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(54) **TWO-PHASE STAINLESS STEEL AND PRODUCTION METHOD THEREFOR**

(57) A duplex stainless steel is provided that has a chemical composition comprising, by mass%, C: 0.03% or less, Si: 1.0% or less, Mn: 1.0% or less, P: 0.04% or less, S: 0.01% or less, Cu: 0.1 to 1.0%, Ni: 5.0 to 7.5%, Cr: 22.0 to 26.0%, W: 6.0 to 12.0%, N: 0.20 to 0.32%,

Mo: 0.01% or less, and a balance: Fe and impurities, in which a metal micro-structure contains, by area ratio, 0.40 to 0.60 of an α -phase, with a balance being a γ -phase and 0.01 or less of other phases.

EP 3 211 107 A1

Description

TECHNICAL FIELD

5 **[0001]** The present invention relates to a duplex stainless steel and a method for producing the same.

BACKGROUND ART

10 **[0002]** There is a need for a stainless steel that has excellent corrosion resistance for use in applications in which corrosion in a high-temperature and high-concentration chloride environment is a problem, such as in the chemical industry field.

15 **[0003]** A duplex stainless steel containing a large amount of Cr (first-generation duplex stainless steel: SUS 329J4L or the like) exhibits excellent corrosion resistance in comparison to conventional stainless steel as typified by SUS 304 or SUS 316L. However, in recent years, the environments in which stainless steel is used have become more severe, and it is no longer possible to exhibit satisfactory corrosion resistance using the traditional duplex stainless steels.

20 **[0004]** Patent Document 1, Patent Document 2 and Patent Document 3 disclose duplex stainless steels (second-generation duplex stainless steels) of which, as the increasing severity of usage environments increases, corrosion resistance is accordingly improved by utilizing Mo and N in accordance with pitting resistance equivalent (PRE, PREW) values represented by the following formula (1) and formula (2) that are known as indices that indicate the corrosion resistance of duplex stainless steel. However, even in the case of these second-generation duplex stainless steels, corrosion resistance is insufficient in a seawater environment.

$$25 \quad \text{PRE} = \text{Cr} + 3.3\text{Mo} + 16\text{N} \quad (1)$$

$$\text{PREW} = \text{Cr} + 3.3(\text{Mo} + 0.5\text{W}) + 16\text{N} \quad (2)$$

30 **[0005]** Patent Document 4, Patent Document 5, Patent Document 6, Non-Patent Document 1 and Non-Patent Document 2 disclose duplex stainless steels containing W (third-generation duplex stainless steels). The third-generation duplex stainless steels have excellent corrosion resistance to the traditional second-generation duplex stainless steels, and are widely used in seawater environments.

LIST OF PRIOR ART DOCUMENTS

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PATENT DOCUMENT

[0006]

- 40 Patent Document 1: JP62-180043A
 Patent Document 2: JP2-258956A
 Patent Document 3: JP5-132741A
 Patent Document 4: JP62-56556A
 Patent Document 5: JP5-132741A
 45 Patent Document 6: JP8-170153A

NON PATENT DOCUMENT

[0007]

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- Non-Patent Document 1: Anthony Comer, Lisa Looney, Corrosion and fatigue characteristics of positively polarised Zeron 100 base & weld metal in synthetic seawater, International Journal of Fatigue, Vol 28, 826-834.
 Non-Patent Document 2: Corrosion Center News, No. 059 (2012)

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SUMMARY OF INVENTION

TECHNICAL PROBLEM

5 **[0008]** Even in the case of third-generation duplex stainless steels, corrosion resistance is insufficient in a hot concentrated chloride environment that is more severe than seawater, such as in the chemical industry field.

[0009] An objective of the present invention is to provide a duplex stainless steel that, by improving the corrosion resistance of third-generation duplex stainless steel, can solve a problem of corrosion under a hot concentrated chloride environment such as in the chemical industry field, as well as a method for producing the duplex stainless steel.

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SOLUTION TO PROBLEM

[0010] Heretofore the influence of W on corrosion resistance and the action mechanism thereof have been considered to be the same as the mechanism of Mo. However, as a result of detailed studies conducted to examine the action mechanisms which contribute to corrosion resistance of Mo and W, the present inventors found that there is a mistake in the conventional findings with respect to the corrosion resistance under severe environments.

