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(54) **FERRITIC STAINLESS STEEL AND FERRITIC STAINLESS STEEL FOR CAR EXHAUST GAS PATHWAY MEMBER**

(57) The present invention relates to a ferritic stainless steel containing 0.03% by mass or less of C; from 0.1 to 0.8% by mass of Si; 1.0% by mass or less of Mn; 0.04% by mass or less of P; 0.01% by mass or less of S; 0.5% by mass or less of Ni; from 12.0 to 15.0% by mass of Cr; 0.03% by mass or less of N; from 0.1 to 0.5% by mass of Nb; from 0.8 to 1.5% by mass of Cu; and 0.1% by mass or less of Al, the balance being Fe and unavoidable impurities, the ferritic stainless steel having a γ_{max} of 55 or less, as represented by the following equation (1):

$$\gamma_{max} = 420C - 11.5Si + 7Mn + 23Ni - 11.5Cr + 470N + 9Cu - 52Al + 189 \quad (1),$$

in which C, Si, Mn, Ni, Cr, N, Cu and Al mean % by mass of the corresponding elements.

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Description

TECHNICAL FIELD

5 **[0001]** The present invention relates to a ferritic stainless steel and a ferritic stainless steel for automobile exhaust gas passage members.

BACKGROUND ART

10 **[0002]** Ferritic stainless steels are used in heat-resistant applications where thermal distortion is problematic, because they have a lower thermal expansion coefficient, better thermal fatigue characteristics and better high-temperature oxidation characteristics as compared with austenitic stainless steels. Typical applications of the ferritic stainless steels include automobile exhaust gas passage members such as exhaust manifolds, front pipes, outer cylinders of catalyst supports, center pipes, mufflers and tail pipes.

15 **[0003]** Recent automobile engines tend to increase a temperature of an exhaust gas in order to improve an exhaust gas purification efficiency and an output, and particularly high heat resistance (high-temperature strength, high-temperature oxidation resistance) is required for members close to the engine, such as an exhaust manifold, a front pipe, and an outer cylinder of a catalyst support. Also, recently, a shape of the exhaust gas passage member tends to be complicated. In particular, the exhaust manifold and the outer cylinder of the catalyst support are formed into complex shapes
20 by various methods such as mechanical press molding, servo press molding, spinning, and hydroforming. The complicated shape leads to concentration of thermal strain at one point due to the start and stop of the engine so that thermal fatigue failure tends to take place, as well as leads to a local increase in a temperature of the material so that abnormal oxidation also tends to take place. Therefore, the heat resistance cannot be sacrificed in order to improve formability.

25 **[0004]** SUH409L and SUS430J1L are known as ferritic stainless steels having high heat resistance. SUH409L has good processability and is often used for exhaust gas passage members. However, in view of the heat resistance level, it is not preferable to apply it to applications where the temperature of the material is more than 800 °C. On the other hand, SUS430J1L has good heat resistance, which can be used at 900 °C. However, since it is hard, any application may be difficult in terms of processability. Therefore, the following ferritic stainless steels have been developed.

30 **[0005]** Patent Document 1 proposes a technique for improving processability by not adding Nb to a steel composition based on SUS 429 and for suppressing deterioration of thermal fatigue characteristics by adding Cu to the steel composition. However, the maintenance in a Cu precipitation temperature range for a long period of time leads to coarse precipitates of Cu due to agglomeration of the precipitates, resulting in a decreased effect of improving the high-temperature strength. Therefore, the thermal fatigue characteristics of the ferritic stainless steel may be degraded.

35 **[0006]** Patent Document 2 propose a technique for improving thermal fatigue characteristics by adding Nb and Cu to a steel composition based on SUS 429, and for leaving martensite in a slab by increasing y_{max} to improve toughness of the slab. However, since the ferritic stainless steel has the increased y_{max} , the martensitic phase may be formed when heated at an elevated temperature as in welding, whereby the thermal fatigue characteristics may be degraded.

CITATION LIST

40 Patent Documents

[0007]

45 Patent Document 1: Japanese Patent Application Publication No. 2012-188748 A
Patent Document 2: Japanese Patent Application Publication No. 2012-007195 A

SUMMARY OF INVENTION

50 Technical Problem

[0008] As described above, the ferritic stainless steels used for applications such as automobile exhaust gas passage members require improved processability that can be processed into complex shapes by various forming methods and can contribute to an increase in design freedom of the member. Further, since the ferritic stainless steels used for
55 applications such as automobile exhaust gas passage members are required to have good thermal fatigue characteristics and good oxidation characteristics even at elevated temperature, it is not desirable that the heat resistance is decreased. However, as can be seen from the patent documents as described above, any ferritic stainless steel that simultaneously achieves improved processability and improved heat resistance has not been provided at this time.

