbonitrides. The representative example of steel containing a combination of Nb and Ti is ferritic stainless steel Type 441 (18%Cr-0.5%Nb-0.2%Ti) (EN 10088-2: EN 1.4509), and this steel is widely used for, for example, the exhaust manifold of an automobile.

- 20 **[0004]** An exhaust manifold is used in a severe cyclically oxidizing environment in which heating and rapid cooling are alternately occurred when an engine is alternately started and stopped. Therefore, in the case where spalling of scale occurs, since base steel is directly exposed to high-temperature exhaust gas, there is a decrease in the wall thickness of the manifold due to the progress of oxidation, which may result in a hole formation or deformation occurring in the wall of the manifold. Therefore, ferritic stainless steel containing a combination of Nb and Ti which is used for the exhaust manifold of an automobile is also required to have excellent adhesion of scale so that spalling of scale does not occur.

- 25 **[0005]** As examples of a method for improving the high-temperature strength and thermal fatigue resistance of ferritic stainless steel containing a combination of Nb and Ti, Patent Literature 1 and Patent Literature 2 disclose methods in which Mo is added. Patent Literature 3 through Patent Literature 5 disclose methods in which Mo, Cu, and W are added. As an example of a method for improving adhesion of scale, Patent Literature 3 discloses a method in which REM, Ca, Y, and Zr are added. Patent Literature 5 discloses a method in which REM and Ca are added. Patent Literature 6 discloses ferritic stainless steel containing a combination of Nb and Ti whose adhesion of scale and thermal fatigue resistance are improved by adding Co and Ni.

- 30 **[0006]** On the other hand, since a muffler, a pipe, and so forth, which are disposed on the downstream side of the exhaust pipe members of an automobile, are exposed to, for example, droplets of water containing snow-melting salt, which is sprayed onto a road, and condensed water containing corrosive ions, which is generated by cooling exhaust gas, such members are required to have satisfactory corrosion resistance (hereinafter, referred to as "corrosion resistance to condensed water") in many cases. Therefore, ferritic stainless steel containing Ti and Mo is used for such members. Examples of such ferritic stainless steel include SUS436L (18%Cr-0.2%Ti-1%Mo) and SUS430LX (18%Cr-0.2%Ti) prescribed in JIS G 4305.

- 35 **[0007]** As described above, since an exhaust manifold and the like disposed on the upstream side and a muffler and the like disposed on the downstream side are required to have different properties, different kinds of ferritic stainless steel are appropriately used depending on intended applications. Therefore, by manufacturing these members by using one kind of ferritic stainless steel, it is possible to decrease the number of steel grades, and there is a decrease in the number of welding positions at which parts made of different kinds of materials are welded, resulting in an improvement in the production efficiency of automobiles due to the stabilized manufacturability of their parts.

Citation List

Patent Literature

[0008]

- 55 PTL 1: Japanese Unexamined Patent Application Publication No. 4-224657
 PTL 2: Japanese Unexamined Patent Application Publication No. 5-70897
 PTL 3: Japanese Unexamined Patent Application Publication No. 2004-218013

PTL 4: Japanese Unexamined Patent Application Publication No. 2008-240143

PTL 5: Japanese Unexamined Patent Application Publication No. 2009-174040

PTL 6: Japanese Patent No. 5505570

5 Summary of Invention

Technical Problem

10 **[0009]** However, in the case of the methods disclosed in Patent Literature 1 through Patent Literature 5, there is a disadvantage in that Mo and W are expensive and cause a deterioration in the workability due to, for example, a deterioration in toughness of a steel sheet. In addition, there is a disadvantage in that Cu causes not only a significant deterioration in workability at room temperature but also a deterioration in oxidation resistance. In addition, in the case of the methods according to Patent Literature 1 through Patent Literature 5, thermal fatigue resistance and oxidation resistance (adhesion of scale), which an exhaust manifold is required to have, and corrosion resistance to condensed water, which a muffler and the like are required to have, are not evaluated at the same time. Moreover, in the case where 15 SUS436L (18%Cr-0.2%Ti-1%Mo) or SUS430LX (18%Cr-0.2%Ti) is used for an exhaust manifold, there is a problem of insufficient thermal fatigue resistance.

[0010] As described above, it may be said that conventional ferritic stainless steel is not good in all of adhesion of scale, thermal fatigue resistance, and corrosion resistance to condensed water.

20 **[0011]** The present invention has been completed to solve the problems described above, and an object of the present invention is to provide ferritic stainless steel excellent not only in adhesion of scale and thermal fatigue resistance but also in corrosion resistance to condensed water.

[0012] Here, the expression "excellent in adhesion of scale" in the present invention refers to a case where, after performing a cyclic oxidation test, in which holding at a temperature of 1000°C for 20 minutes and holding at a temperature of 100°C for 1 minute are alternately performed 400 times each in air (at a heating rate of 5°C/sec and a cooling rate of 1.5°C/sec) on a polished cold-rolled and annealed steel sheet, the ratio of an area in which scale is separated to the total area of the surface of a test piece is less than 5%. 25

[0013] In addition, the expression "excellent in thermal fatigue resistance" refers to a case where, when strain is cyclically applied with a restraint ratio of 0.6 while heating and cooling is alternately performed in a temperature range of 200°C to 900°C in accordance with JSMS-SD-7-03, the number of cycles (thermal fatigue life) at which a value (stress) calculated by dividing a load determined at a temperature of 200°C by the cross-sectional area of the gauged portion of a test piece is 75% of the stress at the 5th cycle is 660 or more. 30

[0014] In addition, the expression "excellent in corrosion resistance to condensed water" refers to a case where, after a test has been repeated for 30 cycles, where, in one cycle of the test, a polished cold-rolled and annealed steel sheet is immersed in a thermostatic bath containing Cl⁻: 500 ppm and SO₄²⁻: 1000 ppm and having a pH of 4 and a temperature of 80°C for 2 hours and then dried for 6 hours, a decrease in weight due to corrosion is 10 g/m² or less. 35

Solution to Problem

40 **[0015]** The present inventors conducted investigations regarding the influence of the amount of (C + N) on the thermal fatigue resistance of ferritic stainless steel containing a combination of Nb, Ti, Co, and Ni and found that it is possible to achieve more excellent thermal fatigue resistance by appropriately controlling the amounts of (C + N) and Ti in steel containing Ti.