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[0011] Figure 1 illustrates polarization curves of pure W and pure Mo under a corrosive environment. As shown in Figure 1, even in a region in which Mo is eluted, almost no W is eluted. Thus, it is expected that the influences of Mo and W on improving corrosion resistance are significantly different.

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[0012] Therefore, detailed studies were performed on the corrosion resistance of duplex stainless steel for which the chemical composition of a third-generation duplex stainless steel was adopted as a basis and which contained a large amount of W but did not contain Mo. As a result, the following findings were obtained.

[0013]

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(a) By appropriately adjusting the chemical composition and production method to obtain an $\alpha+\gamma$ duplex micro-structure in which there is no precipitation of an σ -phase or a χ -phase, duplex stainless steel having excellent corrosion resistance under an environment in which hot concentrated chloride is present is obtained. The corrosion resistance at such time exceeds a corrosion resistance that is predicted from the relational expression of PREW.

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(b) By appropriately adjusting the chemical composition and production method, a passivation film that is formed under an environment in which hot concentrated chloride having a low pH is present can be made a passivation film that is rich in W. A passivation film that is rich in W dramatically improves corrosion resistance under the aforementioned environment.

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[0014] The present invention has been made based on the above findings, and the gist of the present invention is a duplex stainless steel and a production method therefor which are described hereunder.

[0015]

(1) A duplex stainless steel having a chemical composition comprising, by mass%,

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C: 0.03% or less,

Si: 1.0% or less,

Mn: 1.0% or less,

P: 0.04% or less,

S: 0.01% or less,

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Cu: 0.1 to 1.0%,

Ni: 5.0 to 7.5%,

Cr: 22.0 to 26.0%,

W: 6.0 to 12.0%,

N: 0.20 to 0.32%,

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Mo: 0.01% or less, and

balance: Fe and impurities, wherein,

a metal micro-structure contains, by area ratio, 0.40 to 0.60 of an α -phase, with the balance of a γ -phase and 0.01 or less of other phases.

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(2) The duplex stainless steel according to the above (1), wherein a pitting potential corresponding to $100 \mu\text{A}/\text{cm}^2$ when immersed in a 250 g/L NaCl aqueous solution that is held at 90°C is 600 mV (vs. SCE) or more.

(3) The duplex stainless steel according to the above (1) or (2), wherein a chemical composition of an outermost surface of a passivation film after immersion for 24 hours in a testing liquid having a pH of 1 satisfies formula (i) below:

$$W/(Fe+Cr) \geq 0.09 \quad \dots(i)$$

where, each symbol of an element in the above formula represents a content (at%) of each element in the outermost surface of the passivation film.

(4) A method for producing a duplex stainless steel, including, with respect to a steel having a chemical composition according to the above (1), performing a heat treatment of heating to a temperature range of 1150 to 1300°C, and after holding the steel in the temperature range, cooling at a cooling rate that is equal to or higher than a cooling rate of water cooling.

[0016] Note that, in the present invention, the term " α -phase" refers to a ferritic phase and the term " γ -phase" refers to an austenite phase.

ADVANTAGEOUS EFFECTS OF INVENTION

[0017] According to the present invention, a duplex stainless steel that has excellent corrosion resistance is obtained. The duplex stainless steel is suited for use in the chemical industry field and the like in which corrosion under a hot concentrated chloride environment is a problem.

BRIEF DESCRIPTION OF DRAWINGS

[0018]

[Figure 1] Figure 1 is a view illustrating polarization curves of pure W and pure Mo under a corrosive environment. [Figure 2] Figure 2 is a view illustrating the relation between a value for $W/(Fe+Cr)$ at an outermost surface of a passivation film and pitting potential according to an example.

DESCRIPTION OF EMBODIMENTS

[0019] An embodiment of the present invention is described hereunder. Hereinafter, the symbol "%" as used with respect to the content of respective elements refers to "mass%."

1. Chemical Composition of Base Metal

C: 0.03% or less

[0020] C is an austenite former and is effective for stabilizing an austenite phase. However, in stainless steel with a high Cr content such as in the present invention, if the C content exceeds 0.03%, there is a risk that Cr carbides will precipitate and corrosion resistance will deteriorate. Therefore, the C content is made 0.03% or less. Preferably, the C content is 0.01% or less. The above effect will be achieved if even a trace amount of C is contained, and hence the lower limit thereof is not particularly defined. However, to adequately achieve the above effect, a C content of 0.003% or more is preferable.

