



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

(43) Date of publication:
21.08.2013 Bulletin 2013/34

(51) Int Cl.:
C22C 38/00 (2006.01) **C22C 38/28** (2006.01)
C22C 38/54 (2006.01) **C21D 9/46** (2006.01)

(21) Application number: **11832650.3**

(86) International application number:
PCT/JP2011/073980

(22) Date of filing: **12.10.2011**

(87) International publication number:
WO 2012/050226 (19.04.2012 Gazette 2012/16)

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**

(30) Priority: **06.10.2011 JP 2011221763**
14.10.2010 JP 2010231562

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

(72) Inventors:
• **NAKAMURA, Tetsuyuki**
Tokyo 100-0011 (JP)

• **OTA, Hiroki**
Tokyo 100-0011 (JP)
• **KATO, Yasushi**
Tokyo 100-0011 (JP)
• **OGATA, Hiroyuki**
Tokyo 100-0011 (JP)

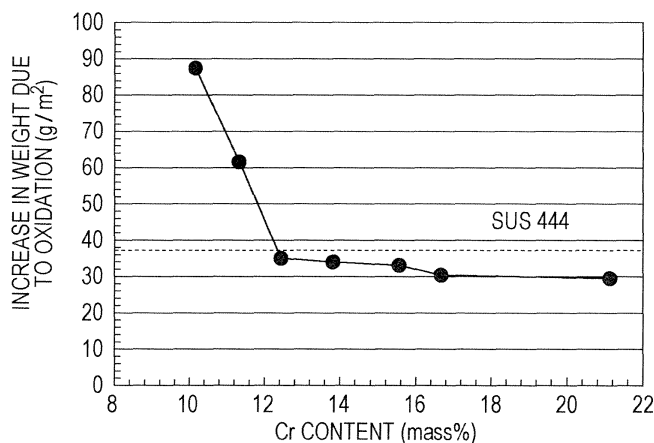
(74) Representative: **Stebbing, Timothy Charles**
Haseltine Lake LLP
Lincoln House, 5th Floor
300 High Holborn
London WC1V 7JH (GB)

(54) **FERRITIC STAINLESS STEEL EXCELLENT IN HEAT RESISTANCE AND WORKABILITY**

(57) An object is to provide ferritic stainless steel excellent in heat resistance (oxidation resistance, a thermal fatigue property and a high-temperature fatigue property) and formability, while preventing a decrease in oxidation resistance due to Cu, without adding expensive chemical elements such as Mo and W. Specifically, ferritic stainless steel having a chemical composition containing, by

mass%, C: 0.015% or less, Si: 0.4 % or more and 1.0% or less, Mn: 1.0% or less, P: 0.040% or less, S: 0.010% or less, Cr: 12% or more and less than 16%, N: 0.015% or less, Nb: 0.3% or more and 0.65% or less, Ti: 0.15% or less, Mo: 0.1% or less, W: 0.1% or less, Cu: 1.0% or more and 2.5 % or less and Al: 0.2% or more and 1.0% or less, while the relationship $Si \geq Al$ is satisfied, and the balance being Fe and inevitable impurities.

FIG. 8



Description

[Technical Field]

[0001] The present invention relates to ferritic stainless steel having high heat resistance (a thermal fatigue property, oxidation resistance and a high-temperature fatigue property) and formability which can be ideally used for the parts of an exhaust system which are used in a high temperature environment such as an exhaust pipe and a catalyst outer cylinder (also called a converter case) of an automobile and a motorcycle and an exhaust air duct of a thermal electric power plant.

[Background Art]

[0002] The parts of an exhaust system such as an exhaust manifold, an exhaust pipe, a converter case and a muffler which are used in the environment of the exhaust system of an automobile are required to be excellent in a thermal fatigue property, a high-temperature fatigue property and oxidation resistance (hereinafter, these properties are collectively called heat resistance). Since the parts such as an exhaust manifold are subjected to heating and cooling due to the repetition of start and stop of engine operation in a state in which they are restrained by the surrounding parts, the thermal expansion and contraction of the material of the parts are restricted, which results in the occurrence of thermal strain. The fatigue phenomenon due to this thermal strain is thermal fatigue. On the other hand, the parts are continuously subjected to vibration while they are heated in the initiation of engine operation. The fatigue phenomenon due to the accumulation of strain caused by this vibration is high-temperature fatigue. The former is low-cycle fatigue and the latter is high-cycle fatigue and both are completely different fatigue phenomena.

[0003] For applications in which heat resistance are required as described above, nowadays, Cr containing steel to which Nb and Si are added such as Type429 (containing 14Cr-0.9Si-0.4Nb) is often used. However, since an exhaust gas temperature has become higher than 900°C with the improvement of engine performance, the thermal fatigue property of Type429 has become unsatisfactory.

[0004] In order to solve this problem, Cr containing steel having a high-temperature yield strength increased by adding Nb and Mo, SUS444 (containing 19Cr-0.5Nb-2Mo) conforming to JIS G 4305 and ferritic stainless steel containing less Cr to which Nb, Mo and W are added and the like have been developed (refer to, for example, Patent Literature 1). However, since the prices of rare metals such as Mo and W have been markedly rising recently, the development of a material having heat resistance equivalent to those of these kinds of steel by using inexpensive raw materials has become to be required.

[0005] Examples of materials having excellent heat resistance without using expensive chemical elements such as Mo and W are disclosed by Patent Literatures 2 through 4. Patent Literature 2 discloses ferritic stainless steel to be used for the parts of an exhaust gas flow channel of an automobile. In Patent Literatures 2, Nb: 0.50 mass% or less, Cu: 0.8 mass% or more and 2.0 mass% or less and V: 0.03 mass% or more and 0.20 mass% or less are added to steel having a Cr content of 10 mass% or more and 20 mass% or less. Patent Literature 3 discloses ferritic stainless steel excellent in a thermal fatigue property. In Patent Literatures 3, Ti: 0.05 mass% or more and 0.30 mass% or less, Nb: 0.10 mass% or more and 0.60 mass% or less, Cu: 0.8 mass% or more and 2.0 mass% or less and B: 0.0005 mass% or more and 0.02 mass% or less are added to steel having a Cr content of 10 mass% or more and 20 mass% or less. Patent Literature 4 discloses ferritic stainless steel to be used for the parts of an exhaust gas flow channel of an automobile. In Patent Literatures 4, Cu: 1 mass% or more and 3 mass% or less is added to steel having a Cr content of 15 mass% or more and 25 mass% or less. These kinds of disclosed steel are all characterized by having a thermal fatigue property improved by adding Cu.

[Citation List]

[Patent Literature]

[0006]

[PTL 1] Japanese Unexamined Patent Application Publication No. 2004-018921

[PTL 2] International Publication No. W02003/004714

[PTL 3] Japanese Unexamined Patent Application Publication No. 2006-117985

[PTL 4] Japanese Unexamined Patent Application Publication No. 2000-297355

[Summary of Invention]

[Technical Problem]

5 **[0007]** However, according to investigations carried out by the present inventors, in the case where Cu is added as in the methods disclosed by Patent Literatures 2 through 4, it has been found that, while a thermal fatigue property is improved, contrarily oxidation resistance is decreased, which results in the deterioration of the overall heat resistance.

[0008] In addition, since a space which an exhaust manifold can occupy in an engine space has become smaller with the weight reduction of an automobile, it has come to be required that an exhaust manifold can be formed into a complex shape.

10 **[0009]** The present invention has been completed in view of the situation described above, and an object of the present invention is to provide ferritic stainless steel excellent in heat resistance (oxidation resistance, a thermal fatigue property and a high-temperature fatigue property) and formability, while preventing a decrease in oxidation resistance due to Cu, without adding expensive chemical elements such as Mo and W.

15 **[0010]** Incidentally, the meaning of "excellent in heat resistance " according to the present invention is that oxidation resistance, a thermal fatigue property and a high-temperature fatigue property are equivalent to or better than those of SUS444. Specifically, it means that oxidation resistance at a temperature of 950°C is equivalent to or better than that of SUS444, that a thermal fatigue property when temperature fluctuations repeatedly occur between the temperatures of 100°C and 850°C is equivalent to or better than that of SUS444 and that a high-temperature fatigue property at a temperature of 850°C is equivalent to or better than that of SUS444. In addition, the meaning of "excellent in formability" according to the present invention is that a mean elongation in the three directions at room temperature is 36% or more.

[Solution to Problem]

25 **[0011]** The present inventors diligently conducted investigations in order to develop ferritic stainless steel excellent in oxidation resistance and a thermal fatigue property by preventing a decrease in oxidation resistance due to Cu which occurs in the conventional methods without adding expensive chemical elements such as Mo or W. As a result, the present inventors found that a high strength in high-temperature can be achieved by adding the combination of Nb: 0.3 mass% or more and 0.65 mass% or less and Cu: 1.0 mass% or more and 2.5 mass% or less. By getting the high strength, a thermal fatigue property can be improved in a wide temperature range. The present inventors found that a decrease in oxidation resistance due to the addition of Cu can be prevented by adding an appropriate amount of Al (0.2 mass% or more and 1.0 mass% or less). The present inventors found that, therefore, heat resistance (a thermal fatigue property and oxidation resistance) equivalent to or better than that of SUS444 can be achieved only by controlling the contents of Nb, Cu and Al to the appropriate range as described above without adding Mo or W. In addition, the present inventors diligently conducted investigations regarding a method for improving oxidation resistance in an environment containing water vapor which is assumed in the case where the ferritic stainless steel is practically used for an exhaust manifold and the like, and found that oxidation resistance in an atmosphere containing water vapor (hereinafter, called water vapor oxidation resistance) also becomes equivalent to or better than that of SUS444 by adjusting a Si content (0.4 mass% or more and 1.0 mass% or less).