[0016] Moreover, the present inventors conducted investigations regarding the corrosion resistance to condensed water of ferritic stainless steel containing a combination of Nb, Ti, Co, and Ni and found that it is possible to improve corrosion resistance to condensed water and to use the steel for members on the downstream side such as a muffler by containing both Mo and Cu in appropriate amounts. 45

[0017] The present invention has been completed on the basis of the knowledge described above, and the subject matter of the present invention is as follows. 50

[1] Ferritic stainless steel having a chemical composition containing, by mass%, C: 0.010% or less, Si: 1.0% or less, Mn: 1.0% or less, P: 0.040% or less, S: 0.030% or less, Cr: 17.0% or more and 18.5% or less, N: 0.015% or less, Nb: 0.40% or more and 0.80% or less, Ti: 0.10% or more and 0.40% or less, Al: 0.20% or less, Ni: 0.05% or more and 0.40% or less, Co: 0.01% or more and 0.30% or less, Mo: 0.02% or more and 0.30% or less, Cu: 0.02% or more and 0.40% or less, and the balance being Fe and inevitable impurities, in which expression (1) below is satisfied. 55

$$C\% + N\%: 0.018\% \text{ or less } \cdots (1)$$

In expression (1), C% and N% respectively denote the contents (mass%) of C and N.

[2] The ferritic stainless steel according to item [1] above, in which the chemical composition further contains, by mass%, one, two, or all selected from Ca: 0.0005% or more and 0.0030% or less, Mg: 0.0002% or more and 0.0020% or less, and B: 0.0002% or more and 0.0020% or less.

[3] The ferritic stainless steel according to item [1] or [2] above, in which the chemical composition further contains, by mass%, one, two, or all selected from V: 0.01% or more and 0.50% or less, W: 0.02% or more and 0.30% or less, and Zr: 0.005% or more and 0.50% or less. Advantageous Effects of Invention

[0018] According to the present invention, it is possible to obtain ferritic stainless steel excellent in adhesion of scale, thermal fatigue resistance, and corrosion resistance to condensed water. Since the ferritic stainless steel according to the present invention is excellent in both heat resistance (adhesion of scale and thermal fatigue resistance) and corrosion resistance to condensed water, the steel can preferably be used for members on both of the upstream and downstream sides of the exhaust system of an automobile.

Brief Description of Drawings

[0019]

Fig. 1 is a diagram illustrating a thermal fatigue test piece.

Fig. 2 is a diagram illustrating temperature and restraint conditions in a thermal fatigue test. Description of Embodiments

[0020] Hereafter, the present invention will be described in detail.

[0021] The ferritic stainless steel according to the present invention has a chemical composition containing, by mass%, C: 0.010% or less, Si: 1.0% or less, Mn: 1.0% or less, P: 0.040% or less, S: 0.030% or less, Cr: 17.0% or more and 18.5% or less, N: 0.015% or less, Nb: 0.40% or more and 0.80% or less, Ti: 0.10% or more and 0.40% or less, Al: 0.20% or less, Ni: 0.05% or more and 0.40% or less, Co: 0.01% or more and 0.30% or less, Mo: 0.02% or more and 0.30% or less, Cu: 0.02% or more and 0.40% or less, and the balance being Fe and inevitable impurities, in which expression (1) below is satisfied, and the steel is excellent in adhesion of scale, thermal fatigue resistance, and corrosion resistance to condensed water.

$$C\% + N\%: 0.018\% \text{ or less } \cdots (1)$$

In expression (1), C% and N% respectively denote the contents (mass%) of C and N.

[0022] Hereafter, the reasons for the limitations on the chemical composition of the ferritic stainless steel according to the present invention will be described. Here, "%" used when describing a chemical composition always refers to "mass%", unless otherwise noted.

C: 0.010% or less

[0023] C is an element which is effective for improving the strength of steel, and it is possible to realize such an effect in the case where the C content is 0.001% or more. Therefore, it is preferable that the C content be 0.001% or more. On the other hand, since spalling of scale occurs in the case where the C content is more than 0.010%, the C content is set to be 0.010% or less. Here, it is preferable that the C content be as low as possible from the viewpoint of achieving satisfactory toughness and workability and preventing a deterioration in thermal fatigue resistance due to a decrease in the amount of solid solution Nb in steel as a result of coarsening of NbC and an increase in amount of NbC precipitated. Therefore, it is preferable that the C content be 0.008% or less. It is more preferable that the C content be 0.005% or more.

Si: 1.0% or less

[0024] Si is an element which is effective for improving oxidation resistance, and it is possible to realize such an effect in the case where the Si content is 0.01% or more. Therefore, it is preferable that the Si content be 0.01% or more. On the other hand, since there is a deterioration in workability in the case where the Si content is more than 1.0%, the Si

content is set to be 1.0% or less. It is more preferable that the Si content be 0.20% or more or even more preferably 0.30% or more. In particular, in the case where the Ni content is 0.20% or more and the Si content is 0.30% or more, the adhesion of scale is particularly excellent. In addition, it is preferable that the Si content be 1.00% or less, more preferably 0.50% or less, or even more preferably 0.40% or less.

Mn: 1.0% or less

[0025] Mn is an element which improves the strength of steel and which functions as a deoxidizing agent. Since it is possible to realize such effects in the case where the Mn content is 0.01% or more, it is preferable that the Mn content be 0.01% or more. On the other hand, since there is a deterioration in oxidation resistance due to a significant increase in weight caused by oxidation in the case where the Mn content is more than 1.0%, the Mn content is set to be 1.0% or less. It is more preferable that the Mn content be 0.20% or more or even more preferably 0.30% or more. In addition, it is preferable that the Mn content be 1.00% or less, more preferably 0.60% or less, or even more preferably 0.50% or less.

P: 0.040% or less

[0026] Since P is an element which causes a deterioration in toughness, it is preferable that the P content be decreased. Therefore, the P content is set to be 0.040% or less, preferably 0.035% or less, or more preferably 0.030% or less.

S: 0.030% or less

[0027] Since S causes a deterioration in formability and corrosion resistance, it is preferable that the S content be as low as possible. Therefore, the S content is set to be 0.030% or less. It is preferable that the S content be 0.006% or less or more preferably 0.003% or less.

Cr: 17.0% or more and 18.5% or less

[0028] Cr is an element which is necessary for improving corrosion resistance and oxidation resistance, and it is necessary that the Cr content be 17.0% or more to achieve good corrosion resistance and oxidation resistance. In the case where the Cr content is less than 17.0%, there is a deterioration in adhesion of scale due to a tendency for the amount of oxide scale to increase, and there may also be a deterioration in thermal fatigue resistance. Moreover, it is not possible to achieve sufficient corrosion resistance to condensed water. On the other hand, since there is a deterioration in manufacturability and workability due to an increase in the hardness of steel in the case where the Cr content is more than 18.5%, the Cr content is set to be 18.5% or less. It is preferable that the Cr content be 17.5% or more and 18.5% or less.

N: 0.015% or less

[0029] Since N causes a deterioration in the toughness and workability of steel, it is preferable that the N content be as low as possible. In addition, in the case where the N content is high, since a high amount of NbC is precipitated due to coarse TiN being precipitated, there is a decrease in the amount of solid solution Nb in steel, which results in a deterioration in thermal fatigue resistance. Moreover, since oxidized spalling of oxide scale tends to start from coarse TiN, there is also a deterioration in adhesion of scale. Therefore, the N content is set to be 0.015% or less, preferably 0.012% or less, or more preferably 0.010% or less.

