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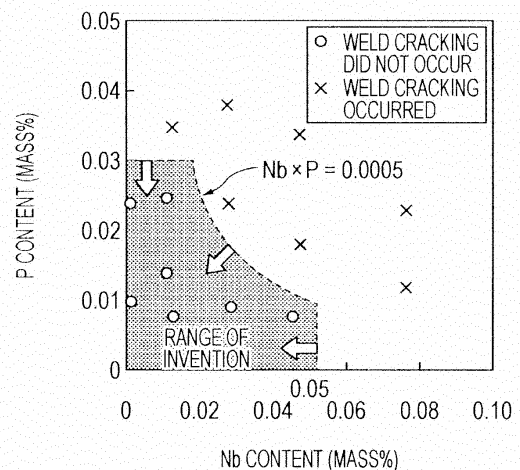
(54) **FERRITIC STAINLESS STEEL**

(57) Provided is ferritic stainless steel that realizes high corrosion resistance of a welded zone and that has high resistance to weld cracking. The ferritic stainless steel contains, by mass%, C: 0.001% to 0.030%, Si: 0.03% to 0.80%, Mn: 0.05% to 0.50%, P: 0.03% or less, S: 0.01% or less, Cr: 19.0% to 28.0%, Ni: 0.01% to less than 0.30%, Mo: 0.2% to 3.0%, Al: more than 0.15% to 1.2%, V: 0.02% to 0.50%, Cu: less than 0.1%, Ti: 0.05% to 0.50%, N: 0.001% to 0.030%, and Nb: less than 0.05%. Expression (1) is satisfied and the balance is Fe and inevitable impurities.

$$\text{Nb} \times \text{P} \leq 0.0005 \quad \dots (1)$$

In Expression (1), each element symbol represents the content (by mass%) of the element.

FIG. 1



Description

Technical Field

[0001] The present invention relates to ferritic stainless steel that is less likely to cause sensitization of a welded zone, that realizes high corrosion resistance of a temper color in a welded zone, and that is less likely to cause weld cracking in a welding bead formed by double welding, the ferritic stainless steel being used in applications where a structure is fabricated by welding, for example, automobile exhaust system materials such as muffler materials, hot-water storage tank materials for electric water heaters, or building materials such as fitting materials, ventilation opening materials, and duct materials.

Background Art

[0002] Ferritic stainless steel has various characteristics that are superior to those of austenitic stainless steel, such as high cost-performance in corrosion resistance, good heat thermal conductivity, a small coefficient of thermal expansion, and resistance to stress corrosion cracking. Therefore, ferritic stainless steel has been used in a variety of applications such as in the production of automobile exhaust system members, construction materials such as roof and fitting materials, and materials used in wet condition such as kitchen furniture, water tanks and hot water tanks.

[0003] In order to fabricate these structures, in many cases, a steel plate of stainless steel is cut and formed into an appropriate shape and subsequently jointing is performed by welding. However, when ferritic stainless steel is used, weld cracking may occur in a double-welded zone, such as a portion in which three plates are joined together or the beginning and end of circumferential welding, in which welding is performed again on a welding bead. As the shapes of welded members have become increasingly complicated, the above-described double-welded zone has increased and occurrence of weld cracking has become a problem.

[0004] The double-welded zone is not flat and welding is performed again on a portion on which scale is present. Therefore, oxygen, nitrogen, and the like are likely to be mixed into a welding bead, which degrades corrosion resistance. However, in the related art, there have been few findings with regard to these problems in double-welded zones.

[0005] Patent Literature 1 discloses ferritic stainless steel having high corrosion resistance and good weldability. This ferritic stainless steel realizes both corrosion resistance and ease of weld penetration due to Mg added in the ferritic stainless steel and an appropriately controlled S content. However, no mention is made of cracking in a double-welded zone or the corrosion resistance of a double-welded zone. In fact, when welding is performed using the ferritic stainless steel disclosed in Patent Literature 1, cracking occurs in a double-welded zone in some cases.

[0006] Patent Literature 2 discloses ferritic stainless steel having good weldability. However, although this ferritic stainless steel has improved ease of weld penetration and improved post-welding workability, no mention is made of potential problems in double-welded zones, such as weld cracking.