Si: 1.0% or less

[0021] Si is effective as a deoxidizing component of steel. However, if the Si content is excessive, there is a concern that the Si will promote precipitation of an σ -phase and a χ -phase. Therefore, the Si content is made 1.0% or less. Preferably, the Si content is 0.5% or less. Although the Si content may be substantially zero if deoxidation is to be performed with another element, it is preferable to contain 0.2% or more of Si to adequately achieve the above effect.

Mn: 1.0% or less

[0022] Mn is an austenite former and contributes to stabilization of an austenite. However, if the Mn content is excessive, there is a concern that MnS that acts as a corrosion starting point will crystallize or precipitate. Therefore, the Mn content is made 1.0% or less. Preferably the Mn content is 0.5% or less. The above effect will be achieved if even a trace amount of Mn is contained, and hence the lower limit thereof is not particularly defined. However, to adequately achieve the above effect, an Mn content of 0.1 % or more is preferable.

EP 3 211 107 A1

P: 0.04% or less

5 **[0023]** P is an impurity element that is unavoidable during the production process, and if the content thereof is excessive there is a risk that workability will be reduced. Therefore, the P content is made 0.04% or less. Preferably, the P content is 0.01% or less.

S: 0.01% or less

10 **[0024]** S is an impurity element that is unavoidable during the production process, and if the content thereof is excessive there is a risk that workability will be reduced. There is also a concern that MnS which acts as a corrosion starting point will crystallize or precipitate. Therefore, the S content is made 0.01% or less. Preferably, the S content is 0.004% or less.

Cu: 0.1 to 1.0%

15 **[0025]** Cu is an austenite former, and is effective for improving resistance to sulfuric acid. Cu is also effective for assisting the formation of a passivation film that contains a large amount of W. Specifically, Cu has an effect of promoting a cathode reaction, and accelerating the formation of a passivation film containing a large amount of W. Therefore, the content of Cu is made 0.1% or more. However, if the content of Cu is excessive, there is a concern that the excessive content may deteriorate formability. Accordingly, the Cu content is set in a range of 0.1 to 1.0%. A preferable lower limit is 0.4%, and a preferable upper limit is 0.6%.

Ni: 5.0 to 7.5%

25 **[0026]** Ni is an austenite former. In order to obtain an $\alpha+\gamma$ duplex micro-structure with a desirable balance with respect to the relation with ferrite forming elements such as Cr and W, an Ni content in the range of 5.0 to 7.5% is necessary. A preferable lower limit is 6.0%, and a preferable upper limit is 6.8%.

Cr: 22.0 to 26.0%

30 **[0027]** Cr is a ferrite forming element and is also a basic element that is effective for improving corrosion resistance. If the Cr content is insufficient or excessive, a temperature range in which an $\alpha+\gamma$ duplex micro-structure can be stably obtained narrows. Therefore, the Cr content is set in a range of 22.0 to 26.0%. A preferable lower limit is 23.0%, and a preferable upper limit is 25.5%.

35 W: 6.0 to 12.0%

40 **[0028]** W is a ferrite forming element and is also an important element for developing excellent corrosion resistance. If the W content is insufficient or is excessive, an $\alpha+\gamma$ duplex micro-structure cannot be stably obtained. Therefore, the W content is set as a value within a range of 6.0 to 12.0%. A preferable lower limit is 8.0%, and a preferable upper limit is 11.0%.

N: 0.20 to 0.32%

45 **[0029]** N is an austenite former, and is an effective element for improving thermal stability and corrosion resistance of a duplex stainless steel. To obtain an $\alpha+\gamma$ duplex micro-structure with a desirable balance with respect to a relation with ferrite forming elements such as Cr and W, an N content of 0.20% or more is necessary. However, if the N content exceeds 0.32%, there is a risk that the toughness and corrosion resistance of the steel will noticeably deteriorate due to the production of nitride. Therefore, the N content is set in a range of 0.20 to 0.32%. A preferable lower limit is 0.24%, and a preferable upper limit is 0.28%.