Nb: 0.40% or more and 0.80% or less

[0030] Nb is an element which is effective for improving thermal fatigue resistance by significantly improving high-temperature strength as a result of solid solution in steel. It is possible to realize such an effect in the case where the Nb content is 0.40% or more. On the other hand, in the case where the Nb content is more than 0.80%, there is a deterioration in the toughness of steel, and there is conversely a deterioration in high-temperature strength due to the generation of a Laves phase (Fe_2Nb) at a high temperature. Therefore, the Nb content is set to be 0.80% or less. It is preferable that the Nb content be 0.43% or more or more preferably 0.45% or more. In addition, it is preferable that the Nb content be 0.60% or less or more preferably 0.50% or less.

Ti: 0.10% or more and 0.40% or less

[0031] Ti prevents the generation of Nb carbonitrides, improves corrosion resistance and formability, and improves grain-boundary corrosion resistance in a weld as a result of being more likely than other elements to combine with C

and N to generate carbonitrides. It is necessary that the Ti content be 0.10% or more to realize such effects. In the case where the Ti content is less than 0.10%, since it is not possible to completely consume C and N by forming Ti carbonitrides, Nb carbonitrides are formed, which results in a deterioration in thermal fatigue resistance due to a decrease in the amount of solid solution Nb. On the other hand, in the case where the Ti content is more than 0.40%, since Nb carbonitrides tend to be precipitated due to an increase in the amount of Ti carbonitrides precipitated, there is a decrease in the amount of solid solution Nb, which results in a deterioration in thermal fatigue resistance. Moreover, there is a deterioration in adhesion of scale due to an increase in the amount of Ti carbonitrides precipitated, and there is a deterioration in corrosion resistance to condensed water due to corrosion which starts with coarse Ti carbonitrides. Therefore, the Ti content is set to be 0.40% or less. It is preferable that the Ti content be 0.15% or more. In addition, it is preferable that the Ti content be 0.30% or less or more preferably 0.25% or less.

Al: 0.20% or less

[0032] Al is an element which is effective for deoxidation, and it is possible to realize such an effect in the case where the Al content is 0.01% or more. Therefore, it is preferable that the Al content be 0.01% or more. On the other hand, since Al causes a deterioration in workability by increasing the hardness of steel, the Al content is set to be 0.20% or less. It is more preferable that the Al content be 0.02% or more. In addition, it is preferable that the Al content be 0.10% or less or more preferably 0.06% or less.

Ni: 0.05% or more and 0.40% or less

[0033] Ni is an element which is important for achieving satisfactory adhesion of scale in the present invention, and it is necessary that the Ni content be 0.05% or more to realize such an effect. In the case where the Ni content is less than 0.05%, since there is a deterioration in adhesion of scale, thermal fatigue failure may start at a point at which spalling of scale occurs. In addition, as described below, in the case of the steel according to the present invention, the thermal expansion coefficient is decreased by containing an appropriate amount of Co, and it is possible to realize the effect described above with less Ni content than in the case of steel containing no Co or an insufficient amount of Co. On the other hand, Ni is an expensive element, and there is conversely a deterioration in adhesion of scale as a result of the generation of a γ phase at a high temperature in the case where the Ni content is more than 0.40%. Therefore, the Ni content is set to be 0.05% or more and 0.40% or less. It is preferable that the Ni content be 0.10% or more or more preferably 0.20% or more. In addition, it is preferable that the Ni content be 0.30% or less or more preferably 0.25% or less.

Co: 0.01% or more and 0.30% or less

[0034] Co is an element which is important in the present invention. Co is an element which is necessary for improving thermal fatigue resistance, and it is necessary that the Co content be 0.01% or more for this purpose. Since Co decreases the amount of thermal expansion when heating is performed by decreasing the thermal expansion coefficient of steel, there is a decrease in the amount of strain generated when heating and cooling are performed, which results in an improvement in thermal fatigue resistance. Moreover, since there is a decrease in the difference in the thermal expansion coefficient between steel and scale due to a decrease in the thermal expansion coefficient of steel, spalling of scale becomes less likely to occur when cooling is performed. Therefore, there is an advantage in that it is possible to prevent spalling of scale from occurring with less Ni content. On the other hand, in the case where the Co content is more than 0.30%, since Co is concentrated at the interface between an oxide layer and base steel, there is a deterioration in adhesion of scale. In the case where the Co content is more than 0.30%, since the side effect of the concentration of Co at the interface decreases the above-described effect of preventing spalling of scale from occurring by decreasing the thermal expansion coefficient, spalling of scale occurs when cooling is performed. Therefore, the Co content is set to be 0.01% or more and 0.30% or less. It is preferable that the Co content be 0.02% or more or more preferably 0.03% or more. In addition, it is preferable that the Co content be 0.10% or less.

Mo: 0.02% or more and 0.30% or less

[0035] Mo is an element which improves thermal fatigue resistance by improving the strength of steel through solid solution strengthening and improves corrosion resistance to condensed water by improving salt corrosion resistance, and it is possible to realize such effects in the case where the Mo content is 0.02% or more. However, Mo is an expensive element. In addition, in the case where the Mo content is high, surface defects occur, and there is a deterioration in workability at room temperature. It is necessary that the Mo content be 0.30% or less to achieve good surface quality without the occurrence of surface defects. Therefore, the Mo content is set to be 0.02% or more and 0.30% or less. It is preferable that the Mo content be 0.04% or more. In addition, it is preferable that the Mo content be 0.10% or less.

Cu: 0.02% or more and 0.40% or less

[0036] Cu is effective for improving thermal fatigue resistance by strengthening steel as a result of being precipitated in the form of refined ϵ -Cu and for improving corrosion resistance to condensed water by improving sulfuric acid corrosion resistance. It is necessary that the Cu content be 0.02% or more to realize such effects. On the other hand, in the case where the Cu content is more than 0.40%, there is a deterioration in cyclic oxidation resistance due to a deterioration in adhesion of oxide scale. Moreover, since Cu tends to be precipitated in the generation of coarse ϵ -Cu, there is also a deterioration in corrosion resistance to condensed water. Therefore, the Cu content is set to be 0.40% or less. Therefore, the Cu content is set to be 0.02% or more and 0.40% or less. It is preferable that the Cu content be 0.04% or more. In addition, it is preferable that the Cu content be 0.10% or less.