[0009] In addition, there is a method of reducing Cr and Si for a decrease in alloying which is a general means, as a means for improving the processability. However, in this method, the y_{max} increases, so that a martensitic phase is easily formed when used at elevated temperature and the thermal fatigue characteristics are degraded. Further, when Cr and Si are reduced, the high-temperature oxidation characteristics are also reduced.

[0010] Further, there is a method of decreasing a slab heating temperature in order to increase strain during hot rolling, as a general means for improving the processability. However, in this case, it is known that the quality of a surface is deteriorated. Moreover, its cause and countermeasure are not specified.

[0011] An object of the present invention is to provide a ferritic stainless steel and a ferritic stainless steel for automobile exhaust gas passage members, which have improved processability and improved heat resistance and also has good surface quality.

Solution to Problem

[0012] In a ferritic stainless steel, the decreasing of Cr and Si to improve the processability leads to an increase in y_{max} and tends to generate a martensitic phase, so that the thermal fatigue characteristics are deteriorated. Therefore, as a result of studying a relationship between the y_{max} and the martensitic phase formation/thermal fatigue characteristics, the present inventors have found that if the y_{max} is 55 or less, no martensitic phase is generated and the thermal fatigue characteristics are not affected.

[0013] Further, when the slab heating temperature is lowered during hot rolling to improve the processability, the surface quality is degraded. Therefore, the present inventors have focused on a formed state of oxide scales in the case where the slab heating temperature is decreased, and have made various studies. As a result, the present inventors have found that local generation of oxide scales based on Fe rather than uniform generation during heating of the slab is one of causes of the deterioration of the surface quality. The local generation of the oxide scales based on Fe would allow surface defects to occur due to the contact of thin portions of the oxide scales based on Fe with a roll of a hot rolling mill. Therefore, as a result of intensive studies, the present inventors have found that Si and Cr greatly affect the local formation of the oxide scales in the case where the slab heating temperature during hot rolling is decreased. Then, the present inventors have found that by controlling amounts of Si and Cr to be added, the oxide scales based on Fe are uniformly generated even if the slab heating temperature is decreased, so that the surface quality during hot rolling can be improved.

[0014] Thus, the present invention relates to a ferritic stainless steel containing 0.03% by mass or less of C; from 0.1 to 0.8% by mass of Si; 1.0% by mass or less of Mn; 0.04% by mass or less of P; 0.01% by mass or less of S; 0.5% by mass or less of Ni; from 12.0 to 15.0% by mass of Cr; 0.03% by mass or less of N; from 0.1 to 0.5% by mass of Nb; from 0.8 to 1.5% by mass of Cu; and 0.1% by mass or less of Al, the balance being Fe and unavoidable impurities, the ferritic stainless steel having a y_{max} of 55 or less, as represented by the following equation (1):

$$y_{max} = 420C - 11.5Si + 7Mn + 23Ni - 11.5Cr + 470N + 9Cu - 52Al + 189 \quad (1),$$

in which C, Si, Mn, Ni, Cr, N, Cu and Al mean % by mass of the corresponding elements.

[0015] Further, the present invention relates to a ferritic stainless steel for automobile exhaust gas passage members, the ferritic stainless steel containing 0.03% by mass or less of C; from 0.1 to 0.8% by mass of Si; 1.0% by mass or less of Mn; 0.04% by mass or less of P; 0.01% by mass or less of S; 0.5% by mass or less of Ni; from 12.0 to 15.0% by mass of Cr; 0.03% by mass or less of N; from 0.1 to 0.5% by mass of Nb; from 0.8 to 1.5% by mass of Cu; and 0.1% by mass or less of Al, the balance being Fe and unavoidable impurities, the ferritic stainless steel having a y_{max} of 55 or less, as represented by the following equation (1):

$$y_{max} = 420C - 11.5Si + 7Mn + 23Ni - 11.5Cr + 470N + 9Cu - 52Al + 189 \quad (1),$$

in which C, Si, Mn, Ni, Cr, N, Cu and Al mean % by mass of the corresponding elements.