50 Mo: 0.01% or less

55 **[0030]** Mo is a ferrite forming element, similarly to Cr and W. However, when Mo is contained in the chemical composition, the Mo decreases the solubility of W, and hence it is necessary to make the Mo content as low as possible. Therefore, the Mo content is made 0.01% or less, and preferably is 0.008% or less.

[0031] The chemical composition of the duplex stainless steel of the present invention contains each of the aforementioned elements in the respectively defined ranges, with the balance of Fe and impurities. The term "impurities" refers to components that are contained in raw materials such as ore or scrap or that are mixed in due to other causes when

industrially producing the steel material.

2. Metal Micro-structure of Base Metal

5 **[0032]** The base metal has an $\alpha+\gamma$ duplex micro-structure in which the area ratio of the σ -phase is from 0.40 to 0.60 and the balance is the γ -phase as well as other phases for which the area ratio is 0.01 or less. In phases other than the σ -phase and γ -phase, particularly in an σ -phase and a χ -phase, a Cr depleted zone is formed around the phase, and consequently corrosion resistance is degraded. Therefore, although it is preferable that the total area ratio of those phases is zero, a total area ratio of 0.01 or less is permissible. Note that, since the corrosion resistance may be degraded if the proportion of the γ -phase is large, preferably the area ratio of the γ -phase is made 0.58 or less.

3. Passivation Film

15 **[0033]** If the duplex stainless steel having the aforementioned chemical composition and metal micro-structure is produced under appropriate conditions, a passivation film formed under an environment in which hot concentrated chloride having a low pH is present can be made a passivation film that is rich in W. Although Fe and Cr in a passivation film undergo corrosion in a low pH environment, a passivation film that contains a large amount of W that effectively contributes to corrosion resistance is excellent in corrosion resistance.

20 **[0034]** Further, in a case where the chemical composition of an outermost surface of the passivation film after immersion for 24 hours in a testing liquid having a pH of 1 satisfies the following formula (i), it is possible to dramatically improve the corrosion resistance of the duplex stainless steel. The left-hand value in the following formula (i) is more preferably set to 0.10% or more.

$$25 \quad W/(Fe+Cr) \geq 0.09 \quad \dots(i)$$

[0035] Where, each symbol of an element in the above formula represents a content (at%) of each element in the outermost surface of the passivation film.

30 4. Method for Producing Duplex Stainless Steel

[0036] The duplex stainless steel of the present invention is made into a product by melting under production conditions that are generally adopted, performing necessary processes such as hot working and cold working, and finally performing a heat treatment including heating in a temperature range of 1150 to 1300°C, and after holding the steel in this temperature range, cooling at a cooling rate that is equal to or higher than a cooling rate of water cooling.

35 **[0037]** This is because, if the aforementioned heat treatment temperature is less than 1150°C, precipitation of the σ -phase or χ -phase is inevitable, while on the other hand, if the aforementioned heat treatment temperature exceeds 1300°C, there is a risk that an $\alpha+\gamma$ duplex micro-structure in which the area ratio of the σ -phase is from 0.4 to 0.6 and the balance is substantially a γ -phase cannot be obtained. Therefore, the heat treatment is performed in a temperature range from 1150 to 1300°C. Although the holding time will vary depending on the thickness of the duplex stainless steel, the holding time may be appropriately selected within a range of 1 to 120 min.

40 **[0038]** If the cooling rate after the steel is held in the aforementioned temperature range is excessively slow there is a risk that an σ -phase or a χ -phase will precipitate during the cooling process, and therefore the steel is cooled at a cooling rate that is equal to or higher than the cooling rate of water cooling. More specifically, it is sufficient to perform cooling at a cooling rate of 40°C/s or more.

45 **[0039]** Hereunder, the present invention is described specifically by way of an example, although the present invention is not limited to the following example.

EXAMPLE 1

50 **[0040]** Ingots having the chemical compositions shown in Table 1 were melted in a 17-kg vacuum furnace, and then subjected to hot rolling to a thickness of 4 to 8 mm. Each of the steels was adjusted so that a pitting resistance equivalent PREW value defined by the following formula was around 43 to 44.

$$55 \quad PREW = Cr + 3.3(Mo+0.5W) + 16N$$

EP 3 211 107 A1

[0041] Where, each symbol of an element in the above formula represents a content (mass%) of the element in the steel.