[0037] In the present invention, since Mo and Cu improve corrosion resistance to condensed water by improving salt corrosion resistance and sulfuric acid corrosion resistance, respectively, it is not possible to achieve sufficient corrosion resistance to condensed water if only one of Mo and Cu is contained. In the present invention, it is possible to achieve excellent corrosion resistance to condensed water precisely because both Mo and Cu are contained in appropriate amounts.

$$C\% + N\%: 0.018\% \text{ or less} \quad \cdots (1)$$

In expression (1), C% and N% denote the contents (mass%) of C and N, respectively.

[0038] As described above, the contents of C and N are set to be 0.010% or less and 0.015% or less respectively from the viewpoint of toughness, workability, and adhesion of scale. Moreover, in the present invention, (C% + N%) is limited to be 0.018% or less from the viewpoint of thermal fatigue resistance as indicated in expression (1) above. In the case where (C% + N%) is more than 0.018%, a high amount of coarse Ti nitride (TiN) is generated, which is accompanied by the precipitation of NbC around the TiN, resulting in an increase in the amount of NbC precipitated. In the case where there is an increase in the amount of NbC precipitated, since there is a decrease in the amount of solid solution Nb in steel, there is a deterioration in the high-temperature strength of steel, which makes it impossible to sufficiently realize the effect of improving thermal fatigue resistance. Therefore, in the present invention, in which a combination of Nb and Ti is added, (C% + N%) is set to be 0.018% or less to realize sufficient effect of solid solution strengthening caused by Nb. It is preferable that (C% + N%) be 0.015% or less. In the case where (C% + N%) is 0.015% or less, since precipitated TiN and NbC are refined, and since there is a decrease in the amount of NbC precipitated around the refined TiN, there is an increase in solid solution Nb in steel. Moreover, as a result of refined NbC being precipitated, it is possible to realize a precipitation strengthening effect. Through such effects, there is an improvement in thermal fatigue resistance. It is more preferable that (C% + N%) be 0.013% or less.

[0039] The present invention is ferritic stainless steel which is excellent in adhesion of scale, thermal fatigue resistance, and corrosion resistance to condensed water and which is characterized by having a chemical composition containing the above-described indispensable constituents and the balance being Fe and inevitable impurities. Moreover, one, two, or all selected from Ca, Mg, and B and/or one, two, or all selected from V, W, and Zr may be contained as needed in the amounts described below.

Ca: 0.0005% or more and 0.0030% or less

[0040] Ca is an element which is effective for preventing nozzle clogging caused by the precipitation of Ti-based inclusions which tend to be generated when continuous casting is performed. It is possible to realize such an effect in the case where the Ca content is 0.0005% or more. On the other hand, it is preferable that the Ca content be 0.0030% or less to achieve good surface quality without the occurrence of surface defects. Therefore, in the case where Ca is contained, it is preferable that the Ca content be 0.0005% or more and 0.0030% or less, more preferably 0.0005% or more and 0.0020% or less, or even more preferably 0.0005% or more and 0.0015% or less.

Mg: 0.0002% or more and 0.0020% or less

[0041] Mg is an element which is effective for improving workability and toughness. Moreover, Mg is an element which is effective for inhibiting coarsening of the carbonitrides of Nb and Ti. In the case where Ti carbonitrides are coarsened, since brittle fracturing starts from the Ti carbonitrides, there is a deterioration in toughness. In addition, in the case where Nb carbonitrides are coarsened, since there is a decrease in the amount of solid solution Nb in steel, there is a deterioration in thermal fatigue resistance. It is possible to realize the above-described effects of improving workability and toughness

and of inhibiting coarsening of the carbonitrides of Ti and Nb in the case where the Mg content is 0.0002% or more. On the other hand, in the case where the Mg content is more than 0.0020%, there may be a deterioration in the surface quality of steel. Therefore, in the case where Mg is contained, it is preferable that the Mg content be 0.0002% or more and 0.0020% or less. It is more preferable that the Mg content be 0.0004% or more. In addition, it is more preferable that the Mg content be 0.0015% or less or even more preferably 0.0010% or less.

B: 0.0002% or more and 0.0020% or less

[0042] B is an element which is effective for improving workability, in particular, secondary workability. It is possible to realize such effects in the case where the B content is 0.0002% or more. On the other hand, since there may be a deterioration in the workability and toughness of steel in the case where the B content is more than 0.0020%, the B content is set to be 0.0020% or less. Therefore, in the case where B is added, it is preferable that the B content be 0.0002% or more and 0.0020% or less. It is more preferable that the B content be 0.0003% or more. In addition, it is more preferable that the B content be 0.0010% or less.

V: 0.01% or more and 0.50% or less

[0043] V is an element which is effective for improving high-temperature strength and which is effective for inhibiting coarsening of the carbonitrides of Ti and Nb. It is possible to realize such effects in the case where the V content is 0.01% or more. On the other hand, in the case where the V content is more than 0.50%, since coarse V(C, N) is precipitated, there may be a deterioration in toughness. Therefore, in the case where V is contained, it is preferable that the V content be 0.01% or more and 0.50% or less. It is more preferable that the V content be 0.02% or more. In addition, it is more preferable that the V content be 0.20% or less.

W: 0.02% or more and 0.30% or less

[0044] W is, like Mo, an element which improves the strength of steel through solid solution strengthening, and it is possible to realize such an effect in the case where the W content is 0.02% or more. However, W is an expensive element, and, in the case where the W content is high, surface defects occur, and there is a significant deterioration in workability due to, for example, a deterioration in toughness. It is preferable that the W content be 0.30% or less to achieve good surface quality. Therefore, in the case where W is contained, it is preferable that the W content be 0.02% or more and 0.30% or less.

Zr: 0.005% or more and 0.50% or less

[0045] Zr is an element which improves oxidation resistance. It is preferable that the Zr content be 0.005% or more to realize such an effect. On the other hand, in the case where the Zr content is more than 0.50%, since Zr-based intermetallic compounds are precipitated, there is a tendency for embrittlement to occur in steel. Therefore, in the case where Zr is contained, it is preferable that the Zr content be 0.005% or more and 0.50% or less.

[0046] Hereafter, the method for manufacturing the ferritic stainless steel according to the present invention will be described.

[0047] The ferritic stainless steel according to the present invention may be manufactured by using an ordinary method for manufacturing stainless steel. Molten steel having the chemical composition described above is prepared by using a melting furnace such as a converter or an electric furnace, subjected to secondary refining by using a method such as a ladle refining method or a vacuum refining method, made into a steel piece (slab) by using a continuous casting method or a ingot casting-slabbing method, and made into a hot-rolled, annealed, and pickled steel sheet by performing hot rolling, hot-rolled-sheet annealing, and pickling. It is recommended that processes such as a cold rolling process, a finish annealing process, a pickling process, and so forth be performed to obtain a cold-rolled and annealed steel sheet. One example of such a method is as follows.