30 **[0012]** In addition, a fatigue resistance property against vibration in practical service conditions of the parts of the exhaust system of an automobile such as an exhaust manifold is also important. Therefore, the present inventors diligently conducted investigations regarding a method for improving a high-temperature fatigue property, and found that a high-temperature fatigue property also becomes equivalent to or better than that of SUS444 by adjusting the balance of a Si content and an Al content ($Si \geq Al$).

35 **[0013]** Moreover, the present inventors diligently conducted investigations regarding the influence of Cr on formability and oxidation resistance, and found that formability can be improved by reducing a Cr content without there being a significant influence on oxidation resistance.

40 Although it has been well known in the past that formability can be improved by reducing a Cr content. But there is a decrease in oxidation resistance by reducing a Cr content. The decrease in oxidation resistance has been compensated for by adding Mo and W, instead of Cr, in the past as disclosed by Patent Literature 1. In contrast to this, according to the present invention, it has been found that both excellent oxidation resistance and formability can be achieved by adding an appropriate amount of Al without adding expensive chemical elements such as Mo and W, even if a Cr content is reduced.

45 **[0014]** The present invention has been completed on the basis of the knowledge of the present inventors described above.

50 **[0015]** That is to say, the present invention provides ferritic stainless steel excellent in heat resistance and formability having a chemical composition containing, by mass%, C: 0.015% or less, Si: 0.4 % or more and 1.0% or less, Mn: 1.0% or less, P: 0.040% or less, S: 0.010% or less, Cr: 12% or more and less than 16%, N: 0.015% or less, Nb: 0.3% or more

and 0.65% or less, Ti: 0.15% or less, Mo: 0.1% or less, W: 0.1% or less, Cu: 1.0% or more and 2.5 % or less and Al: 0.2% or more and 1.0% or less, while the relationship $Si \geq Al$ is satisfied, and the balance being Fe and inevitable impurities.

[0016] In addition, the present invention provides ferritic stainless steel excellent in heat resistance and formability having a chemical composition further containing one, two or more chemical elements selected from among, by mass%, B: 0.003% or less, REM: 0.08% or less, Zr: 0.5% or less, V: 0.5% or less, Co: 0.5% or less and Ni: 0.5% or less.

[Advantageous Effects of Invention]

[0017] According to the present invention, ferritic stainless steel having heat resistance (a thermal fatigue property, oxidation resistance and a high-temperature fatigue property) equivalent to or better than that of SUS444 (JIS G 4305) and excellent formability can be obtained without adding expensive Mo or W. Therefore, the steel according to the present invention can be ideally used for the parts of the exhaust system of an automobile.

[Brief Description of Drawings]

[0018]

[Fig. 1] Fig. 1 is a diagram illustrating a thermal fatigue test specimen.

[Fig. 2] Fig. 2 is a diagram illustrating conditions of temperature and constraint in a thermal fatigue test.

[Fig. 3] Fig. 3 is a diagram illustrating a high-temperature fatigue test specimen.

[Fig. 4] Fig. 4 is a graph illustrating the influence of a Cu content on a thermal fatigue property.

[Fig. 5] Fig. 5 is a graph illustrating the influence of an Al content on oxidation resistance (an increase in weight due to oxidation).

[Fig. 6] Fig. 6 is a graph illustrating the influence of a Si content on water vapor oxidation resistance (an increase in weight due to oxidation).

[Fig. 7] Fig. 7 is a graph illustrating the influence of a Si content - an Al content (Si - Al) on a high-temperature fatigue property.

[Fig. 8] Fig. 8 is a graph illustrating the influence of a Cr content on water vapor oxidation resistance (an increase in weight due to oxidation).

[Fig. 9] Fig. 9 is a graph illustrating the influence of a Cr content on a mean elongation in the three directions at room temperature.

[Description of Embodiments]

[0019] Firstly, the fundamental experiments which led to the completion of the present invention will be described. Hereinafter, % used when describing chemical composition always denotes mass%.

Steel having a basic chemical composition containing C: 0.005% or more and 0.007% or less, N: 0.004% or more and 0.006% or less, P: 0.02% or more and 0.03% or less, S: 0.002% or more and 0.004% or less, Si: 0.85%, Mn: 0.4%, Cr: 14%, Nb: 0.45%, Al: 0.35%, Ti: 0.007%, Mo: 0.01% or more and 0.03% or less and W: 0.01% or more and 0.03% or less and a Cu content which was adjusted variously in the range of 0% or more and 3% or less was smelted by using an experimental method and made into a steel ingot of 50 kg, then the steel ingot was subjected to forging and a heat treatment into a steel material having a cross section of 35 mm × 35 mm, then a thermal fatigue test specimen having the dimensions illustrated in Fig. 1 was made of the steel material. Then, the thermal fatigue life of the specimen was observed by performing a thermal cycle heat treatment in which a restraint ratio was 0.30 and in which heating and cooling were repeated so that temperature fluctuations repeatedly occurred between 100°C and 850°C as illustrated in Fig. 2. The thermal fatigue life represents as the number of cycles at which the stress first started to continuously decrease from that in the previous cycle. The stress was derived by calculated as the quotient of the load detected at 100°C divided by the cross section area of the soaked parallel portion of a test specimen indicated in Fig. 1. This number of cycles corresponded to that at which a crack occurred in the test specimen. Incidentally, a similar test was performed with SUS444 (19%Cr-2%Mo-0.5%Nb steel) for comparison.

[0020] Fig. 4 illustrates the influence of Cu content on thermal fatigue life in the thermal fatigue test described above. This figure indicates that thermal fatigue life equivalent to or longer than that of SUS444 (about 1350 cycles) can be achieved by setting the Cu content to be 1.0% or more. Therefore, it is necessary that the Cu content be 1.0% or more in order to improve a thermal fatigue property.

[0021] Steel having a basic chemical composition containing C: 0.006%, N: 0.007%, P: 0.02% or more and 0.03% or less, S: 0.002% or more and 0.004% or less, Mn: 0.2%, Si: 0.85%, Cr: 14%, Nb: 0.49%, Cu: 1.5%, Ti: 0.007%, Mo: 0.01% or more and 0.03% or less and W: 0.01% or more and 0.03% or less and an Al content which was adjusted variously in the range of 0% or more and 2% or less was smelted by using an experimental method and made into a

steel ingot of 50 kg, then the steel ingot was subjected to hot rolling, hot rolled annealing, cold rolling and finishing annealing and made into a cold rolled and annealed steel sheet having a thickness of 2 mm.

A test specimen of 30 mm × 20 mm was cut out of the cold rolled steel sheet obtained as described above, then a hole of 4 mmφ was punched in the upper part of the test specimen, then the surface and the edge face of the specimen was polished with a #320 emery paper, then degreased and then used in a continuous oxidation test in air described below.

<Continuous oxidation test in air>

[0022] The test specimen described above was held in a furnace in air at a temperature of 950°C for duration of 200 hours, and then an increase in weight per unit area due to oxidation (g/m²) was derived from the observed difference in the mass of the test specimen before and after the heating test.

[0023] Fig. 5 illustrates the influence of Al content on the increase in weight due to oxidation in the continuous oxidation test in air described above. This figure indicates that an oxidation resistance equivalent to or better than that of SUS444 (increase in weight due to oxidation: 19 g/m² or less) can be achieved by setting the Al content to be 0.2% or more.

[0024] Steel having a basic chemical composition containing C: 0.006%, N: 0.007%, P: 0.02% or more and 0.03% or less, S: 0.002% or more and 0.004% or less, Mn: 0.2%, Al: 0.45%, Cr: 14%, Nb: 0.49%, Cu: 1.5%, Ti: 0.007%, Mo: 0.01% or more and 0.03% or less and W: 0.01% or more and 0.03% or less and a Si content which was adjusted variously was smelted by using an experimental method and made into a steel ingot of 50 kg. Then the steel ingot was subjected to hot rolling, hot rolled annealing, cold rolling and finishing annealing and made into a cold rolled and annealed steel sheet having a thickness of 2 mm. A test specimen of 30 mm × 20 mm was cut out of the cold rolled steel sheet obtained as described above. Then a hole of 4 mmφ was punched in the upper part of the test specimen, then the surface and the edge face of the specimen was polished with a #320 emery paper. Then degreased and then used in a continuous oxidation test in water vapor atmosphere described below.

<Continuous oxidation test in water vapor atmosphere>

[0025] The test specimen described above was held in a furnace in a water vapor atmosphere in which a gas of 10 vol%CO₂-20 vol%H₂O-5 vol%O₂-bal. N₂ was blown at a rate of 0.5 L/min, and then an increase in weight per unit area due to oxidation (g/m²) was derived from the observed difference in the mass of the specimen before and after the heating test.