Citation List

Patent Literature

[0007]

PTL 1: Japanese Unexamined Patent Application Publication No. 8-246105

PTL 2: Japanese Unexamined Patent Application Publication No. 2009-91654

Summary of Invention

Technical Problem

[0008] In the light of the foregoing problems of the related art, an object of the present invention is to provide ferritic stainless steel that is less likely to cause sensitization of a welded zone, that realizes high corrosion resistance of a temper color in a welded zone, and that is less likely to cause weld cracking in a welding bead when double welding is performed.

Solution to Problem

[0009] In order to address the above-described problems, in the present invention, the influence of various elements on weld cracking occurring in double welding was extensively studied. Note that the term "double welding" herein refers

to the act of welding the same portion twice or more times, and the term "double-welded zone" herein refers to a portion and the periphery of the portion which has been repeatedly subjected to the process of melting and solidification twice or more due to double welding, such as a portion in which welding beads overlap each other at the beginning and end of welding when circumferential welding is performed or a portion in which welding beads overlap each other when welding is performed crosswise.

[0010] A portion in which weld cracking had occurred due to double welding was cut out and the fracture surface was observed with a SEM (scanning electron microscope). A film-like precipitation of Nb was observed on the fracture surface. For comparison, a portion in which weld cracking had not occurred was cut out and observed with a SEM. A film-like precipitate of Nb as was observed on the above-described fracture surface was not observed. It is considered that a film-like precipitation of Nb is responsible for the occurrence of weld cracking.

[0011] The influence of various elements on weld cracking in a double-welded zone was studied and, as a result, it was found that weld cracking does not occur in a steel having a low P content and a low Nb content. Cross welding was performed by bead-on-plate welding using various ferritic stainless steels, and presence or absence of weld cracks in a double-welded zone was examined using an optical microscope. Fig. 1 shows the results. In Fig. 1, a ferritic stainless steel in which weld cracks were absent is marked with a circle, and a ferritic stainless steel in which weld cracks were present is marked with a cross. It is shown that weld cracking did not occur in the range in which Nb is less than 0.05%, P is 0.03% or less, and $Nb \times P$ is 0.0005 or less.

[0012] It became clear that a reduction in the Nb content leads to suppression of weld cracking. However, because Nb is an element that is effective in suppressing sensitization of a welding bead, the reduction in the Nb content may disadvantageously increase the risk of the sensitization. In addition, since the surface of a double-welded zone is not flat and scale is formed on the surface of the double-welded zone, impurities are likely to be mixed into a welding bead. Thus, a double-welded zone is under disadvantageous welding conditions from the viewpoint of sensitization. Consequently, the influence of various elements on sensitization of a welding bead was examined. As a result, it became clear that, in addition to the reduction in Nb, addition of V and Al are also effective in suppressing sensitization of a welded zone. This is presumably because V and Al form VN and AlN, respectively, which suppress formation of a Cr nitride.

[0013] Furthermore, an oxide layer called "temper color" is formed on a welding bead and, as a result, deficiency of Cr occurs as in the case of sensitization, which degrades corrosion resistance. Therefore, the influence of various elements on the corrosion resistance of a temper color was evaluated. As a result, the following findings were obtained. When Si, Al, and Ti are concentrated at a temper color, a dense oxide layer having a good protection function is formed. In addition, the amount of oxidized Cr due to welding is reduced, which suppresses the deficiency of Cr due to oxidation. Thus, when the Si, Al, and Ti contents are set appropriately, the corrosion resistance of a welding bead is enhanced.

[0014] Further studies have been conducted on the basis of the above-described findings and, as a result, the present invention has been made. The summary of the present invention is described below.

[0015]

[1] Ferritic stainless steel containing, by mass%, C: 0.001% to 0.030%, Si: 0.03% to 0.80%, Mn: 0.05% to 0.50%, P: 0.03% or less, S: 0.01% or less, Cr: 19.0% to 28.0%, Ni: 0.01% to less than 0.30%, Mo: 0.2% to 3.0%, Al: more than 0.15% to 1.2%, V: 0.02% to 0.50%, Cu: less than 0.1%, Ti: 0.05% to 0.50%, N: 0.001% to 0.030%, and Nb: less than 0.05%,

wherein Expression (1) is satisfied and the balance is Fe and inevitable impurities,

$$Nb \times P \leq 0.0005 \quad \dots (1)$$

where each element symbol represents the content (% by mass%) of the element.