[0042] Thereafter, after heating and holding at the temperatures shown in Table 1, the respective steels were subjected to water cooling and specimens were obtained. Commercially available stainless steels having the chemical compositions shown in Table 2 were also prepared as specimens. With respect to these specimens, observation of the metal micro-structure of the base metal, measurement of corrosion resistance, and component analysis of a passivation film were performed.

[Table 1]

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Table 1

Steel No.	Chemical composition (by mass%, balance: Fe and impurities)											PREW	Heat treatment temperature (°C)	Cooling rate (°C/s)
	C	Si	Mn	P	S	Cu	Ni	Cr	N	W	Mo			
1	0.003	0.26	0.48	<0.001	0.001	0.49	6.96	25.04	0.26	8.44	<0.01	43.0	1200	45
2	0.004	0.26	0.49	<0.001	0.001	0.49	6.96	25.07	0.26	8.46	<0.01	43.1	1200	43
3	0.003	0.27	0.49	<0.001	0.001	0.49	6.97	25.02	0.25	8.46	<0.01	43.2	1200	50
4	0.003	0.26	0.48	<0.001	0.001	0.49	6.96	25.04	0.26	8.44	<0.01	43.0	1150	49
5	0.004	0.26	0.49	<0.001	0.001	0.49	6.96	25.07	0.26	8.46	<0.01	43.1	1150	42
6	0.003	0.27	0.49	<0.001	0.001	0.49	6.97	25.02	0.25	8.46	<0.01	43.2	1150	44
7	0.003	0.26	0.48	<0.001	0.001	0.49	6.96	25.04	0.26	8.44	<0.01	43.0	1050 #	40
8	0.004	0.26	0.49	<0.001	0.001	0.49	6.96	25.07	0.26	8.46	<0.01	43.1	1050 #	42
9	0.003	0.27	0.49	<0.001	0.001	0.49	6.97	25.02	0.25	8.46	<0.01	43.2	1050 #	39
10	0.003	0.26	0.48	<0.001	0.001	0.49	6.96	25.04	0.26	8.44	<0.01	43.0	950 #	37
11	0.004	0.26	0.49	<0.001	0.001	0.49	6.96	25.07	0.26	8.46	<0.01	43.1	950 #	41
12	0.003	0.27	0.49	<0.001	0.001	0.49	6.97	25.02	0.25	8.46	<0.01	43.2	950 #	38
13	0.003	0.26	0.48	<0.001	0.001	0.49	6.96	25.04	0.26	8.44	<0.01	43.0	850 #	33
14	0.004	0.26	0.49	<0.001	0.001	0.49	6.96	25.07	0.26	8.46	<0.01	43.1	850 #	31
15	0.003	0.27	0.49	<0.001	0.001	0.49	6.97	25.02	0.25	8.46	<0.01	43.2	850 #	34
16	0.012	0.29	0.49	0.027	0.001	0.50	6.97	25.53	0.30	1.95*	3.21 *	44.1	1100 #	40
17	0.013	0.29	0.47	0.025	0.001	0.49	6.97	25.50	0.30	1.94*	3.23 *	44.1	1100 #	38
18	0.010	0.30	0.48	0.024	0.001	0.49	6.95	25.55	0.30	2.02*	3.22 *	44.2	1100 #	39
19	0.019	0.51	0.46	0.024	<0.001	0.44	6.69	25.15	0.26	2.07*	3.09 *	43.0	1100 #	39
20	0.015	0.49	0.49	0.025	<0.001	0.46	6.67	25.31	0.26	2.09*	3.08 *	43.1	1100 #	39
21	0.016	0.47	0.48	0.024	<0.001	0.50	6.70	25.30	0.26	2.06*	3.11 *	43.2	1100 #	39
22	0.003	0.26	0.48	<0.001	0.001	0.49	6.96	25.04	0.26	8.44	<0.01	43.0	1100 #	38
23	0.004	0.26	0.49	<0.001	0.001	0.49	6.96	25.07	0.26	8.46	<0.01	43.1	1100 #	39
24	0.003	0.27	0.49	<0.001	0.001	0.49	6.97	25.02	0.25	8.46	<0.01	43.2	1100 #	38