[0026] Fig. 6 illustrates the influence of the Si content on the increase in weight due to oxidation in the oxidation test in water vapor atmosphere described above. This figure indicates that water vapor oxidation resistance equivalent to that of SUS444 (increase in weight due to oxidation: 37g/m² or less) cannot be achieved, unless the Si content is set to be 0.4% or more.

[0027] Steel having a basic chemical composition containing C: 0.006%, N: 0.007%, P: 0.02% or more and 0.03% or less, S: 0.002% or more and 0.004% or less, Mn: 0.2%, Cr: 14%, Nb: 0.49%, Cu: 1.5%, Ti: 0.007%, Mo: 0.01% or more and 0.03% or less and W: 0.01% or more and 0.03% or less and the contents of Si and Al which were adjusted variously was smelted by using an experimental method and made into a steel ingot of 50 kg. Then the steel ingot was subjected to hot rolling,

hot rolled annealing, cold rolling and finishing annealing and made into a cold rolled and annealed steel sheet having a thickness of 2 mm. A high-temperature fatigue test specimen having a shape illustrated in Fig. 3 was made of the cold rolled steel sheet obtained as described above and then used in a high-temperature fatigue test described below.

<High-temperature fatigue test>

[0028] The high-temperature fatigue property of the test specimen described above was evaluated by using a Schenck type fatigue testing machine and by performing reversed vibration of 22 Hz (1300 rpm) at a temperature of 850°C. Here, a bending stress of 70 MPa was exerted on the surface of the steel sheet during the test, and the fatigue property was evaluated in terms of a number of cycles until fracture occurred.

[0029] Fig. 7 illustrates the influence of Si - Al on the number of cycles in the high-temperature fatigue test described above. This figure indicates that it is necessary to satisfy the relationship Si ≥ Al in order to achieve a high-temperature fatigue property equivalent to that of SUS444 (24 × 10⁵ cycles).

[0030] Steel having a basic chemical composition containing C: 0.006%, N: 0.007%, P: 0.02% or more and 0.03% or less, S: 0.002% or more and 0.004% or less, Mn: 0.2% Si: 0.85%, Al: 0.45%, Nb: 0.49%, Cu: 1.5%, Ti: 0.007%, Mo: 0.01% or more and 0.03% or less and W: 0.01% or more and 0.03% or less and a Cr content which was adjusted variously was smelted by using an experimental method and made into a steel ingot of 50 kg. Then the steel ingot was subjected to hot rolling, hot rolled annealing, cold rolling and finishing annealing and made into a cold rolled and annealed steel sheet having a thickness of 2 mm. A test specimen of 30 mm × 20 mm was cut out from the cold rolled steel sheet

obtained as described above, then a hole of 4 mm ϕ was punched in the upper part of the test specimen. Then the surface and the edge face of the specimen was polished with a #320 emery paper, then degreased and then used in the oxidation test in water vapor atmosphere described above.

[0031] Fig. 8 illustrates the influence of the Cr content on the increase in weight due to oxidation in the oxidation test in water vapor atmosphere described above. This figure indicates that water vapor oxidation resistance equivalent to that of SUS444 (increase in weight due to oxidation: 37 g/m² or less) can be achieved in the case where the Cr content is 12% or more.

[0032] In addition, tensile tests were conducted at room temperature with tensile test pieces conforming to JIS NO. 13B which were made of these cold rolled and annealed steel sheets. Tensile test pieces had the directions of tension respectively in the rolling direction (L direction), in the direction at right angles to the rolling direction (C direction) and in the direction at a 45° angles to the rolling direction (D direction). A mean elongation was derived from the breaking elongations which were obtained by performing tensile tests in the three directions at room temperature and calculated by the equation below.

$$\text{Mean elongation El (\%)} = (E_L + 2E_D + E_C) / 4,$$

where E_L : El (%) in L direction, E_D : El (%) in D direction and E_C : El (%) in C direction.

Fig. 9 illustrates the influence of the Cr content on the mean value of elongations in the three directions (L, C and D directions) in the tensile test. This figure indicates that excellent formability in terms of the mean elongation in the three directions (L, C and D directions) of 36% or more can be achieved in the case where the Cr content is less than 16%.

[0033] The present invention has been completed by conducting further investigations on the basis of the results of the fundamental experiments described above.

[0034] The ferritic stainless steel according to the present invention will be described in detail hereafter. Firstly, the chemical composition according to the present invention will be described.

[0035] C: 0.015% or less

Although C is a chemical element which is effective for increasing the strength of steel, there is a significant decrease in toughness and formability in the case where C content is more than 0.015%. Therefore, according to the present invention, the C content is set to be 0.015% or less. Incidentally, it is preferable that the C content be as small as possible from the viewpoint of achieving formability and that the carbon content be 0.008% or less. On the other hand, it is preferable that the C content be 0.001% or more in order to achieve strength which is required of the parts of an exhaust system, more preferably 0.002% or more and 0.008% or less.

[0036] Si: 0.4% or more and 1.0% or less

Si is a chemical element which is important for improving oxidation resistance in a water vapor atmosphere. As Fig. 6 indicates, it is necessary to set Si content to be 0.4% or more in order to achieve water vapor oxidation resistance equivalent to that of SUS444. On the other hand, there is a significant decrease in formability in the case where the Si content is more than 1.0%. Therefore, the Si content is set to be 0.4% or more and 1.0% or less, preferably 0.5% or more and 0.9% or less. Although the mechanism through which water vapor oxidation resistance is increased in the case where the Si content is 0.4% or more is not clear, it is considered that a dense continuous oxide layer is formed on the surface of a steel sheet in the case where the Si content is 0.4% or more and the penetration of gas elements from outside is prevented, which results in an increase in water vapor oxidation resistance. It is preferable that the Si content be 0.5% or more in the case where there is a necessity of oxidation resistance in a severer environment.

[0037] Mn: 1.0% or less

Although Mn is a chemical element which causes an increase in the strength of steel and which is effective as a deoxidation agent, a γ phase tends to be formed at a high temperature in the case where Mn content is excessively large, the excessive Mn content results in a decrease in heat resistance. Therefore, the Mn content is set to be 1.0% or less, preferably 0.7% or less. It is preferable that the Mn content be 0.05% or more in order to realize the effect of increasing strength and deoxidation.

[0038] P: 0.040% or less

Since P is a harmful chemical element which causes a decrease in ductility, it is preferable that P content be as small as possible. Therefore, the P content is set to be 0.040% or less, preferably 0.030% or less.

[0039] S: 0.010% or less

Since S is a harmful chemical element which causes a decrease in elongation and an r value. S has a negative influence on formability and S causes a decrease in corrosion resistance which is the basic property of stainless steel. It is preferable that S content be as small as possible. Therefore, the S content is set to be 0.010% or less, preferably 0.005% or less.

[0040] Cr: 12% or more and less than 16%

Cr is a chemical element which is effective for increasing corrosion resistance and oxidation resistance, which are the

characteristics of stainless steel. Sufficient oxidation resistance cannot be achieved in the case where Cr content is less than 12%. On the other hand, Cr is a chemical element which causes an increase in hardness and a decrease in ductility of steel at room temperature by solid solution strengthening, in particular, these negative influences become significant in the case where the Cr content is 16% or more. Therefore, the Cr content is set to be 12% or more and less than 16%, preferably 12% or more and 15% or less.

[0041] N: 0.015% or less

N is a chemical element which causes a decrease in the ductility and the formability of steel, and these negative influences are significant in the case where N content is more than 0.015%. Therefore, the N content is set to be 0.015% or less. Incidentally, it is preferable that the N content be as small as possible from the viewpoint of achieving ductility and formability and that the N content be less than 0.010%.

[0042] Nb: 0.3% or more and 0.65% or less

Nb is a chemical element which is effective for increasing corrosion resistance, formability and intergranular corrosion resistance at welds by forming carbide, nitride and carbonitride in combination with C and N. Nb is effective for increasing a thermal fatigue property by increasing high-temperature strength. These effects can be realized by setting Nb content to be 0.3% or more. On the other hand, a Laves phase (Fe_2Nb) tends to be precipitated in the case where the Nb content is more than 0.65%, which results in the acceleration of embrittlement. Therefore, the Nb content is set to be 0.3% or more and 0.65% or less, preferably 0.4% or more and 0.55% or less.

[0043] Mo: 0.1% or less

Since Mo is an expensive chemical element, additionally in view of the purpose of the present invention, Mo is not added positively. However, Mo may be mixed in from the material of steel such as scrap in the range of 0.1% or less. Therefore, Mo content is set to be 0.1% or less.

[0044] W: 0.1% or less

Since W is an expensive chemical element like Mo, additionally in view of the purpose of the present invention, W is not added positively. However, W may be mixed in from the material of steel such as scrap in the range of 0.1% or less.

Therefore, W content is set to be 0.1% or less.