[0048] Molten steel having the chemical composition described above is prepared by using, for example, a converter or an electric furnace, subjected to secondary refining by using an AOD method or a VOD method, and made into a slab by using a continuous casting method. This slab is heated to a temperature of 1000°C to 1250°C and subjected to hot rolling to obtain a hot-rolled steel sheet having a desired thickness. This hot-rolled steel sheet is subjected to continuous annealing at a temperature of 900°C to 1100°C and subjected to descaling by performing shot blasting and pickling to obtain a hot-rolled, annealed, and pickled steel sheet. Although this hot-rolled, annealed, and pickled steel sheet may be directly used for an application such as for an exhaust manifold, a flange, a pipe, or a muffler for which the present invention is intended, cold rolling, annealing, and pickling may further be performed to obtain a cold-rolled, annealed, and pickled steel sheet. In such a cold rolling process, cold rolling with process annealing may be performed two or

more times as needed. The total rolling reduction ratio in the cold rolling process, in which cold rolling is performed once, twice, or more, is set to be 60% or more or preferably 70% or more. The cold-rolled-sheet annealing temperature is set to be 900°C to 1150°C or preferably 950°C to 1100°C. In addition, depending on intended applications, the shape and properties of the steel sheet may be controlled by performing light-reduction rolling (such as skin pass rolling) after the pickling has been performed. In addition, annealing may be performed in a reducing atmosphere containing hydrogen to obtain a bright annealed steel sheet without performing pickling.

[0049] By performing bending or the like, depending on application, on the hot-rolled and annealed product sheet or the cold-rolled and annealed product sheet which has been manufactured as described above, the product sheet is formed into the exhaust pipe or catalyst outer cylinder of an automobile or a motorcycle, the exhaust air duct of a thermal power generation plant, or a fuel cell-related member. There is no particular limitation on the method used for welding such members, and an arc welding method such as TIG, MIG, or MAG, a resistance welding method such as a spot welding method or a seam welding method, a high-frequency resistance welding method such as an electric resistance welding method, or a high-frequency induction welding method may be used.

EXAMPLES

[0050] Molten steel Nos. 1 through 40 having the chemical compositions given in Table 1 were prepared and cast into steel ingots having a weight of 30 kg by using a vacuum melting furnace. Subsequently, the ingots were heated to a temperature of 1170°C and subjected to hot rolling to obtain sheet bars having a thickness of 35 mm and a width of 150 mm. Each of these sheet bars was divided into two pieces. One of the two pieces was subjected to forging to obtain a square bar having a cross section of 30 mm × 30 mm. The square bar was annealed at a temperature of 950°C to 1050°C and machined to obtain a thermal fatigue test piece illustrated in Fig. 1. The thermal fatigue test described below was performed on the test piece. The annealing temperature was controlled in the temperature range of 950°C to 1050°C in accordance with the chemical composition while the microstructure was checked. The same applies to the annealing described below.

[0051] The other half of the two pieces described above was heated to a temperature of 1050°C and subjected to hot rolling to obtain a hot-rolled steel sheet having a thickness of 5 mm. Subsequently, the steel sheet was subjected to hot-rolled-sheet annealing in a temperature range of 900°C to 1050°C and pickled to obtain a hot-rolled, annealed, and pickled steel sheet. At this stage, the surface quality of the steel sheet was visually inspected. The steel sheet was subjected to cold rolling to a thickness of 2 mm and subjected to finish annealing in a temperature range of 900°C to 1050°C to obtain a cold-rolled and annealed steel sheet. The steel sheet was subjected to the cyclic oxidation test and the condensed water immersion test described below.

<Cyclic oxidation test>

[0052] A test piece having a width of 20 mm and a length of 30 mm was taken from the cold-rolled and annealed steel sheet described above, the entire 6 surfaces of the test piece were polished by using #320 emery paper, and the polished test piece was subjected to the test. In the oxidation test, holding at a temperature of 1000°C for 20 minutes and holding at a temperature of 100°C for 1 minute were alternately performed 400 times each in air. Heating and cooling were performed respectively at a heating rate of 5°C/sec and at a cooling rate of 1.5°C/sec. After the test, by performing visual observation to determine whether spalling of scale occurred or not, adhesion of scale was evaluated. The obtained results are given in Table 1.

<Thermal fatigue test>

[0053] The thermal fatigue life of the thermal fatigue test piece described above was evaluated by cyclically applying strain with a restraint ratio of 0.6 as illustrated in Fig. 2 while heating and cooling was alternately performed in a temperature range of 200°C to 900°C. The determination was performed in accordance with the "Standard for high temperature low cycle fatigue testing" (JSMS-SD, 7-03) published by the Society of Material Science, Japan. First, the stress of each of the cycles was defined as a value calculated by dividing a load determined at a temperature of 200°C by the cross-sectional area (50.3 mm²) of the gauged portion of the test piece illustrated in Fig. 1. The thermal fatigue life of the test piece was defined as the number of cycles at which the stress was 75% of the stress at the 5th cycle, at which the behavior becomes stable. Thermal fatigue resistance was evaluated on the basis of the fatigue life. The obtained results are given in Table 1.

[0054] Here, the restraint ratio described above was, as illustrated in Fig. 2, calculated by using the equation restraint ratio $\eta = a/(a + b)$, where $a = (\text{free thermal expansion strain} - \text{controlled strain})/2$ and $b = \text{controlled strain}/2$. In addition, the term "free thermal expansion strain" refers to strain generated when heating is performed with no mechanical stress being applied, and the term "controlled strain" refers to strain with respect to a state in which no stress is applied at room

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temperature. Substantial strain generated in the material due to restraint is equal to (free thermal expansion strain - controlled strain), that is, strain with respect to the free thermal expansion strain.

<Condensed water immersion test>

[0055] A test piece having a width of 60 mm and a length of 80 mm was taken from the cold-rolled and annealed steel sheet obtained as described above, the entire 6 surfaces of the test piece were polished by using #320 emery paper, and the polished test piece was subjected to the test. At the time of the test, the end surfaces of the test pieces were covered with a protection tape. The testing solution, that is, simulated condensed water, contained Cl⁻: 500 ppm and SO₄²⁻: 1000 ppm and had a pH of 4. The solution was held in a thermostatic bath so that the temperature of the solution was 80°C. The test was repeated 30 cycles, where, in one cycle of the test, the test piece was immersed in the solution for 2 hours and then dried for 6 hours. After the test had been performed, corrosion product was removed, and a decrease in weight due to corrosion was calculated from the weight of the test piece determined before and after the test.