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(continued)

Steel No.	Chemical composition (by mass%, balance: Fe and impurities)										PREW	Heat treatment temperature (°C)	Cooling rate (°C/s)	
	C	Si	Mn	P	S	Cu	Ni	Cr	N	W				Mo
25	0.003	0.26	0.48	<0.001	0.001	<0.01 *	6.96	25.42	0.27	8.52	<0.01	43.8	1200	50
26	0.007	0.30	0.48	<0.001	<0.001	<0.01 *	6.89	25.13	0.26	8.58	<0.01	43.5		45
27	0.008	0.29	0.49	<0.001	0.001	<0.01 *	7.12	25.10	0.27	8.49	<0.01	43.4		45
28	0.003	0.26	0.48	<0.001	0.001	0.49	6.96	25.04	0.26	8.44	<0.01	43.0	1150	0.05 #
29	0.003	0.26	0.48	<0.001	0.001	<0.01 *	6.96	25.42	0.27	8.52	<0.01	43.8		0.1 #

* indicates that conditions do not satisfy those defined by the present invention.

indicates that production conditions do not satisfy the preferable conditions described in the present invention.

[Table 2]

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Table 2

Steel No.	Chemical composition (by mass%, balance: Fe and impurities)											PREW	Heat treatment temperature (°C)	Cooling rate (°C/s)
	C	Si	Mn	P	S	Cu	Ni	Cr	N	W	Mo			
30	0.019	0.40	0.75	0.025	0.001	<0.01 *	6.39	24.530	0.17	<0.01 *	3.22	37.9	1100 #	41
31	0.011	0.41	0.77	0.021	0.001	<0.01 *	6.34	24.550	0.17	<0.01 *	3.24	38.0		42
32	0.013	0.39	0.71	0.024	0.001	<0.01 *	6.45	24.810	0.19	<0.01 *	3.23	38.5		39

* indicates that conditions do not satisfy those defined by the present invention.

indicates that production conditions do not satisfy the preferable conditions described in the present invention.

EP 3 211 107 A1

<Observation of metal micro-structure of base metal>

[0043] A cross-section of each specimen was observed under an optical microscope at a magnification of 500, and the area ratios of the σ -phase and the γ -phase were measured. In addition, the presence/absence of an σ -phase and a χ -phase was verified, and steel in which there was no σ -phase or χ -phase precipitation was marked with "O", while steel in which precipitation of at least one of σ -phase and χ -phase was observed was marked with "x", and the total area ratios of these phases were measured.

<Measurement of corrosion resistance>

[0044] A disk-like test specimen having a diameter of 15 mm and a plate thickness of 2 mm was cut out from each specimen, and the surface was finished by #600 wet polishing. Testing was performed in accordance with JIS G 0577 (2014), and a pitting potential V_{C100} corresponding to $100 \mu A/cm^2$ was measured. Note that, since an environment in which hot concentrated chloride is present was assumed, a 250 g/L NaCl aqueous solution that was kept at 90°C was used as the aqueous solution.

<Component Analysis of Passivation Film>

[0045] Some of the specimens were immersed for 24 hours in a testing liquid having a pH of 1, and thereafter measurement of each main metal element in the passivation film was performed by X-ray photoelectron spectroscopy and a value of $W/(Fe+Cr)$ in the outermost surface of the passivation film was calculated.

[0046] The results of the above measurements are summarized in Table 3.

[Table 3]

Table 3

Test No.	Steel No.	Metal micro-structure				Left-hand value in formula (i)†	Petting potential (mV vs. SCE)	
		Ratio of σ -phase	Ratio of γ -phase	Presence/absence of σ , χ -phase	Total ratio of σ , χ -phase			
1	1	0.55	0.45	○	-	0.10	663	Inventive example
2	2	0.55	0.45	○	-	0.10	661	
3	3	0.52	0.48	○	-	0.10	701	
4	4	0.57	0.43	○	-	0.09	630	
5	5	0.46	0.54	○	-	0.10	685	
6	6	0.44	0.56	○	-	0.11	722	

EP 3 211 107 A1

(continued)