[0045] Cu: 1.0% or more and 2.5% or less

Cu is a chemical element which is very effective for improving a thermal fatigue property. As Fig. 3 indicates, it is necessary that Cu content be 1.0% or more in order to achieve a thermal fatigue property equivalent to or better than that of SUS444. However, in the case where the Cu content is more than 2.5%, ϵ -Cu is precipitated when cooling is performed after a heat treatment, which results in an increase in the hardness of steel and results in embrittlement tending to occur when hot work is performed. More importantly, while a thermal fatigue property is improved by adding Cu, contrarily the oxidation resistance of steel is decreased, which results in the deterioration of the overall heat resistance. The reason for this has not been fully identified. However, Cu seems to concentrate in a Cr depletion layer where scale has formed thereon and prevent Cr, an element that should improve intrinsic oxidation resistance of stainless steel, from diffusing again. Therefore, the Cu content is set to be 1.0% or more and 2.5% or less, preferably 1.1% or more and 1.8% or less.

[0046] Ti: 0.15% or less

Ti is effective for improving corrosion resistance, formability and intergranular corrosion resistance of a welded part by fixing C and N like Nb does. However, this effect saturates and there is an increase in the hardness of steel in the case where Ti content is more than 0.15% in the present invention in which Nb is contained. Therefore, the Ti content is set to be 0.15% or less. Since Ti has higher affinity for N than Nb does, Ti tends to form TiN of a large size. Since TiN of a large size tends to become the origin of a crack and causes a decrease in toughness, it is preferable that the Ti content be 0.01% or less in the case where the toughness of a hot rolled steel sheet is necessary. Incidentally, since it is not necessary to positively add Ti in the present invention, the lower limit of the Ti content includes 0%.

[0047] Al: 0.2% or more and 1.0% or less

Al is a chemical element which is essential for increasing the oxidation resistance of Cu containing steel as Fig. 5 indicates. In addition, since Al is effective as a solid solution strengthening element and, in particular, is effective for increasing high-temperature strength at a temperature of higher than 800°C, Al is a chemical element which is important for improving a high-temperature fatigue property in the present invention. It is necessary that Al content be 0.2% or more in order to achieve oxidation resistance equivalent to or better than that of SUS444. On the other hand, there is a decrease in formability due to an increase in the hardness of steel in the case where the Al content is more than 1.0%. Therefore, the Al content is set to be 0.2% or more and 1.0% or less, preferably 0.3% or more and 1.0% or less, more preferably 0.3% or more and 0.5% or less.

[0048] $\text{Si} \geq \text{Al}$

Since Al is effective as a solid solution strengthening element and, in particular, effective for increasing high-temperature strength at a high temperature of higher than 800°C, Al is a chemical element which is important for improving a high-temperature fatigue property in the present invention as described above, and Si is a chemical element which is important for effectively utilizing this effect of solid solution strengthening of Al. In the case where the amount of Si is less than

that of Al, there is a decrease in the amounts of solid solution Al, because Al preferentially forms oxides and nitrides at high temperature, which decreases the contribution of Al to strengthening. On the other hand, in the case where the amount of Si is larger than that of Al, Si is preferentially oxidized and forms a dense continuous oxide layer on the surface of a steel sheet. Since this oxide becomes a barrier to the diffusion of oxygen and nitrogen, Al is kept in the state of a solid solution without being oxidized or nitrated, which makes it possible to improve a high-temperature fatigue property by strengthening steel through solid solution strengthening. Therefore, it is necessary that the relationship $Si \geq Al$ be satisfied in order to achieve a high-temperature fatigue property equivalent to or better than that of SUS444.

[0049] One, two or more chemical elements selected from among B, REM, Zr, V, Co and Ni may be further contained in the ferritic stainless steel according to the present invention in addition to the chemical composition described above.

[0050] B: 0.003% or less

B is a chemical element which is effective for improving formability, in particular, secondary formability. However, in the case where B content is more than 0.003%, B causes a decrease in formability by forming BN. Therefore, in the case where B is contained, the B content is set to be 0.003% or less. Since the effect described above is realized in the case where the B content is 0.0004% or more, it is more preferable that the B content be 0.0004% or more and 0.003% or less.

[0051] REM: 0.08% or less and Zr: 0.5% or less

REM (rare earth elements) and Zr are chemical elements which are effective for improving oxidation resistance and may be added as needed in the present invention. However, in the case where the content of REM is more than 0.080%, the steel become easier to occur the embrittle crack and, in the case where Zr content is more than 0.50%, the steel also become easier to occur the embrittle crack due to the precipitation of a Zr intermetallic compound. Therefore, in the case where REM is contained, the content of REM is set to be 0.080% or less, and, in the case where Zr is contained, the Zr content is set to be 0.50% or less. Since the effect described above is realized in the case where the content of REM is 0.01% or more and in the case where the Zr content is 0.0050% or more, it is preferable that the content of REM be 0.001% or more and 0.080% or less and that the Zr content be 0.0050% or more and 0.50% or less.

[0052] V: 0.5% or less

V is a chemical element which is effective for improving formability and oxidation resistance. However, in the case where V content is more than 0.50%, V(C,N) of a large size is precipitated, which results in the deterioration of surface quality. Therefore, in the case where V is contained, the V content is set to be 0.50% or less. It is preferable that the V content be 0.15% or more and 0.50% or less in order to realize the effect of improving formability and oxidation resistance, more preferably 0.15% or more and 0.4% or less.

[0053] Co: 0.5% or less

Co is a chemical element which is effective for improving toughness. However, Co is an expensive chemical element and the effect of Co saturates in the case where Co content is more than 0.5%. Therefore, in the case where Co is contained, the Co content is set to be 0.5% or less. Since the effect described above is effectively realized in the case where the Co content is 0.02% or more, it is preferable that the Co content be 0.02% or more and 0.5% or less, more preferably 0.02% or more and 0.2% or less.

[0054] Ni: 0.5% or less

Ni is a chemical element which improves toughness. However, since Ni is expensive and a chemical element which strongly forms a γ phase, Ni causes a decrease in oxidation resistance by forming a γ phase at a high temperature in the case where Ni content is more than 0.5%. Therefore, in the case where Ni is contained, the Ni content is set to be 0.5% or less. Since the effect described above is effectively realized in the case where the Ni content is 0.05% or more, it is preferable that the Ni content be 0.05% or more and 0.5% or less, more preferably 0.05% or more and 0.4% or less.

[0055] The remainder of the chemical composition consists of Fe and inevitable impurities. Among the inevitable impurities, it is preferable that an O content be 0.010% or less, a Sn content be 0.005% or less, a Mg content be 0.005% or less and a Ca content be 0.005% or less, more preferably the O content be 0.005% or less, the Sn content be 0.003% or less, the Mg content be 0.003% or less and the Ca content be 0.003% or less.

[0056] The method for manufacturing the ferritic stainless steel will be described hereafter.

The stainless steel according to the present invention may be manufactured in a common method for manufacturing ferritic stainless steel and there is no particular limitation on manufacturing conditions. Examples of ideal manufacturing methods include smelting steel by using a well-known melting furnace such as a steel converter or an electric furnace, further, optionally, making the steel have the chemical composition according to the present invention described above by performing secondary refining such as ladle refining or vacuum refining, then making a slab of the steel by using a continuous casting method or an ingot casting-blooming rolling method, and then making the slab a cold rolled and annealed steel sheet through the processes such as hot rolling, hot rolled annealing, pickling, cold rolling, finishing annealing, pickling and so forth. Incidentally, the cold rolling described above may be performed one time or repeated two times or more with process annealing in between, and the processes of cold rolling, finishing annealing and pickling may be performed repeatedly. Moreover, optionally, hot rolled annealing may be omitted, and skin pass rolling may be performed after cold rolling or finishing annealing in the case where brightness of a steel sheet is required.

[0057] Examples of more preferable manufacturing conditions are as follows.

It is preferable that some of the conditions of a hot rolling process and a cold rolling process be specified. In addition, in a steel making process, it is preferable to smelt molten steel having the essential chemical composition described above and the optional chemical elements to be added as needed and to perform secondary refining by using a VOD method (Vacuum Oxygen Decarburization method). Although the smelted molten steel may be made into a steel material by using a well-known method, it is preferable to use a continuous casting method from the viewpoint of productivity and material quality. The steel material obtained through a continuous casting process is heated up to a temperature of, for example, from 1000°C or higher and 1250°C or lower, and then made into a hot rolled steel sheet having a specified thickness. It is needless to say that the steel material may be made into a material of a shape other than a sheet. This hot rolled steel sheet is subjected to, as needed, batch annealing at a temperature of 600°C or higher and 800°C or lower or continuous annealing at a temperature of 900°C or higher and 1100°C or lower, and then made into a hot rolled sheet product after being descaled by performing pickling or the like. In addition, as needed, descaling may be performed by using a shot blasting method before pickling being performed.

[0058] Moreover, in order to obtain a cold rolled steel sheet, the hot rolled and annealed steel sheet obtained as described above is made into a cold rolled steel sheet through a cold rolling process. In this cold rolling process, in accordance with manufacturing circumstances, cold rolling may be performed two times or more with process annealing in between as needed. The total rolling ratio of the cold rolling process, in which cold rolling is performed for one, two or more times, is set to be 60% or more, preferably 70% or more. The cold rolled steel sheet is subjected to continuous annealing (finishing annealing) at a temperature of 900°C or higher and 1150°C or lower, preferably 950°C or higher and 1120°C or lower, and pickling, and then made into a cold rolled and annealed steel sheet. In addition, in accordance with use application, the shape of and the material quality of the steel sheet may be adjusted by performing rolling with a light reduction ratio such as skin pass rolling after cold rolled annealing being performed.