[2] The ferritic stainless steel described in [1] further containing, by mass%, one or more elements selected from Zr: 1.0% or less, W: 1.0% or less, REM: 0.1% or less, Co: 0.3% or less, and B: 0.1% or less.

Advantageous Effects of Invention

[0016] According to the present invention, ferritic stainless steel that is, when double welding is performed, less likely to cause sensitization of a welded zone, that realizes high corrosion resistance of a temper color in a welded zone, and that is less likely to cause weld cracking in a welding bead, is provided.

Brief Description of Drawings

[0017]

[Fig. 1] Fig. 1 is a diagram for explaining the effects of the Nb content and the P content on weld cracking in a double-welded zone.

[Fig. 2] Fig. 2 is a schematic diagram illustrating cross welding.

5 Description of Embodiments

[0018] The reasons for the limitations on constituent elements of the present invention are described below.

10 1. Composition

[0019] First, the reasons for the limitations on the composition of the steel according to the present invention are described. Note that, when referring to a composition, "%" always denotes "mass%".

C: 0.001% to 0.030%

[0020] C is an element that is inevitably contained in steel. A high C content increases the strength of steel. A low C content enhances the workability of steel. The C content of 0.001% or more is adequate to achieve a sufficient strength of steel. If the C content exceeds 0.030%, degradation of the workability of steel becomes significant and a Cr carbide is precipitated, which increases the risk of degradation of corrosion resistance due to the local deficiency of Cr. Thus, the C content is set to 0.001% to 0.030%, preferably set to 0.002% to 0.018%, and more preferably set to 0.002% to 0.010%.

Si: 0.03% to 0.80%

[0021] Si is an element that is useful for deoxidation. In the present invention, Si is an important element that concentrates at a temper color formed by welding together with Al and Ti, thereby enhances the protection function of an oxide layer, and thus improves the corrosion resistance of a welded zone. This effect is obtained when the content of Si added is 0.03%. However, if the content of Si exceeds 0.80%, degradation of the workability of steel becomes significant, which leads to difficulty in a forming process. Thus, the Si content is set to 0.03% to 0.80%, preferably set to more than 0.30% to 0.80%, and more preferably set to 0.33% to 0.50%.

Mn: 0.05% to 0.50%

[0022] Manganese is an element that is inevitably contained in steel and has an effect on increasing strength. This effect is obtained when the Mn content is 0.05% or more. However, if the content of Mn exceeds 0.50%, precipitation of MnS, which acts as an origin of corrosion, is increased, which degrades corrosion resistance. Therefore, the Mn content is set to 0.05% to 0.50% and preferably set to 0.08% to 0.40%.

P: 0.03% or less

[0023] Phosphorus is an element that is inevitably contained in steel. An excessively high P content degrades the weldability of steel and increases the risk of intergranular corrosion. In the present invention, it was found that an increase in the P content results in occurrence of weld cracking in a double-welded zone. An increase in the P content lowers the solidification temperature of ferritic stainless steel, and consequently an Nb carbonitride in the liquid phase is precipitated and forms a film-like shape. This inhibits flow of a molten pool in a solidification process and formation of crystal grains. Therefore, it is considered that weld cracking is likely to occur in a ferritic stainless steel having a high P content. It is considered that the risk of weld cracking increases particularly in double welding because the repetition of the process of melting and solidification causes further condensation of Nb and, as a result, Nb precipitation becomes likely to occur. If the P content exceeds 0.03%, the adverse effect of P on weld cracking becomes significant. Therefore, the P content is set to 0.03% or less and preferably set to 0.025% or less.

S: 0.01% or less

[0024] Sulfur is an element that is inevitably contained in steel. In the case that S content exceeds 0.01% corrosion resistance is degrade, because formation of water-soluble sulfides such as CaS and MnS is enhanced. Therefore, the S content is set to 0.01% or less, more preferably set to 0.006% or less, and further preferably set to 0.003% or less.