Test No.	Steel No.	Metal micro-structure				Left-hand value in formula (i)†	Petting potential (mV vs. SCE)	
		Ratio of σ -phase	Ratio of γ -phase	Presence/absence of σ , χ -phase	Total ratio of σ , χ -phase			
7	7	0.38 *	0.60	×	0.02 *	0.03	188	Comparative example
8	8	0.43	0.55	×	0.02 *	0.02	152	
9	9	0.35 *	0.63	×	0.02 *	0.03	218	
10	10	0.34 *	0.62	×	0.04 *	0.03	220	
11	11	0.29 *	0.66	×	0.05 *	0.03	238	
12	12	0.42	0.54	×	0.04 *	0.04	308	
13	13	0.38 *	0.55	×	0.07 *	0.01	-4	
14	14	0.37 *	0.56	×	0.07 *	0.01	12	
15	15	0.43	0.51	×	0.06 *	0.01	44	
16	16 *	0.48	0.52	○	-	0.07	416	
17	17 *	0.51	0.49	○	-	0.06	404	
18	18 *	0.48	0.52	○	-	0.06	433	
19	19 *	0.55	0.45	○	-	0.06	378	
20	20 *	0.52	0.48	○	-	0.06	404	
21	21 *	0.51	0.49	○	-	0.06	411	
22	22	0.34 *	0.66	○	-	0.08	574	
23	23	0.31 *	0.69	○	-	0.07	509	
24	24	0.33 *	0.65	×	0.02 *	0.03	294	
25	25 *	0.55	0.45	○	-	0.05	523	
26	26 *	0.50	0.50	○	-	0.05	526	
27	27 *	0.53	0.47	○	-	0.05	514	
28	28	0.56	0.33	×	0.11 *	0.01	-44	
29	29 *	0.57	0.30	×	0.13 *	0.01	-68	
30	30 *	0.68 *	0.32	○	-	-	219	
31	31 *	0.66 *	0.34	○	-	-	230	
32	32 *	0.66 *	0.34	○	-	-	248	

* indicates that conditions do not satisfy those defined by the present invention.
 † $W/(Fe+Cr) \geq 0.09 \dots (i)$

[0047] As shown in Table 3, in test Nos. 1 to 6 in which the chemical composition and metal micro-structure satisfied the specification of the present invention, the pitting potential was 600 mV or more and favorable corrosion resistance was exhibited.

[0048] In contrast, the results showed that the corrosion resistance was inferior in test Nos. 16 to 21, 25 to 27 and 29 to 32 in which at least the chemical composition deviated from the range specified by the present invention and in test Nos. 7 to 15, 22 to 24 and 28 in which at least the metal micro-structure deviated from the range specified by the present invention.

[0049] As shown in Figure 2, there is a constant correlation between the value of $W/(Fe+Cr)$ in the outermost surface of the passivation film and the pitting potential, and it is possible to make the pitting potential 600 mV or more when the

value for W/(Fe+Cr) is 0.09 or more.

INDUSTRIAL APPLICABILITY

5 **[0050]** According to the present invention, a duplex stainless steel having excellent corrosion resistance is obtained. The duplex stainless steel is suitable for use in the chemical industry field and the like in which corrosion under a hot concentrated chloride environment is a problem.

10 **Claims**

1. A duplex stainless steel having a chemical composition comprising, by mass%,
 C: 0.03% or less,
 Si: 1.0% or less,
 15 Mn: 1.0% or less,
 P: 0.04% or less,
 S: 0.01% or less,
 Cu: 0.1 to 1.0%,
 Ni: 5.0 to 7.5%,
 20 Cr: 22.0 to 26.0%,
 W: 6.0 to 12.0%,
 N: 0.20 to 0.32%,
 Mo: 0.01% or less, and
 balance: Fe and impurities, wherein,
 25 a metal micro-structure contains, by area ratio, 0.40 to 0.60 of an α -phase, with the balance of a γ -phase and 0.01 or less of other phases.
2. The duplex stainless steel according to claim 1, wherein a pitting potential corresponding to 100 $\mu\text{A}/\text{cm}^2$ when immersed in a 250 g/L NaCl aqueous solution that is held at 90°C is 600 mV (vs. SCE) or more.
- 30 3. The duplex stainless steel according to claim 1 or 2, wherein a chemical composition of an outermost surface of a passivation film after immersion for 24 hours in a testing liquid having a pH of 1 satisfies formula (i) below:

35
$$W/(Fe+Cr) \geq 0.09 \quad \dots(i)$$

where, each symbol of an element in the formula represents a content (at%) of each element in the outermost surface of the passivation film.