[0059] The hot rolled sheet product or cold rolled and annealed sheet product obtained as described above are formed into the exhaust pipe of an automobile or a motor bicycle, a material to be used for a catalyst outer cylinder, the exhaust air duct of a thermal electric power plant, or a part related to a fuel cell (such as a separator, an inter connector or a reformer) by performing bending work or other kinds of work in accordance with use application. There is no limitation on welding methods for assembling these parts, and common arc welding methods such as MIG (Metal Inert Gas), MAG (Metal Active Gas) and TIG (Tungsten Inert Gas), resistance welding methods such as spot welding and seam welding, high-frequency resistance welding methods such as electric resistance welding and high-frequency induction welding methods may be applied.

[EXAMPLES]

[EXAMPLE 1]

[0060] Each of the steel No. 1 through 23 having chemical compositions given in Table 1 was smelted by using a vacuum melting furnace and made into steel ingot of 50 kg, then the steel ingot was subjected to forging, and then the forged ingot was divided into two pieces. Thereafter, one of the divided ingots was heated up to a temperature of 1170°C, then subjected to hot rolling and made into a hot rolled steel sheet having a thickness 5 mm, then subjected to hot rolled annealing, pickling, cold rolling with a rolling ratio of 60%, finishing annealing at a temperature of 1040°C, cooling at a cooling rate of 5°C /sec, pickling and then made into a cold rolled and annealed steel sheet having a thickness of 2 mm. Each of the steel No. 1 through 11 is an example in the range according to the present invention, and each of the steel No. 12 through 23 is a comparative example out of the range according to the present invention. Incidentally, among the comparative examples, steel No. 19 has a chemical composition corresponding to Type429, No. 20 has a chemical composition corresponding to SUS444, and No. 21, No. 22 and No. 23 respectively have chemical compositions corresponding to example 3 of Patent Literature 2, example 3 of Patent Literature 3 and example 5 of Patent Literature 4.

[0061] The cold rolled steel sheets No. 1 through 23 were used in the two kinds of continuous oxidation tests, a high-temperature fatigue test and a tensile test at room temperature as described below.

<Continuous oxidation test in air>

[0062] A sample of 30 mm × 20 mm was cut out of each of the cold rolled and annealed steel sheet obtained as described above, then a hole of 4 mmφ was punched in the upper part of the sample, then the surface and the edge face of the sample was polished with a #320 emery paper, then degreased and then the sample was suspended in a furnace heated up to a temperature of 950°C in air for a holding time of 200 hours. After the test, the mass of the sample was observed, and then an increase in weight due to oxidation (g/m²) was calculated by deriving the difference between the mass observed before and after the test. Incidentally, the test was repeated two times, and oxidation resistance in air was evaluated by using the mean value of the difference in mass.

<Continuous oxidation test in water vapor atmosphere>

[0063] A sample of 30 mm × 20 mm was cut out from each of the cold rolled and annealed steel sheet obtained as described above. Then a hole of 4 mmφ was punched in the upper part of the sample, then the surface and the edge face of the sample was polished with a #320 emery paper and then degreased. Thereafter, the sample was held in a furnace heated up to a temperature of 950°C in a water vapor atmosphere in which a gas of 10 vol%CO₂-20 vol%H₂O-5 vol%O₂-bal. N₂ was blown at a rate of 0.5 L/min for a holding time of 200 hours, then, after the test, the mass of the sample was observed, and then an increase in weight due to oxidation (g/m²) was calculated by deriving the difference between the mass observed before and after the test.

<High-temperature fatigue test>

[0064] A test specimen illustrated in Fig. 3 was cut out from the cold rolled and annealed steel sheet obtained as described above was subjected to reversed vibration of 1300 rpm (22 Hz) at a temperature of 850°C by using a Schenck type fatigue testing machine. Incidentally, a bending stress of 70 MPa was exerted on the surface of the steel sheet during the test, and evaluation was done in terms of a number of cycles (cycle) until fracture occurred.

<Tensile test at room temperature>

[0065] A tensile test piece conforming to JIS No. 13B which had the directions of tension respectively in the rolling direction (L direction), in the direction at right angle to the rolling direction (C direction) and in the direction at 45° angles to the rolling direction (D direction) was cut out from the cold rolled and annealed steel sheet described above. Then tensile tests in these directions were conducted at room temperature, then breaking elongations were observed and then a mean elongation was derived by using the equation below.

$$\text{Mean elongation El (\%)} = (E_L + 2E_D + E_C) / 4,$$

where E_L : El (%) in L direction, E_D : El (%) in D direction and E_C : El (%) in C direction.

[EXAMPLE 2]

[0066] The rest of the pieces which were obtained by dividing the ingot of 50 kg into two pieces in Example 1 was heated up to a temperature of 1170°C, and then hot rolled into a sheet bar having a thickness of 30 mm and a width of 150 mm. Thereafter, this sheet bar was subjected to forging and made into a bar of 35 mm × 35 mm, annealing at a temperature of 1040°C, then machined into a thermal fatigue test specimen having the dimensions illustrated in Fig. 1, and then used in a thermal fatigue test as described below.

<Thermal fatigue test>

[0067] In a thermal fatigue test, a thermal fatigue life was observed by repeatedly heating and cooling the test specimen between the temperatures of 100°C and 850°C at a restraint ratio of 0.30. Here, a heating rate and a cooling rate were both 10°C/sec, a holding time at a temperature of 100°C was 2 minutes and a holding time at a temperature of 850°C was 5 minutes. The thermal fatigue life represents as the number of cycles at which the stress first started to continuously decrease from that in the previous cycle. The stress was derived by calculated as the quotient of the load detected at 100°C divided by the cross section area of the soaked parallel portion of a test specimen indicated in Fig. 1.

[0068] The results of the continuous oxidation test in air, the continuous oxidation test in water vapor atmosphere, the high-temperature fatigue test and the tensile test at room temperature in Example 1 and those of the thermal fatigue test in Example 2 are summarized in Table 2. As Table 2 indicates, it is clear that any of the steel of the example of the present invention which is within the range of the present invention has heat resistance (oxidation resistance, a thermal fatigue property and a high-temperature fatigue property) equivalent to or better than that of SUS444 and excellent formability in terms of a mean elongation in the three directions (L, C and D direction) at room temperature of 36% or more, which means it has been confirmed that the steel satisfies the object of the present invention. In contrast, the steel of the comparative example which is out of the range according to the present invention is poor in either of oxidation resistance, thermal fatigue resistance, a high-temperature fatigue property or formability, which means it has been confirmed that the steel does not satisfy the object of the present invention.

[Industrial Applicability]

[0069] The steel according to the present invention can be ideally used not only for the parts of an exhaust system of an automobile but also the parts of an exhaust system of a thermal electric power system and the parts of a solid-oxide fuel cell for which similar properties as that of the parts of an exhaust system of an automobile are required.

5

10

15

20

25

30

35

40

45

50

55

[0070]

[Table 1]

mass%																
Sample No.	C	Si	Mn	Al	P	S	Cr	Cu	Nb	Ti	Mo	W	N	Others	Si - Al	Note
1	0.008	0.84	0.25	0.51	0.031	0.002	12.8	1.32	0.48	0.008	0.02	0.02	0.008		0.33	Example
2	0.007	0.76	0.28	0.40	0.029	0.003	14.5	1.45	0.46	0.007	0.03	0.01	0.009		0.36	Example
3	0.008	0.91	0.31	0.67	0.030	0.003	15.1	1.48	0.49	0.009	0.02	0.02	0.007		0.24	Example
4	0.009	0.69	0.29	0.38	0.028	0.003	13.4	1.23	0.47	0.007	0.02	0.03	0.008		0.31	Example
5	0.006	0.54	0.54	0.31	0.027	0.004	15.2	1.37	0.44	0.006	0.01	0.02	0.008		0.23	Example
6	0.007	0.89	0.48	0.43	0.028	0.003	14.3	1.54	0.49	0.008	0.01	0.03	0.007		0.46	Example
7	0.009	0.76	0.24	0.37	0.029	0.003	14.9	1.19	0.46	0.009	0.03	0.02	0.006		0.39	Example
8	0.007	0.80	0.73	0.45	0.025	0.003	13.7	1.67	0.45	0.007	0.02	0.01	0.007	V: 0.21	0.35	Example
9	0.007	0.73	0.81	0.4	0.026	0.004	15.5	1.59	0.45	0.008	0.02	0.01	0.007	B: 0.0015	0.33	Example
10	0.008	0.68	0.89	0.32	0.026	0.002	12.9	1.24	0.43	0.008	0.01	0.02	0.008	Co: 0.09	0.36	Example
11	0.007	0.94	0.39	0.52	0.028	0.002	13.5	1.55	0.45	0.007	0.01	0.02	0.007	Ni: 0.34	0.42	Example
12	0.006	<u>1.34</u>	0.5	0.37	0.024	0.003	14.0	1.15	0.48	0.006	0.01	0.03	0.006		0.97	Comparative Example
13	0.007	0.69	0.44	<u>1.49</u>	0.025	0.002	12.7	1.46	0.47	0.009	0.02	0.02	0.007		-0.8	Comparative Example
14	0.008	0.92	0.78	<u>0.13</u>	0.027	0.003	15.6	1.29	0.48	0.007	0.02	0.02	0.008		0.79	Comparative Example
15	0.009	0.47	0.63	0.68	0.029	0.002	14.4	1.51	0.46	0.008	0.03	0.02	0.006		<u>-0.21</u>	Comparative Example
16	0.008	0.81	0.35	0.54	0.026	0.003	13.9	<u>0.53</u>	0.44	0.007	0.02	0.01	0.008		0.27	Comparative Example
17	0.008	0.52	0.21	0.39	0.030	0.004	<u>17.1</u>	1.46	0.48	0.003	0.02	0.02	0.008	V: 0.06	0.13	Comparative Example