Advantageous Effects of Invention

[0016] According to the present invention, it is possible to provide a ferritic stainless steel and a ferritic stainless steel for automobile exhaust gas passage members, which have improved processability and improved heat resistance, as well as good surface quality.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

5 **[0017]** A ferritic stainless steel according to the present invention contains C, Si, Mn, P, S, Ni, Cr, N, Nb, Cu and Al, and the balance is Fe and unavoidable impurities. Further, the ferritic stainless steel may further contain one or more selected from the group consisting of Ti, Mo, V, Zr, W, Co and B as optional components.

[0018] Here, in the present specification, a content of an element without definition of a lower limit indicates that the element can be contained up to an unavoidable impurity level. Reasons for limitation of each element are described below.

10 **[0019]** C and N are generally regarded as elements effective for improving high-temperature strength, such as creep strength. However, when excessive amounts of C and N are contained, a martensitic phase tends to be generated, so that thermal fatigue characteristics, oxidation characteristics and processability are degraded. For a steel composition containing Nb as an element for fixing C and N as carbonitrides, an appropriate amount of Nb for C and N concentrations is required, so costs of the ferritic stainless steel are increased. On the other hand, if C and N are to be significantly decreased, the burden on steelmaking will be excessive and cost will increase. For those reasons, in the present invention, both of C and N are limited to 0.03% by mass or less. It should be noted that in view of the oxidation characteristics and the processability, each of C and N is preferably 0.015% by mass or less.

15 **[0020]** Both of Si and Cr greatly affect the high-temperature oxidation characteristics and the processability. Higher amounts of Si and Cr added provide better high-temperature oxidation characteristics, but decrease the processability. Further, although the high-temperature oxidation characteristics are improved, the surface quality is deteriorated when the slab heating temperature during hot rolling is decreased, because the oxide scales based on Fe are locally generated without being uniformly generated. In order to provide the surface quality, the addition range of Si and Cr should be strictly limited. Therefore, in order to achieve all of the processability, high-temperature oxidation resistance and surface quality during hot rolling, Si is limited to 0.1 to 0.8% by mass, and preferably 0.2 to 0.6% by mass. For the same reason, Cr is limited to 12.0 to 15.0% by mass.

20 **[0021]** Mn is an alloy element that improves the high-temperature oxidation characteristics, particularly scale stripability, of ferritic stainless steel, but an excessive addition of Mn degrades the processability. Further, since Mn is also an austenite phase stabilizing element, excessive addition of Mn to a steel type having a small amount of Cr added facilitates the formation of the martensitic phase, resulting in deterioration of the thermal fatigue characteristics and processability. Therefore, Mn is limited to 1.0% by mass or less, and preferably 0.8% by mass or less.

25 **[0022]** P and S adversely affect the high-temperature oxidation resistance and toughness of a hot-rolled sheet, so it is preferable to reduce them as much as possible. Therefore, P is limited to 0.04% by mass or less, and S is limited to 0.01% by mass or less.

30 **[0023]** Ni is an element effective for improvement of low-temperature toughness. However, since Ni is an austenite phase stabilizing element, excessive addition of Ni to a steel type having a low Cr content generates a martensitic phase as with Mn, thereby reducing the thermal fatigue characteristics and processability. Further, since Ni is expensive, excessive addition of Ni should be avoided. Therefore, the Ni content is limited to 0.5% by mass or less. A lower limit of the Ni content is not particularly limited, but it is preferably more than 0% by mass, and more preferably 0.01% by mass or more.

35 **[0024]** Nb fixes C and N as carbonitrides, and the remaining solution Nb after fixing of carbonitrides has an effect of increasing the high-temperature strength. However, the addition of an excessive amount of Nb deteriorates the processability. Therefore, the Nb content is limited to 0.1 to 0.5% by mass, and preferably 0.2 to 0.4% by mass.

40 **[0025]** Cu is an element that improves the high-temperature strength. In order to obtain the required high-temperature strength, a Cu content of 0.8% by mass or more is required. However, as the Cu content increases, the processability and the high-temperature oxidation resistance are deteriorated. Therefore, the Cu content is limited to 0.8 to 1.5% by mass, and preferably 0.9 to 1.3% by mass.

45 **[0026]** Al is added as a deoxidizer during steel making, and also exhibits an effect of improving the high-temperature oxidation resistance. However, excessive addition of Al lowers surface properties and adversely affects the processability. Therefore, a lower Al content is preferable, and it is limited to 0.1% by mass or less, and preferably 0.05% by mass or less.