[Table 1]

Steel No.	Chemical Composition (mass%)													Adhesion of Scale	Thermal Fatigue Resistance	Corrosion Resistance to Condensed Water	Note
	C	Si	Mn	P	S	Cr	N	Nb	Ti	Al	Ni	Co	Mo	Cu	Other	C+N	
1	0.008	0.34	0.39	0.026	0.002	18.2	0.007	0.43	0.26	0.03	0.11	0.18	0.09	0.10	-	0.015	○
2	0.005	0.30	0.25	0.032	0.003	18.0	0.010	0.42	0.23	0.02	0.36	0.08	0.07	0.08	-	0.015	⊙
3	0.005	0.62	0.57	0.021	0.002	17.9	0.006	0.54	0.22	0.10	0.34	0.05	0.02	0.02	-	0.011	⊙
4	0.006	0.69	0.20	0.035	0.002	18.3	0.009	0.48	0.26	0.04	0.32	0.06	0.03	0.08	-	0.014	⊙
5	0.009	0.45	0.41	0.024	0.001	17.2	0.009	0.44	0.12	0.01	0.10	0.11	0.03	0.09	-	0.018	○
6	0.004	0.44	0.45	0.037	0.002	17.1	0.006	0.54	0.21	0.02	0.36	0.17	0.07	0.06	-	0.010	⊙
7	0.004	0.55	0.19	0.032	0.002	18.4	0.008	0.40	0.19	0.14	0.12	0.12	0.07	0.06	-	0.012	○
8	0.004	0.22	0.51	0.035	0.002	17.8	0.009	0.60	0.19	0.18	0.34	0.11	0.07	0.08	-	0.013	○
9	0.004	0.63	0.35	0.037	0.002	18.0	0.010	0.53	0.28	0.15	0.30	0.16	0.10	0.07	-	0.014	⊙
10	0.004	0.37	0.47	0.024	0.001	17.2	0.008	0.47	0.24	0.15	0.25	0.07	0.07	0.09	-	0.013	⊙
11	0.006	0.26	0.34	0.036	0.002	17.8	0.008	0.43	0.18	0.15	0.25	0.03	0.07	0.06	-	0.014	○
12	0.004	0.40	0.21	0.034	0.001	17.2	0.006	0.43	0.35	0.05	0.31	0.05	0.05	0.03	W:0.11	0.009	⊙
13	0.004	0.18	0.53	0.032	0.003	17.4	0.007	0.57	0.29	0.02	0.36	0.09	0.02	0.06	V:0.18	0.011	○
14	0.004	0.51	0.39	0.034	0.002	17.6	0.010	0.45	0.34	0.14	0.27	0.01	0.04	0.03	Zr:0.07	0.013	○
15	0.005	0.31	0.51	0.022	0.002	17.0	0.006	0.49	0.17	0.08	0.35	0.07	0.02	0.03	B:0.0009	0.012	○
16	0.004	0.87	0.36	0.024	0.002	17.5	0.009	0.54	0.33	0.05	0.24	0.19	0.10	0.07	Ca:0.0008	0.014	⊙
17	0.004	0.16	0.41	0.036	0.003	17.2	0.011	0.58	0.27	0.03	0.22	0.15	0.02	0.06	B:0.0008, Mg:0.0009	0.015	○
18	0.003	0.59	0.29	0.027	0.002	17.8	0.005	0.43	0.10	0.15	0.15	0.06	0.10	0.08	Ca:0.0007, Mg:0.0011	0.008	○
19	0.004	0.47	0.29	0.024	0.002	18.3	0.010	0.55	0.28	0.09	0.21	0.15	0.04	0.02	V:0.04, B:0.0005	0.014	⊙
20	0.006	0.72	0.55	0.039	0.002	17.7	0.008	0.47	0.18	0.18	0.39	0.04	0.02	0.02	-	0.014	⊙
21	0.003	0.90	0.54	0.023	0.002	18.4	0.010	0.41	0.33	0.16	0.38	0.19	<0.01	<0.01	-	0.014	⊙
22	0.004	0.67	0.26	0.023	0.001	17.3	0.009	0.40	0.34	0.13	0.23	0.19	0.06	<0.01	-	0.013	⊙
23	0.003	0.66	0.53	0.034	0.003	18.0	0.009	0.47	0.14	0.06	0.32	0.14	<0.01	0.05	-	0.012	⊙
24	0.004	0.12	0.56	0.034	0.002	17.7	0.010	0.58	0.27	0.04	0.20	0.08	0.01	0.01	-	0.014	○
25	0.009	0.67	0.18	0.025	0.003	17.8	0.010	0.44	0.14	0.12	0.35	0.13	0.07	0.07	-	0.019	⊙
26	0.005	0.83	0.16	0.040	0.002	18.4	0.007	0.48	0.18	0.04	0.12	<0.005	0.09	0.04	-	0.012	○
27	0.004	0.70	0.35	0.028	0.002	17.4	0.008	0.58	0.16	0.11	<0.01	0.12	0.04	0.03	-	0.012	×
28	0.005	0.76	0.22	0.028	0.002	17.8	0.007	0.58	0.11	0.13	<0.01	<0.005	0.04	0.04	-	0.012	×
29	0.004	0.84	0.40	0.028	0.002	18.5	0.006	0.57	0.20	0.09	0.17	0.11	0.08	0.55	-	0.010	×
30	0.005	0.57	0.18	0.021	0.003	17.2	0.010	0.57	0.45	0.16	0.33	0.20	0.09	0.07	-	0.015	×
31	0.018	0.87	0.45	0.034	0.001	17.0	0.006	0.56	0.27	0.06	0.33	0.19	0.04	0.08	-	0.024	×
32	0.008	0.54	0.31	0.022	0.002	17.5	0.018	0.46	0.33	0.08	0.16	0.01	0.08	0.04	-	0.026	×
33	0.004	0.75	0.21	0.036	0.003	16.3	0.006	0.51	0.27	0.13	0.15	0.08	0.03	0.07	-	0.010	×
34	0.003	0.58	0.39	0.038	0.002	18.0	0.006	0.32	0.18	0.17	0.29	0.11	0.05	0.03	-	0.010	⊙
35	0.008	0.80	0.43	0.032	0.003	18.2	0.009	0.42	0.08	0.08	0.14	0.10	0.04	0.05	-	0.017	○
36	0.009	0.41	0.29	0.029	0.003	18.1	0.007	0.46	0.19	0.05	0.25	0.08	0.06	0.10	-	0.016	⊙
37	0.007	0.41	0.34	0.031	0.002	17.8	0.010	0.48	0.20	0.04	0.28	0.04	0.07	0.08	-	0.017	⊙
38	0.008	0.37	0.25	0.028	0.003	17.7	0.006	0.45	0.24	0.07	0.30	0.09	0.05	0.07	-	0.014	⊙
39	0.006	0.45	0.38	0.025	0.003	18.3	0.010	0.50	0.22	0.06	0.29	0.06	0.08	0.09	-	0.016	⊙
40	0.007	0.48	0.31	0.033	0.002	18.0	0.009	0.51	0.18	0.10	0.26	0.05	0.06	0.05	-	0.016	⊙

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

· Remainder which is different from the constituents described above is Fe and inevitable impurities.