(continued)

mass%																
Sample No.	C	Si	Mn	Al	P	S	Cr	Cu	Nb	Ti	Mo	W	N	Others	Si - Al	Note
18	0.007	0.76	0.84	0.43	0.027	0.003	9.7	1.64	0.43	0.008	0.01	0.03	0.007		0.33	Comparative Example
19	0.007	0.87	0.33	0.03	0.029	0.002	14.8	0.02	0.44	0.030	0.01	0.01	0.008		0.84	Comparative Example*1
20	0.008	0.31	0.42	0.02	0.031	0.003	18.7	0.02	0.52	0.003	1.87	0.02	0.008		0.291	Comparative Example*2
21	0.008	0.32	0.05	0.01	0.028	0.002	17.0	1.93	0.33	0.002	0.01	0.02	0.01	Ni: 0.10, V: 0.10	0.31	Comparative Example*3
22	0.009	0.46	0.54	0.00	0.029	0.003	18.9	1.36	0.35	0.080	0.01	0.02	0.007	Ni: 0.10, V: 0.03, B: 0.0030	0.458	Comparative Example*4
23	0.006	0.22	0.05	0.05	0.005	0.005	18.8	1.65	0.42	0.090	0.02	0.02	0.006	Ni: 0.15	0.168	Comparative Example*5
<u>Underline indicates the value out of the range according to the present invention.</u>																
*1: Type429 *2: SUS444 *3: Example 3 of Patent literature 2																
*4: Example 3 of Patent literature 3 *5: Example 5 of Patent literature 4																

[0071]

[Table 2]

Sample No.	Weight gain by oxidation (g/m ²)	Thermal Fatigue Life (cycle)	Weight gain by water vapor oxidation (g/m ²)	Mean Elongation in Three Directions (%)	High- Temperature Fatigue Life at 850°C (x10 ⁻⁵ cycles)	Note
1	18	1330	34	36	30	Example
2	17	1340	34	36	33	Example
3	16	1350	33	36	26	Example
4	17	1370	34	37	29	Example
5	16	1340	35	37	27	Example
6	16	1310	33	36	32	Example
7	16	1370	34	37	31	Example
8	17	1360	34	36	36	Example
9	16	1340	34	36	27	Example
10	18	1300	34	37	29	Example
11	17	1410	33	36	33	Example
12	17	1280	<u>39</u>	<u>32</u>	30	Comparative Example
13	18	1380	<u>71</u>	<u>31</u>	9	Comparative Example
14	<u>55</u>	1400	<u>40</u>	37	<u>15</u>	Comparative Example
15	17	1290	<u>77</u>	36	<u>11</u>	Comparative Example
16	15	<u>910</u>	32	38	26	Comparative Example
17	13	1440	29	<u>34</u>	31	Comparative Example
18	<u>52</u>	1300	<u>>100</u>	38	<u>14</u>	Comparative Example
19	<u>45</u>	<u>630</u>	<u>>100</u>	<u>34</u>	<u>8</u>	Comparative Example*1
20	19	1250	37	31	24	Comparative Example*2
21	>100	1650	<u>>100</u>	<u>31</u>	<u>15</u>	Comparative Example*3
22	>100	1380	<u>>100</u>	<u>35</u>	<u>10</u>	Comparative Example*4

(continued)

Sample No.	Weight gain by oxidation (g/m ²)	Thermal Fatigue Life (cycle)	Weight gain by water vapor oxidation (g/m ²)	Mean Elongation in Three Directions (%)	High- Temperature Fatigue Life at 850°C (x10 ⁻⁵ cycles)	Note
23	>100	1540	<u>≥100</u>	<u>34</u>	<u>12</u>	Comparative Example*5
<u>underline</u> indicates the value out of the range according to the present invention. *1: Type429 *2: SUS444 *3: Example 3 of Patent literature 2 *4: Example 3 of Patent literature 3 *5: Example 5 of Patent literature 4						

Claims

1. Ferritic stainless steel having a chemical composition containing, by mass%, C: 0.015% or less, Si: 0.4 % or more and 1.0% or less, Mn: 1.0% or less, P: 0.040% or less, S: 0.010% or less, Cr: 12% or more and less than 16%, N: 0.015% or less, Nb: 0.3% or more and 0.65% or less, Ti: 0.15% or less, Mo: 0.1% or less, W: 0.1% or less, Cu: 1.0% or more and 2.5 % or less and Al: 0.2% or more and 1.0% or less, while the relationship $Si \geq Al$ is satisfied, and the balance being Fe and inevitable impurities.
2. Ferritic stainless steel having a chemical composition further containing one, two or more chemical elements selected from among, by mass%, B:0.003% or less, REM: 0.08% or less, Zr: 0.5% or less, V: 0.5% or less, Co: 0.5% or less and Ni: 0.5% or less.