50 **[0027]** Ti is an element which fixes solution C and N in steel as carbonitrides to improve ductility and processability. Further, Ti can also be expected to produce effects of suppressing grain boundary precipitation of Cr carbides and improving corrosion resistance. However, the addition of an excessive amount of Ti deteriorates the surface properties of the steel material due to formation of TiN, which adversely affects weldability and low-temperature toughness. Therefore, Ti may be optionally added in an amount of 0.20% by mass or less, and preferably 0.1% by mass or less.

55 **[0028]** Mo, V, Zr, W and Co are elements that improve the high-temperature strength and thermal fatigue resistance by solution strengthening or precipitation strengthening. However, the addition of an excessive amount excessively hardens the steel material. Therefore, each of Mo, Zr, W and Co may be optionally added in an amount of 0.5% by mass or less, and V may be optionally added in an amount of 0.1% by mass or less.

[0029] B is an element that improves the secondary workability of steel and suppresses cracking during multistage forming. However, excessive addition of B deteriorates the productivity and weldability. Therefore, B may be optionally

added in an amount of 0.01% by mass or less.

[0030] Each of equations (1) and (2) represents y_{\max} , which is an index for generation of an austenitic phase. When the y_{\max} is too high, the martensitic phase tends to be formed, and when the martensitic phase is present, the thermal fatigue characteristics are deteriorated. Therefore, in order not to form the martensitic phase, the y_{\max} is controlled to 55 or less. In addition, the equation (1) is y_{\max} in the case where Mo or Ti which is an optional component, is not contained, and the equation (2) is y_{\max} in the case where Mo or Ti which is an optional component is contained.

$$y_{\max} = 420C - 11.5Si + 7Mn + 23Ni - 11.5Cr + 470N + 9Cu - 52Al + 189 \quad (1)$$

$$y_{\max} = 420C - 11.5Si + 7Mn + 23Ni - 11.5Cr + 470N + 9Cu - 12Mo - 49Ti - 52Al + 189 \quad (2).$$

In the equations (1) and (2), C, Si, Mn, Ni, Cr, N, Cu and Al mean % by mass of the corresponding elements.

[0031] A method for producing the ferritic stainless steel according to the present invention is not particularly limited, and the ferritic stainless steel may be produced by carrying out the steps of heating a slab cast by a certain method at a temperature of from 1000 to 1250 °C for 1 to 3 hours; subjecting the slab to hot rolling by a certain method; annealing the slab at a temperature of from 900 to 1100 °C; washing the slab with an acid and subjecting it to cold rolling by a certain method; and annealing it at a temperature of from 900 to 1100 °C and washing it with an acid.

[0032] In the ferritic stainless steel of the present invention thus produced, even if the slab heating temperature is decreased, the oxide scales based on Fe are uniformly generated, and the surface quality during hot rolling is satisfactory. Moreover, the ferritic stainless steel has improved processability and heat resistance. Therefore, the ferritic stainless steel according to the present invention is suitable for heat resistance, in particular for automobile exhaust gas passage members.

EXAMPLES

[0033] Hereinafter, the present invention will be more specifically described by Examples. It should be noted that the present invention is not limited to these examples.

[0034] Various ferritic stainless steels having the steel compositions as shown in Table 1 were melted in a vacuum melting furnace and cast into 30 kg ingots. After heating each ingot (slab) at 1100 °C for 2 h, the ingot was subjected to hot rolling, annealing, cold rolling and finish annealing in this order to produce a cold-rolled and annealed sheet having a thickness of 1.5 mm. The ingot was also forged and annealed to produce a round bar annealed material. In the table below, Nos. 1 to 20 represent inventive steels, and Nos. 21 to 30 represent comparative steels. Among them, No. 21 represents the steel corresponding to Patent Document 1, and No. 22 represents the steel corresponding to Patent Document 2.

[Table 1]

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Table 1. Steel Composition (% by mass)