[0056] Here, in Table 1, the judgment criteria of the tests described above were as follows.

(1) adhesion of scale: after the cyclic oxidation test had been performed, a case where the ratio of an area in which scale was separated to the total area of the surface of a test piece was 0% (no spalling of scale was observed in the visual observation) was judged as ⊙ (satisfactory), a case where the area ratio was more than 0% and less than 5% was judged as ○ (satisfactory), and a case where the area ratio was 5% or more was judged as × (unsatisfactory).
 (2) thermal fatigue resistance: a case of a thermal fatigue life of 750 cycles or more was judged as ⊙ (satisfactory), a case of a thermal fatigue life of 660 cycles or more and less than 750 cycles was judged as ○ (satisfactory), and a case of a thermal fatigue life of less than 660 cycles was judged as × (unsatisfactory).
 (3) corrosion resistance to condensed water: a case of a decrease in weight due to corrosion of 5 g/m² or less was judged as ⊙ (satisfactory), a case of a decrease in weight due to corrosion of more than 5 g/m² and 10 g/m² or less was judged as ○ (satisfactory), and a case of a decrease in weight due to corrosion of more than 10 g/m² was judged as × (unsatisfactory).

[0057] As indicated in Table 1, it is clarified that the examples of the present invention, Nos. 1 through 20 and Nos. 36 through 40, were all excellent in adhesion of scale, thermal fatigue resistance, and corrosion resistance to condensed water. Nos. 2 through 4, 6, 9, 10, 12, 14 through 16, 19, 20, and 36 through 40, which were the examples of the present invention, and in which the contents of Si and Ni were within the preferable ranges ($\text{Si} \geq 0.30\%$ and $\text{Ni} \geq 0.20\%$), were particularly excellent in adhesion of scale. Nos. 1, 2, 6 through 11, 16, and 38, which were the examples of the present invention, and in which (C + N), and the contents of Ti, Co, Mo, and Cu were within the preferable ranges ($(\text{C} + \text{N}) \leq 0.015\%$, $\text{Ti} \geq 0.15\%$, $\text{Co} \geq 0.02\%$, $\text{Mo} \geq 0.04\%$, and $\text{Cu} \geq 0.04\%$), were particularly excellent in thermal fatigue resistance. Nos. 1, 2, 6 through 11, 16, 18, and 36 through 40, which were the examples of the present invention, and in which the contents of Mo and Cu were within the preferable ranges ($\text{Mo} \geq 0.04\%$, and $\text{Cu} \geq 0.04\%$), were particularly excellent in corrosion resistance to condensed water. In addition, the surface quality of all the hot-rolled, annealed, and pickled steel sheets of the examples of the present invention were good with no surface defect.

[0058] On the other hand, comparative example Nos. 21 and 24, in which the contents of Mo and Cu were both less than the lower limits of the present invention, comparative example No. 22, in which the Cu content was less than the lower limit of the present invention, and comparative example No. 23, in which the Mo content was less than the lower limit of the present invention, were all unsatisfactory in corrosion resistance to condensed water.

[0059] Comparative example No. 25, in which (C + N) was more than the upper limit of the present invention, was unsatisfactory in thermal fatigue resistance. Comparative example No. 26, in which the Co content was less than the lower limit of the present invention, was unsatisfactory in thermal fatigue resistance. Comparative example No. 27, in which the Ni content was less than the lower limit of the present invention, was unsatisfactory in adhesion of scale and thermal fatigue resistance.

[0060] Comparative example No. 28, in which the contents of Ni and Co were both less than the lower limit of the present invention, was unsatisfactory in adhesion of scale and thermal fatigue resistance. Comparative example No. 29, in which the Cu content was more than the upper limit of the present invention, was unsatisfactory in adhesion of scale and corrosion resistance to condensed water.

[0061] Comparative example No. 30, in which the Ti content was more than the upper limit of the present invention, was unsatisfactory in all of adhesion of scale, thermal fatigue resistance, and corrosion resistance to condensed water. Comparative example No. 31, in which the C content was more than the upper limit of the present invention, was unsatisfactory in adhesion of scale and thermal fatigue resistance. Comparative example No. 32, in which the N content was more than the upper limit of the present invention, was unsatisfactory in adhesion of scale and thermal fatigue resistance.

[0062] Comparative example No. 33, in which the Cr content was less than the lower limit of the present invention, was unsatisfactory in all of adhesion of scale, thermal fatigue resistance, and corrosion resistance to condensed water. Comparative example No. 34, in which the Nb content was less than the lower limit of the present invention, and comparative example No. 35, in which the Ti content was less than the lower limit of the present invention, were both unsatisfactory in thermal fatigue resistance.

[0063] As described above, it was clarified that the steels within the range of the present invention were excellent in all of adhesion of scale, thermal fatigue resistance, and corrosion resistance to condensed water.

Industrial Applicability

[0064] Since the ferritic stainless steel sheet according to the present invention is excellent in all of adhesion of scale, thermal fatigue resistance, and corrosion resistance to condensed water, the steel sheets can preferably be used for all the exhaust system members of an automobile or the like such as exhaust manifolds, various kinds of exhaust pipes, flanges, converter cases, and mufflers, and, since it is possible to form all the exhaust pipe members by using one steel

grade, there is an improvement in efficiency from the viewpoint of the stable availability and weldability of a steel material. Moreover, the steel can preferably be used for the exhaust system members of a thermal power generation system and the members of a fuel cell.

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Claims

1. Ferritic stainless steel having a chemical composition containing, by mass%,

C: 0.010% or less,

10 Si: 1.0% or less,

Mn: 1.0% or less,

P: 0.040% or less,

S: 0.030% or less,

Cr: 17.0% or more and 18.5% or less,

15 N: 0.015% or less,

Nb: 0.40% or more and 0.80% or less,

Ti: 0.10% or more and 0.40% or less,

Al: 0.20% or less,

Ni: 0.05% or more and 0.40% or less,

20 Co: 0.01% or more and 0.30% or less,

Mo: 0.02% or more and 0.30% or less,

Cu: 0.02% or more and 0.40% or less, and

the balance being Fe and inevitable impurities,

wherein expression (1) below is satisfied:

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$$C\% + N\%: 0.018\% \text{ or less } \cdots (1),$$

where, in expression (1), C% and N% respectively denote the contents (mass%) of C and N.

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2. The ferritic stainless steel according to Claim 1,

wherein the chemical composition further contains, by mass%, one, two, or all selected from

Ca: 0.0005% or more and 0.0030% or less,

Mg: 0.0002% or more and 0.0020% or less, and

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B: 0.0002% or more and 0.0020% or less.

3. The ferritic stainless steel according to Claim 1 or 2, wherein the chemical composition further contains, by mass%, one, two, or all selected from

V: 0.01% or more and 0.50% or less,

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W: 0.02% or more and 0.30% or less, and

Zr: 0.005% or more and 0.50% or less.