FIG. 1

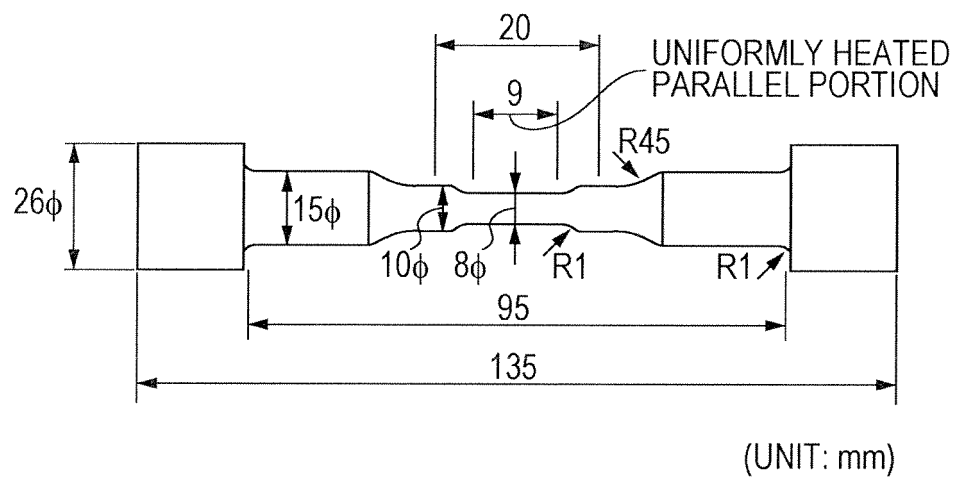


FIG. 2

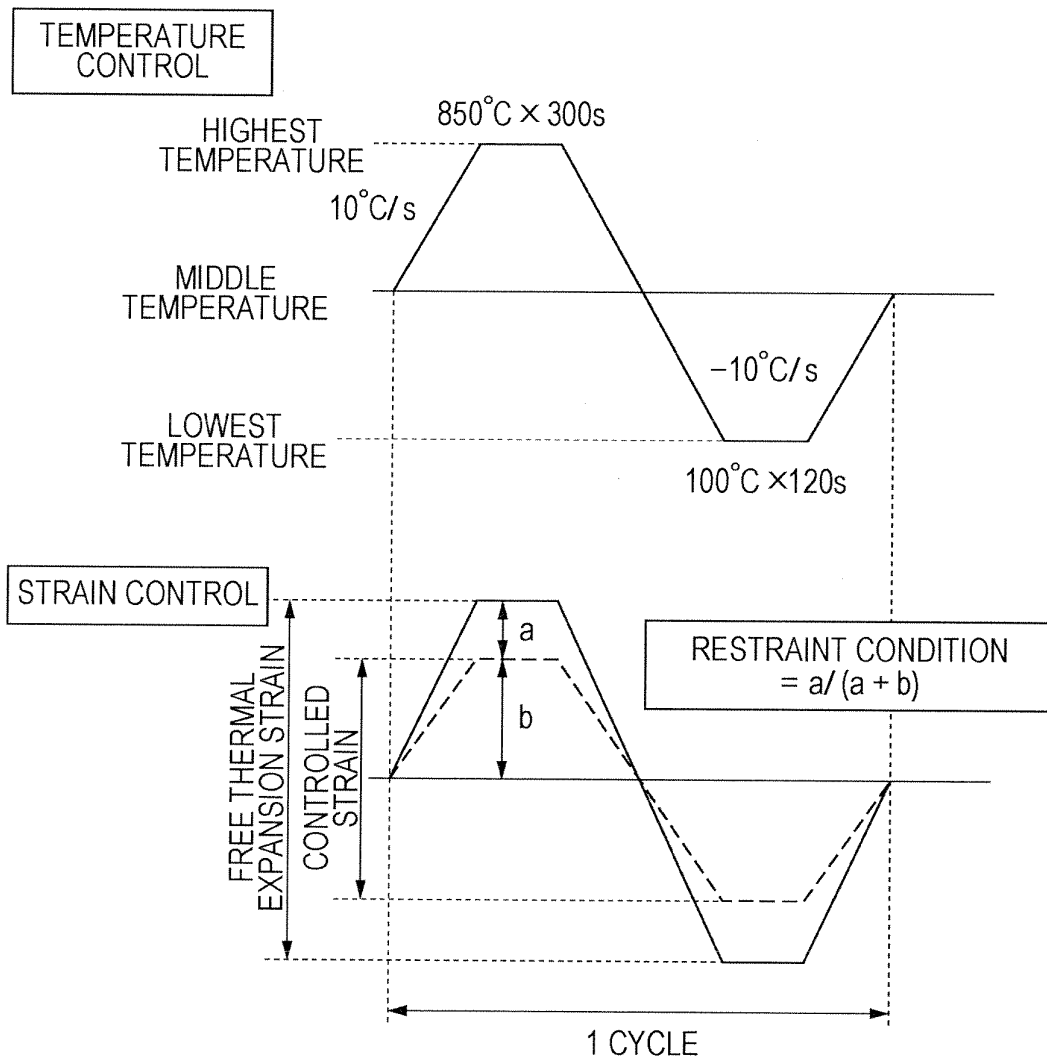


FIG. 3

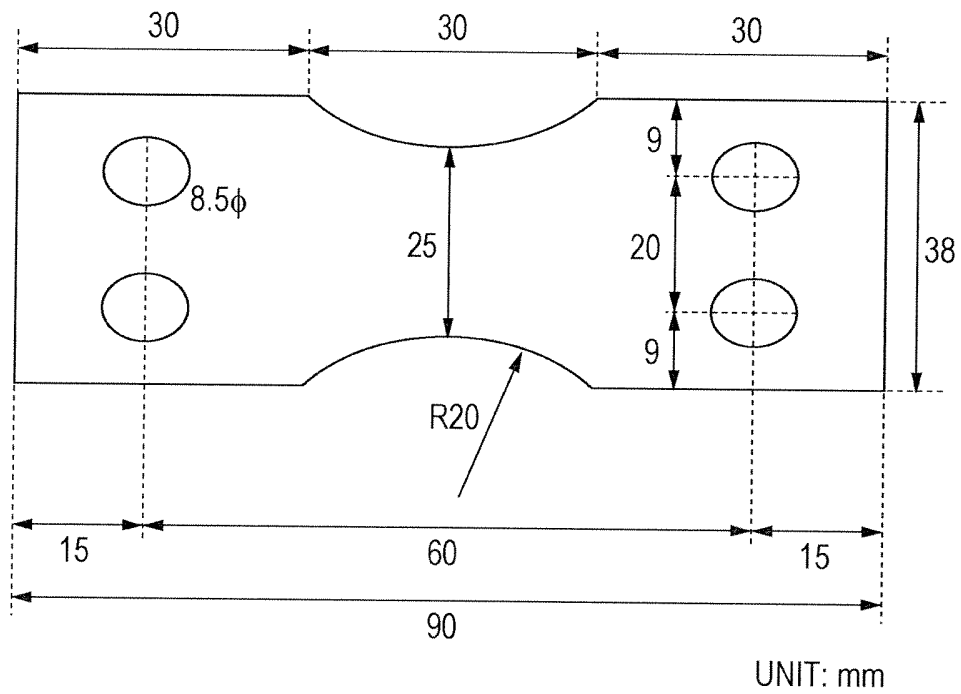


FIG. 4

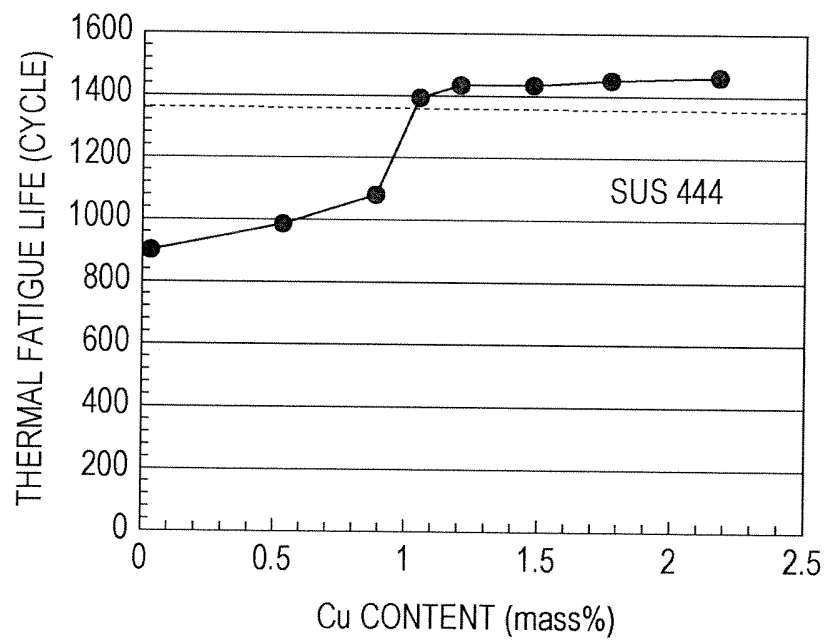


FIG. 5

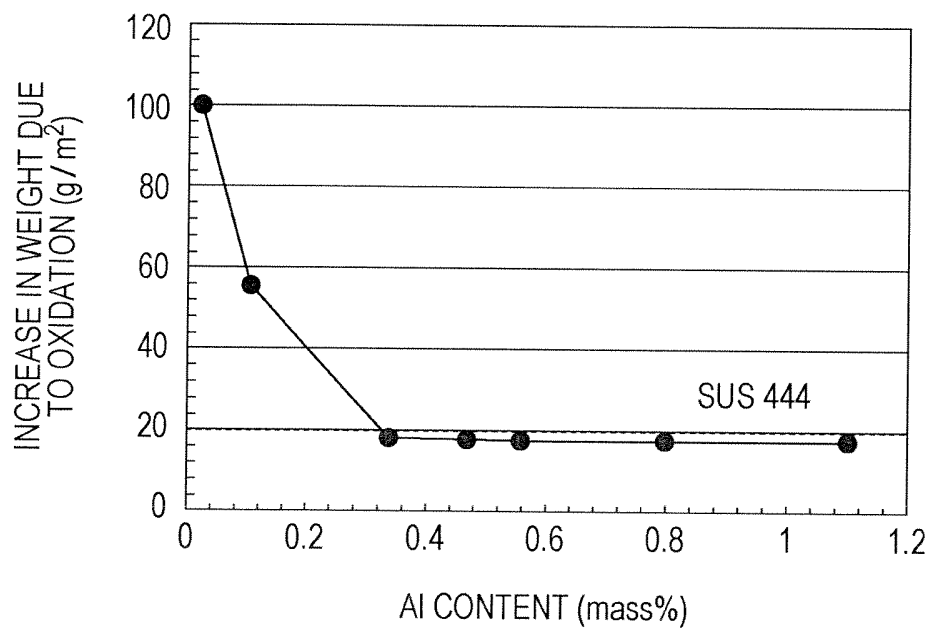


FIG. 6

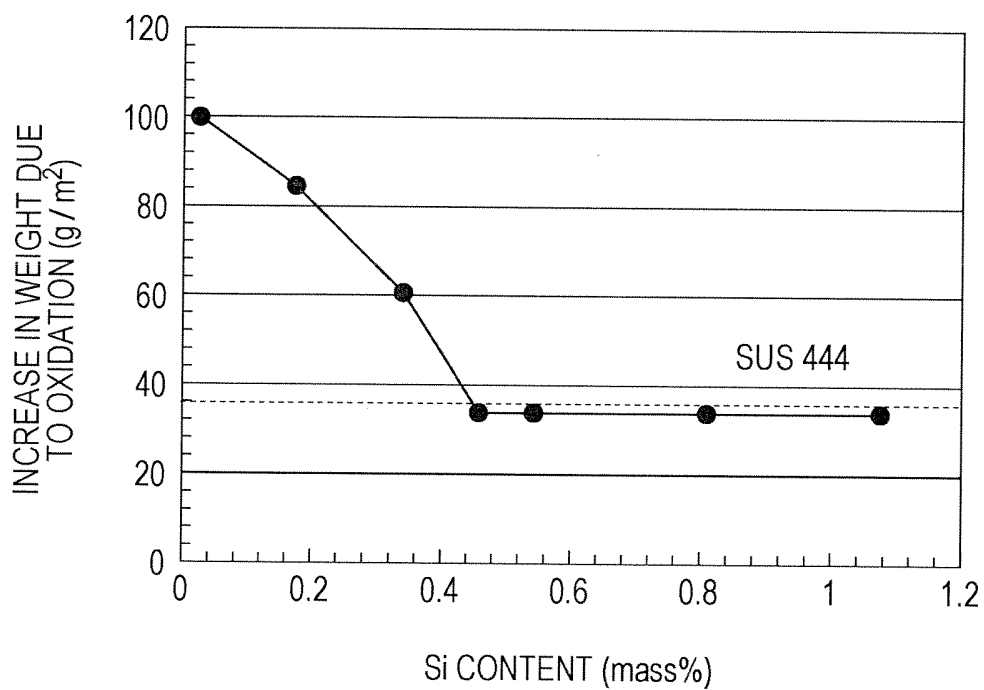


FIG. 7

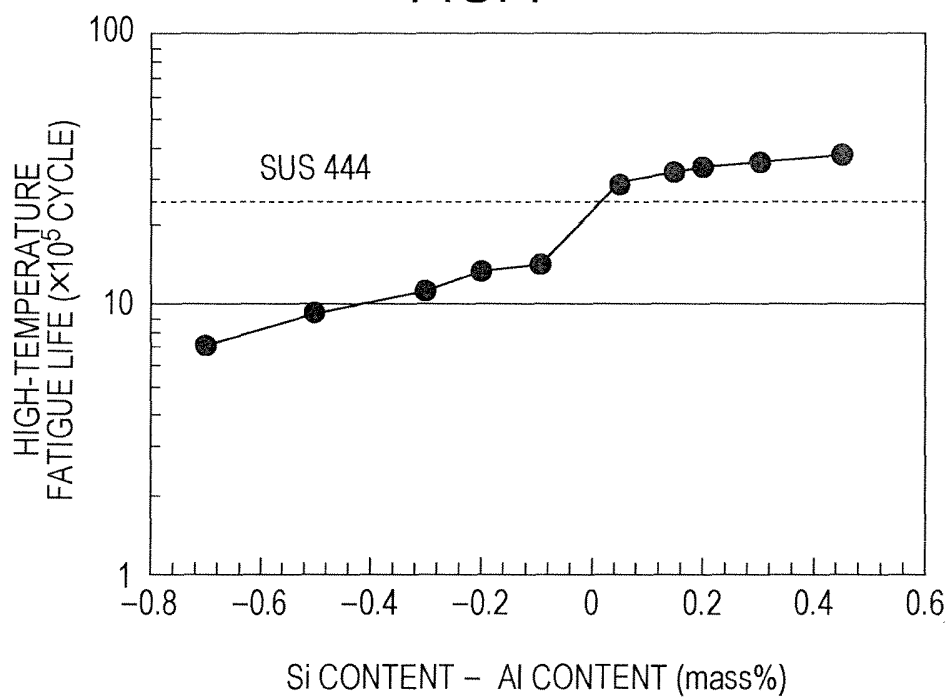


FIG. 8

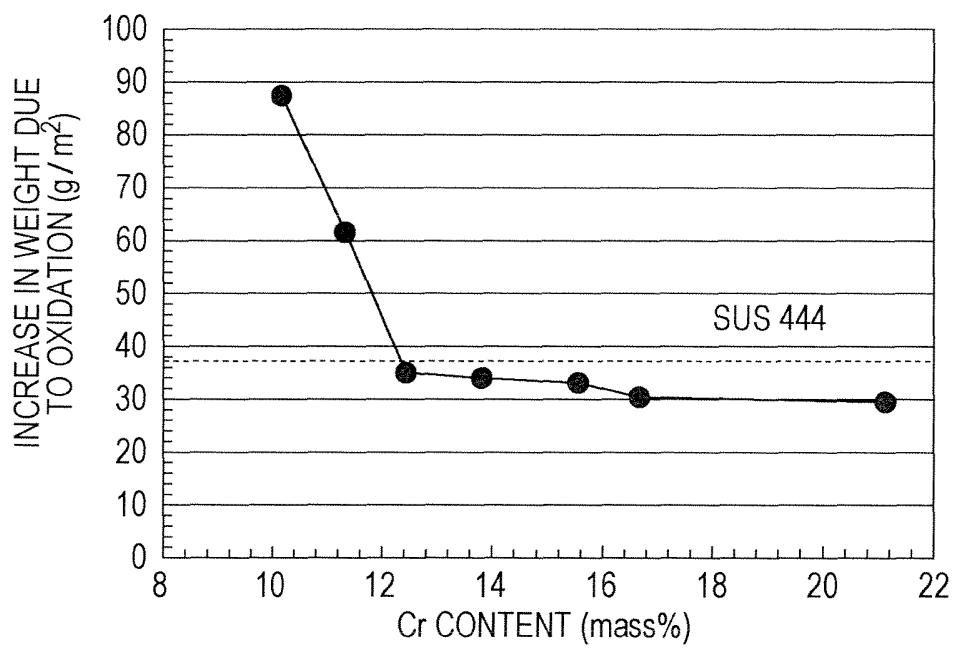
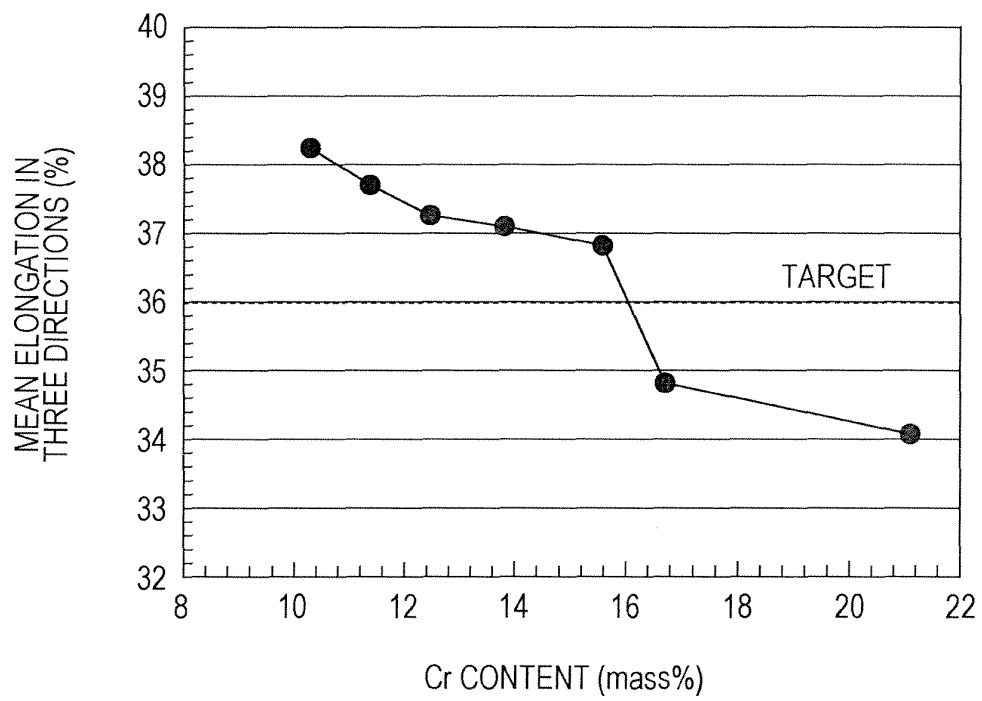


FIG. 9



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/073980

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00 (2006.01) i, C22C38/28 (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)

C22C38/00-38/60, C21D9/46

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2012
Kokai Jitsuyo Shinan Koho	1971-2012	Toroku Jitsuyo Shinan Koho	1994-2012

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2009/110640 A1 (JFE Steel Corp.), 11 September 2009 (11.09.2009), entire text; all drawings & JP 2009-235569 A & US 2011/0008200 A1 & EP 2166120 A1 & CN 101688280 A & KR 10-2010-0023009 A	1, 2
A	WO 2009/110641 A1 (JFE Steel Corp.), 11 September 2009 (11.09.2009), entire text; all drawings & JP 2009-235573 A & US 2011/0123387 A1 & EP 2264202 A1 & CN 101965415 A & KR 10-2010-0105800 A	1, 2

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

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
10 January, 2012 (10.01.12)Date of mailing of the international search report
24 January, 2012 (24.01.12)Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

Facsimile No.

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/073980

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2008/105134 A1 (Nippon Steel & Sumikin Stainless Steel Corp.), 04 September 2008 (04.09.2008), entire text; all drawings & JP 2008-240143 A & US 2009/0092513 A1 & EP 2058413 A1 & CN 101454471 A & KR 10-2009-0031858 A	1, 2
A	JP 2009-235555 A (Nippon Steel & Sumikin Stainless Steel Corp.), 15 October 2009 (15.10.2009), entire text (Family: none)	1, 2
A	JP 11-350081 A (Nippon Steel Corp.), 21 December 1999 (21.12.1999), entire text (Family: none)	1, 2

Form PCT/ISA/210 (continuation of second sheet) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 2004018921 A [0006]
- WO 2003004714 A [0006]
- JP 2006117985 A [0006]
- JP 2000297355 A [0006]