	C	Si	Mn	P	S	Ni	Cr	N	Nb	Cu	Al	Other	$y_{max} (\leq 55)$
1	0.008	0.12	0.32	0.027	0.001	0.10	14.49	0.019	0.31	1.01	0.023		45.7
2	0.009	0.19	0.79	0.030	0.001	0.39	14.92	0.015	0.20	1.29	0.012		51.6
3	0.019	0.65	0.30	0.029	0.001	0.11	13.98	0.009	0.16	1.39	0.010		49.5
4	0.008	0.31	0.98	0.027	0.002	0.11	13.43	0.010	0.31	1.02	0.082		53.4
5	0.007	0.41	0.40	0.028	0.002	0.45	13.99	0.018	0.38	0.82	0.027		53.9
6	0.010	0.30	0.20	0.028	0.001	0.12	13.49	0.009	0.21	1.49	0.049		53.9
7	0.004	0.49	0.59	0.029	0.002	0.19	14.04	0.022	0.34	1.19	0.028		51.7
8	0.021	0.59	0.22	0.027	0.002	0.06	13.11	0.004	0.30	0.91	0.033		51.5
9	0.009	0.30	0.31	0.027	0.001	0.11	13.48	0.009	0.31	1.01	0.029		50.6
10	0.005	0.79	0.21	0.026	0.001	0.29	12.51	0.005	0.30	0.89	0.061		53.5
11	0.004	0.69	0.15	0.031	0.001	0.08	12.09	0.005	0.44	0.85	0.069		53.0
12	0.008	0.39	0.29	0.028	0.001	0.02	13.04	0.008	0.11	1.29	0.019		54.8
13	0.019	0.21	0.49	0.027	0.002	0.11	13.98	0.009	0.48	0.98	0.023	V:0.05	51.4
14	0.010	0.31	0.29	0.027	0.001	0.10	13.45	0.011	0.29	1.00	0.029	Ti:0.20	41.7
15	0.008	0.30	0.30	0.026	0.002	0.10	13.59	0.008	0.28	1.01	0.022	Mo:0.41	43.8
16	0.009	0.29	0.31	0.027	0.001	0.11	13.60	0.009	0.33	0.99	0.038	V:0.09, Ti:0.03	48.7
17	0.009	0.31	0.29	0.028	0.002	0.11	13.93	0.009	0.30	1.00	0.025	Zr:0.41	45.3
18	0.006	0.30	0.39	0.025	0.001	0.09	13.41	0.011	0.28	1.09	0.032	W:0.29, B:0.0009	52.0
19	0.009	0.32	0.30	0.026	0.002	0.12	13.59	0.009	0.35	0.90	0.019	Co:0.19	49.0
20	0.008	0.29	0.30	0.027	0.001	0.11	13.52	0.011	0.30	1.01	0.025	B:0.0025	51.1
21	0.005	0.50	0.50	0.027	0.001	0.06	14.00	0.007	0.00	1.20	0.041	Ti:0.15, V:0.05, B:0.0005	33.8
22	0.015	0.41	0.79	0.029	0.001	0.10	12.91	0.015	0.26	0.99	0.019	V:0.03	64.9
23	0.032	0.31	0.29	0.026	0.002	0.11	13.43	0.009	0.30	1.00	0.023		61.0
24	0.008	0.30	0.30	0.028	0.001	0.10	13.54	0.011	0.08	1.01	0.031		50.2
25	0.009	0.81	0.30	0.025	0.001	0.12	13.60	0.010	0.52	1.00	0.019		44.6
26	0.007	0.30	0.30	0.027	0.001	0.11	13.69	0.032	0.30	1.00	0.105		54.3
27	0.007	0.29	0.31	0.027	0.001	0.51	11.89	0.009	0.30	0.99	0.033		77.2
28	0.007	0.30	0.29	0.028	0.001	0.10	15.08	0.009	0.29	0.71	0.032		28.3
29	0.008	0.09	0.31	0.027	0.002	0.12	13.47	0.008	0.30	0.99	0.023		52.8
30	0.006	0.31	1.01	0.028	0.001	0.09	13.68	0.007	0.31	1.51	0.036		54.8

The underline indicates the outside of the range defined in the present invention.

50 **[0035]** A method of confirming a generated state of the oxide scales when the slab heating temperature is decreased will be described.

55 **[0036]** Each ingot was cut into 5 mm t × 25 mm w × 35 mm L, and the surface was polished with a # 120 polishing belt, and heated at 1000 °C for 2 h in an electric furnace which reproduced similar oxygen content and water vapor content to the hot rolling heating furnace. The generated state of oxide scales was then confirmed by cross-sectional observation. Uniform generation of the oxide scales based on Fe was evaluated as good (○: the same hereinafter), and local generation or no generation of the oxide scales was evaluated as poor (×: the same hereinafter).

[0037] The cold-rolled and annealed sheet having a thickness of 1.5 mm was subjected to a high-temperature oxidation test and processability evaluation.