- 40 4. A method for producing a duplex stainless steel, including, with respect to a steel having a chemical composition according to claim 1, performing a heat treatment of heating to a temperature range of 1150 to 1300°C, and after holding the steel in the temperature range, cooling at a cooling rate that is equal to or higher than a cooling rate of water cooling.
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- 50
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FIGURE 1

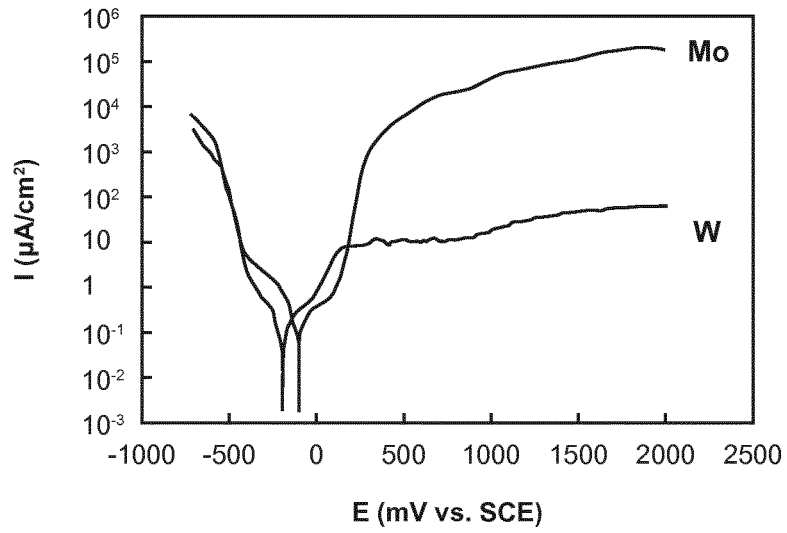
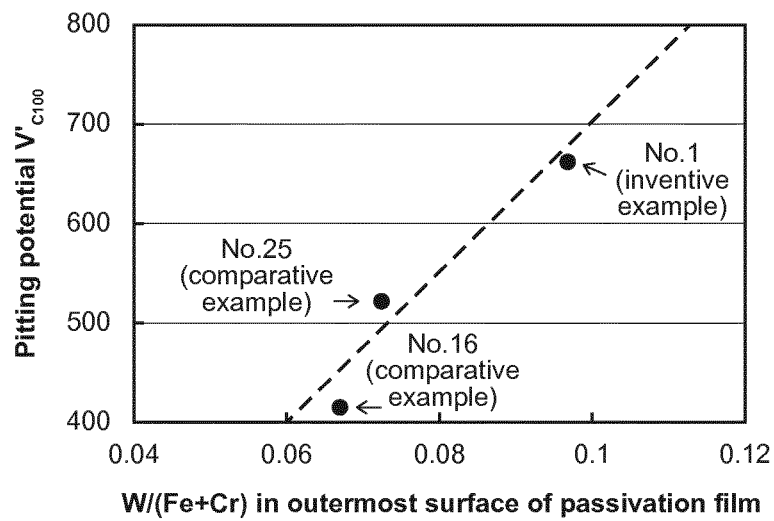


FIGURE 2



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/079962

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00(2006.01)i, C21D6/00(2006.01)i, C22C38/44(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/0000-38/60, C21D6/00

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	1996-2015
Kokai Jitsuyo Shinan Koho	1971-2015	Toroku Jitsuyo Shinan Koho	1994-2015

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

JSTPlus (JDreamIII)

C. 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 56-119721 A (Sumitomo Metal Industries, Ltd.), 19 September 1981 (19.09.1981), (Family: none)	1-4
A	JP 10-60598 A (NKK Corp.), 03 March 1998 (03.03.1998), (Family: none)	1-4

 Further documents are listed in the continuation of Box C.
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"&" document member of the same patent family

Date of the actual completion of the international search
14 December 2015 (14.12.15)Date of mailing of the international search report
22 December 2015 (22.12.15)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/079962

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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REFERENCES CITED IN THE DESCRIPTION

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