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FIG. 1

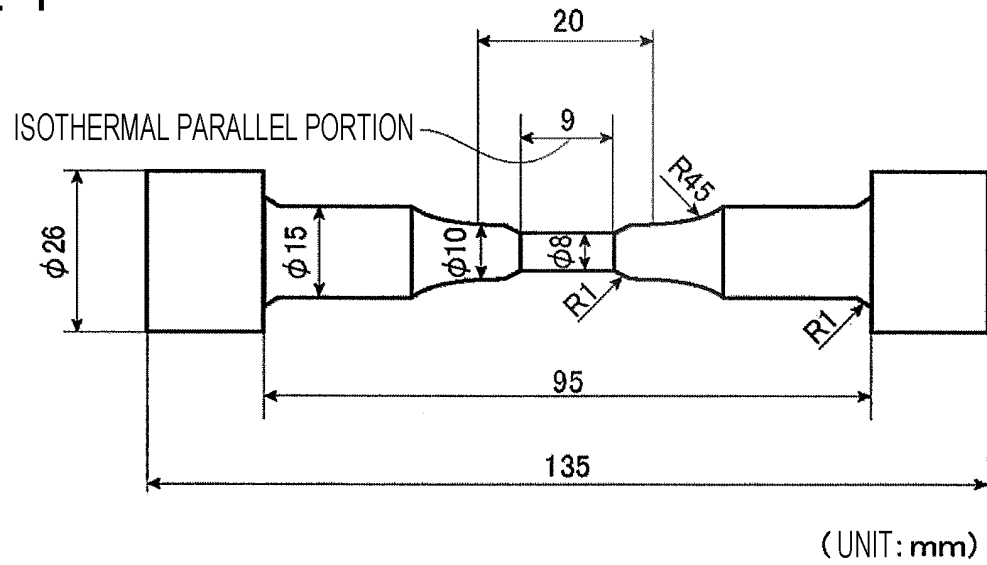
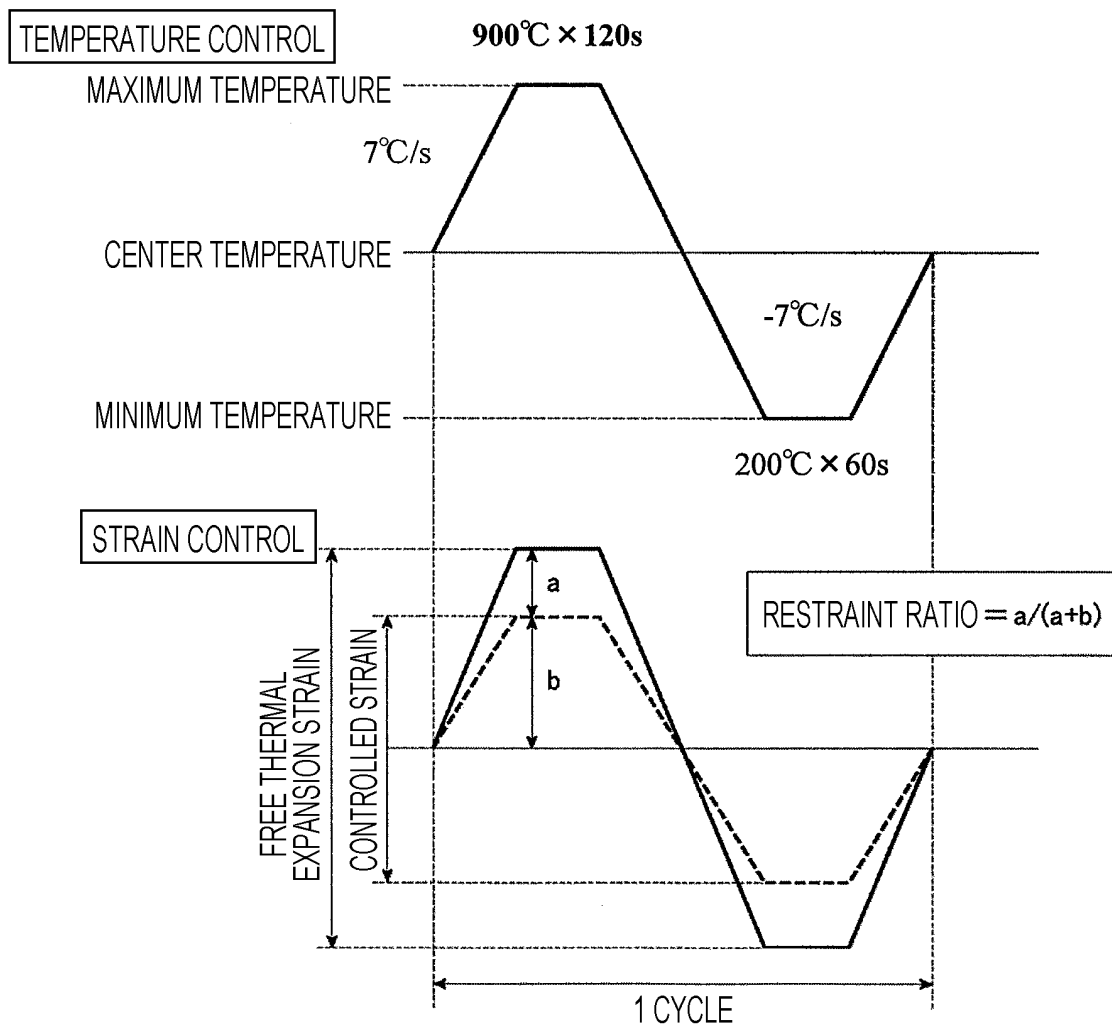


FIG. 2



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2017/043381

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. C22C38/00 (2006.01) i, C22C38/52 (2006.01) i, C22C38/54 (2006.01) i,
C21D9/46 (2006.01) n

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-C22C38/60, C21D9/46

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.
X	WO 2013/179616 A1 (JFE STEEL CORP.) 05 December 2013, claims, paragraphs [0001]-[0010], [0014]-[0034], [0039], [0049], table 1 & US 2015/0139851 A1, claims, paragraphs [0002]-[0015], [0023]-[0062], [0067], [0077], table 1 & EP 2857538 A1 & TW 201410884 A & CN 104364404 A & KR 10-2015-0002872 A	1-3
A	JP 2014-145097 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORP.) 14 August 2014 (Family: none)	1-3



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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"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)

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"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

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Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

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INTERNATIONAL SEARCH REPORT

International application No.
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Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2013-209726 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORP.) 10 October 2013 & US 2015/0020933 A1 & WO 2013/146815 A1 & CN 104093871 A & CA 2866136 A1 & KR 10-2014-0117586 A & MX 2014011517 A	1-3
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REFERENCES CITED IN THE DESCRIPTION

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