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[0038] For the high temperature oxidation test, each sample having a size of 25 mm × 35 mm was prepared, and a continuous oxidation test was carried out in an air atmosphere in the electric furnace by heating the sample in the furnace at 875 °C for 200 h, and the weight of the sample was then measured. Measurement results of an increase in oxidation content were compared with the weight before the test, and a weight change of 5 mg/cm² or less was evaluated as ○, and a weight change of more than 5 mg/cm² was evaluated as ×.

[0039] The processability evaluation was conducted in accordance with a normal temperature tensile test. Each sample of JIS 13 B was prepared, and an elongation at breakage in the rolling direction was measured. A sample with an elongation at breakage of 35% or more was evaluated as ○, and a sample with an elongation at breakage of less than 35% was evaluated as ×.

[0040] Each sample for a thermal fatigue test was prepared from the round bar annealed material and subjected to a thermal fatigue test. Here, for the sample for the thermal fatigue test, a round bar sample was used which was prepared by cutting the round bar annealed material having a diameter of 10 mm and providing a notch of R = 2.83 mm at a central portion between target positions so as to have a diameter of 7 mm (the length between the target positions was 15 mm). In the thermal fatigue test, heating and cooling were carried out in a range from the minimum temperature of 200 °C to the maximum temperature of 750 °C in a high-frequency heating device at 3 °C/sec, and each of retention times at the minimum and maximum temperatures was 30 seconds, which was regarded as one cycle. Further, the thermal fatigue test was carried out at a restraint rate of 25%. The number of cycles in which the maximum stress in each cycle was reduced by 25% from a value in a steady state was regarded as the thermal fatigue life, a thermal fatigue life of 1600 cycles or more were evaluated as ○, and a thermal fatigue life of less than 1600 cycles was evaluated as ×.

[Table 2]

	Formed State of Oxide Scales	High-Temperature Oxidation characteristics (≤ 5mg/cm ²)	Elongation (≥ 35%)	Thermal Fatigue Characteristics (≥ 1600 cycles)
1	○	○(0.9mg/cm ²)	○(36%)	○(1750 cycles)
2	○	○(0.5mg/cm ²)	○(36%)	○(1740 cycles)
3	○	○(0.5mg/cm ²)	○(36%)	○(1720 cycles)
4	○	○(0.5mg/cm ²)	○(36%)	○(1780 cycles)
5	○	○(0.5mg/cm ²)	○(36%)	○(1650 cycles)
6	○	○(1.0mg/cm ²)	○(37%)	○(1780 cycles)
7	○	○(0.5mg/cm ²)	○(36%)	○(1800 cycles)
8	○	○(0.5mg/cm ²)	○(36%)	○(1710 cycles)
9	○	○(0.5mg/cm ²)	○(38%)	○(1750 cycles)
10	○	○(0.6mg/cm ²)	○(36%)	○(1700 cycles)
11	○	○(1.2mg/cm ²)	○(36%)	○(1760 cycles)
12	○	○(0.5mg/cm ²)	○(38%)	○(1660 cycles)
13	○	○(0.5mg/cm ²)	○(36%)	○(1850 cycles)
14	○	○(0.5mg/cm ²)	○(38%)	○(1800 cycles)
15	○	○(0.5mg/cm ²)	○(36%)	○(1820 cycles)
16	○	○(0.5mg/cm ²)	○(37%)	○(1780 cycles)
17	○	○(0.5mg/cm ²)	○(36%)	○(1800 cycles)
18	○	○(0.5mg/cm ²)	○(36%)	○(1790 cycles)
19	○	○(0.5mg/cm ²)	○(36%)	○(1770 cycles)
20	○	○(0.5mg/cm ²)	○(38%)	○(1750 cycles)
21	○	○(0.5mg/cm ²)	○(38%)	×(1540 cycles)
22	○	○(0.5mg/cm ²)	○(36%)	×(1520 cycles)

(continued)

	Formed State of Oxide Scales	High-Temperature Oxidation characteristics ($\leq 5\text{mg/cm}^2$)	Elongation ($\geq 35\%$)	Thermal Fatigue Characteristics (≥ 1600 cycles)
5	○	○(1.3mg/cm ²)	×(34%)	×(1510 cycles)
	○	○(0.5mg/cm ²)	○(38%)	×(1550 cycles)
10	×	○(0.4mg/cm ²)	×(33%)	○(1880 cycles)
	○	○(13mg/cm ²)	×(33%)	○(1750 cycles)
	○	×(7.5mg/cm ²)	○(37%)	×(1450 cycles)
	×	○(0.4mg/cm ²)	×(34%)	×(1470 cycles)
15	○	×(6.8mg/cm ²)	○(39%)	○(1760 cycles)
	○	×(6.4mg/cm ²)	×(34%)	○(1840 cycles)

[0041] As can be seen from Table 2, all of the ferritic stainless steels according to Inventive Examples had the improved generated state of oxide scales, the improved high-temperature oxidation characteristics, the improved processability and the improved thermal fatigue characteristics.

[0042] In contrast, the ferritic stainless steels according to Comparative Example 21 that did not contain Nb, Comparative Example 24 where Nb was less than the lower limit, and Comparative Example 28 where Cu was less than the lower limit had insufficient high-temperature strength, so that the thermal fatigue characteristics were decreased. Furthermore, the ferritic stainless steel according to Comparative Example 28 had an excessive Cr content, so that the processability was deteriorated, as well as the oxide scales based on Fe were non-uniformly generated during heating at 1000 °C for 2 h. Each of the ferritic stainless steels according to Comparative Examples 22 and 23 had the y_{max} more than the upper limit, so that the martensitic phase was easily generated, and the thermal fatigue characteristics were deteriorated. Furthermore, the ferritic stainless steel according to Comparative Example 23 had the higher content of C, so that the processability was also insufficient.

[0043] In the ferritic stainless steel according to Comparative Example 27, the Ni content and y_{max} was more than the upper limits, so that the thermal fatigue characteristics were deteriorated, as well as the Cr content was lower, so that the high-temperature oxidation characteristics were also insufficient.

[0044] The ferritic stainless steel according to Comparative Example 25 had the higher content of Si, so that the oxide scales based on Fe did not uniformly form during heating at 1000 °C for 2 h, as well as it had the higher contents of Si and Nb, so that the processability was also deteriorated.

[0045] The ferritic stainless steel according to Comparative Example 26 had the decreased processability, because N and Al were excessive.

[0046] The ferritic stainless steel according to Comparative Example 29 had the decreased high-temperature oxidation characteristics because the Si content was lower.

[0047] The ferritic stainless steel according to Comparative Example 30 had the decreased processability as well as the decreased high-temperature oxidation characteristics, because the Mn and Cu contents were excessive.

[0048] As described above, in all of the ferritic stainless steels according to Comparative Examples, any of the formed state of the oxide scales, the high-temperature oxidation characteristics, the processability, and the thermal fatigue characteristics was insufficient.

[0049] The present application claims priority based on Japanese Patent Application No. 2017-7842 filed on January 19, 2017, which is incorporated herein by reference in its entirety.

INDUSTRIAL APPLICABILITY

[0050] The ferritic stainless steel according to the present invention has improved surface quality, high-temperature oxidation characteristics, processability and thermal fatigue characteristics, and is suitable for use in exhaust gas flow passage members of various internal combustion engines including automobiles, such as exhaust manifolds, front pipes, center pipes, and outer cylinders of catalytic converters.

Claims

1. A ferritic stainless steel, containing:

5 0.03% by mass or less of C;
 from 0.1 to 0.8% by mass of Si;
 1.0% by mass or less of Mn;
 0.04% by mass or less of P;
 0.01% by mass or less of S;
 10 0.5% by mass or less of Ni;
 from 12.0 to 15.0% by mass of Cr;
 0.03% by mass or less of N;
 from 0.1 to 0.5% by mass of Nb;
 from 0.8 to 1.5% by mass of Cu; and
 15 0.1% by mass or less of Al, the balance being Fe and unavoidable impurities, the ferritic stainless steel having
 a y_{\max} of 55 or less, as represented by the following equation (1):

$$y_{\max} = 420C - 11.5Si + 7Mn + 23Ni - 11.5Cr + 470N + 9Cu - 52Al + 189 \quad (1),$$

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in which C, Si, Mn, Ni, Cr, N, Cu and Al mean % by mass of the corresponding elements.

2. The ferritic stainless steel according to claim 1, further containing one or more selected from the group consisting
 of Ti: 0.20% by mass or less; Mo: 0.5% by mass or less; V: 0.1% by mass or less; Zr: 0.5% by mass or less; W:
 25 0.5% by mass or less; Co: 0.5% by mass or less; and B: 0.01% by mass or less, wherein the ferritic stainless steel
 has a y_{\max} of 55 or less, as represented by the following formula (2):

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$$y_{\max} = 420C - 11.5Si + 7Mn + 23Ni - 11.5Cr + 470N + 9Cu - 12Mo - 49Ti - 52Al + 189$$

30 (2),

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in which C, Si, Mn, Ni, Cr, N, Cu, Mo, Ti and Al mean % by mass of the corresponding elements.

3. The ferritic stainless steel according to claim 1, wherein the ferritic stainless steel is for heat resistance.

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4. A ferritic stainless steel for automobile exhaust gas passage members, the ferritic stainless steel containing:

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0.03% by mass or less of C;
 from 0.1 to 0.8% by mass of Si;
 1.0% by mass or less of Mn;
 0.04% by mass or less of P;
 0.01% by mass or less of S;
 0.5% by mass or less of Ni;
 from 12.0 to 15.0% by mass of Cr;
 45 0.03% by mass or less of N;
 from 0.1 to 0.5% by mass of Nb;
 from 0.8 to 1.5% by mass of Cu; and
 0.1% by mass or less of Al, the balance being Fe and unavoidable impurities, the ferritic stainless steel having
 a y_{\max} of 55 or less, as represented by the following equation (1):

50

$$y_{\max} = 420C - 11.5Si + 7Mn + 23Ni - 11.5Cr + 470N + 9Cu - 52Al + 189 \quad (1),$$

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in which C, Si, Mn, Ni, Cr, N, Cu and Al mean % by mass of the corresponding elements.

5. The ferritic stainless steel for automobile exhaust gas passage members according to claim 4, further containing
 one or more selected from the group consisting of Ti: 0.20% by mass or less; Mo: 0.5% by mass or less; V: 0.1%

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by mass or less; Zr: 0.5% by mass or less; W: 0.5% by mass or less; Co: 0.5% by mass or less; and B: 0.01% by mass or less, wherein the ferritic stainless steel has a γ_{\max} of 55 or less, as represented by the following formula (2):

$$\gamma_{\max} = 420C - 11.5Si + 7Mn + 23Ni - 11.5Cr + 470N + 9Cu - 12Mo - 49Ti - 52Al + 189 \quad (2),$$

in which C, Si, Mn, Ni, Cr, N, Cu, Mo, Ti and Al mean % by mass of the corresponding elements.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2017/031988

5	A. CLASSIFICATION OF SUBJECT MATTER Int.Cl. C22C38/00(2006.01)i, C21D9/46(2006.01)i, C22C38/48(2006.01)i, C22C38/54(2006.01)i, F01N13/16(2010.01)i		
	According to International Patent Classification (IPC) or to both national classification and IPC		
10	B. FIELDS SEARCHED		
	Minimum documentation searched (classification system followed by classification symbols) Int.Cl. C22C38/00-38/60, C21D9/46, F01N13/16		
15	Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
	Published examined utility model applications of Japan	1922-1996	
	Published unexamined utility model applications of Japan	1971-2017	
	Registered utility model specifications of Japan	1996-2017	
	Published registered utility model applications of Japan	1994-2017	
	Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
20	C. DOCUMENTS CONSIDERED TO BE RELEVANT		
	Category*	Citation of document, with indication, where appropriate, of the relevant passages	
		Relevant to claim No.	
25	X A	JP 2009-235555 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORPORATION) 15 October 2009, paragraphs [0001], [0008], table 1, comparative example no. 26 (Family: none)	2-3 1, 4-5
30	X A	JP 2012-188748 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORPORATION) 04 October 2012, paragraphs [0027]-[0044], table 5, steel type 0A, 0C, 1-3, 6-7, 9-11, 21 & US 2016/0024627 A1, paragraphs [0096]-[0136], table 5 & WO 2012/108479 A1 & CN 103348023 A	2-3, 5 1, 4
35			
40	<input checked="" type="checkbox"/>	Further documents are listed in the continuation of Box C.	<input type="checkbox"/> See patent family annex.
45	* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family	
50	Date of the actual completion of the international search 21 November 2017 (21.11.2017)	Date of mailing of the international search report 28 November 2017 (28.11.2017)	
55	Name and mailing address of the ISA/ Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Authorized officer	Telephone 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.
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A	JP 2008-297631 A (NISSHIN STEEL CO., LTD.) 11 December 2008 & US 2004/0170518 A1 & US 2009/0053093 A1 & US 2010/0119404 A1 & US 2011/0176954 A1 & US 2013/0263979 A1 & EP 1413640 A1 & DE 60204323 T2 & ES 2240764 T3 & CN 1524130 A & KR 10-2004-0007764 A	1-5
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REFERENCES CITED IN THE DESCRIPTION

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- JP 2017007842 A [0049]