Cr: 19.0% to 28.0%

[0025] Cr is an element that is most important for maintain the corrosion resistance of stainless steel. If the content of Cr is less than 19.0%, sufficient corrosion resistance fails to be achieved at a welding bead or the periphery thereof at which the Cr content in the surface layer is reduced due to oxidation caused by welding. On the other hand, if the content of Cr exceeds 28.0%, the workability and manufacturability of steel are degraded. Therefore, the Cr content is set to 19.0% to 28.0%, preferably set to 21.0% to 26.0%, and more preferably set to 21.0% to 24.0%.

Ni: 0.01% to less than 0.30%

[0026] Ni is an element that enhances the corrosion resistance of stainless steel and that suppresses progress of corrosion in a corrosive environment in which a passive film is not able to be formed and active dissolution occurs. This effect is obtained when the content of Ni added is 0.01% or more. However, if the content of Ni added is 0.30% or more, the workability of steel is degraded and the cost is increased because Ni is an expensive element. Therefore, the Ni content is set to 0.01% to less than 0.30%, preferably set to 0.03% to 0.24%, and more preferably set to 0.03% to less than 0.15%.

Mo: 0.2% to 3.0%

[0027] Mo is an element that promotes repassivation of a passive film and enhances the corrosion resistance of stainless steel. The above-described effect becomes more significant when Mo is contained in steel together with Cr. Mo produces the effect of enhancing corrosion resistance when the content of Mo is 0.2% or more. However, if the Mo content exceeds 3.0%, the strength of steel is increased and the rolling load on the steel is increased accordingly, which leads to degradation of the manufacturability of steel. Therefore, the Mo content is set to 0.2% to 3.0%, preferably set to 0.6% to 2.4%, more preferably set to 0.6% to 2.0%, and further preferably set to 0.8% to 1.3%.

Al: more than 0.15% to 1.2%

[0028] Aluminum is an element effective for deoxidation. In the invention, Al improves the corrosion resistance of the weld by concentrating at a temper color formed by welding together with silicon and titanium.

[0029] In addition, Al has a stronger affinity for nitrogen than Cr and forms AlN. This inhibits formation of a Cr nitride. In this manner, this element also suppresses sensitization of a welding bead. This effect is obtained when the content of Al exceeds 0.15%. However, if the content of Al exceeds 1.2%, the diameter of ferrite crystal grains is increased, which degrades the workability and manufacturability of steel. Therefore, the Al content is set to more than 0.15% to 1.2% and preferably set to 0.17% to 0.8%.

V: 0.02% to 0.50%

[0030] V is an element that enhances corrosion resistance and the workability of steel and reduces the risk of weld cracking. This element combines to nitrogen to create VN and thereby suppresses sensitization of a welded zone. Although it is known that adding Nb and Ti in combination is effective to suppress sensitization of a welded zone, in the present invention, there is a need to reduce the Nb content in order to suppress weld cracking in a double-welded zone. However, if Ti is added to steel alone, a sufficient effect of suppressing sensitization may fail to be produced. Therefore, addition of V and Al as alternatives to Nb is effective to suppress the sensitization of a welded zone. This effect is obtained when the content of V is 0.02% or more. On the other hand, if the content of V exceeds 0.50%, the workability of steel is degraded. Thus, the V content is set to 0.02% to 0.50% and preferably set to 0.03% to 0.40%.

Cu: less than 0.1%

[0031] Cu is an impurity that is inevitably contained in steel. In the ferritic stainless steel having high corrosion resistance and having such a Cr content and a Mo content as in the present invention, Cu increases passivity maintaining current, thereby causing a passive film to be unstable, and, as a result, degrading corrosion resistance. The effect of degrading corrosion resistance becomes significant if the Cu content is 0.1% or more. Therefore, the Cu content is set to less than 0.1%.

Ti: 0.05% to 0.50%

[0032] Ti is an element that preferentially combines to C and N and thereby suppresses degradation of corrosion

resistance caused by precipitation of a Cr carbonitride. In the present invention, Ti is an element that is important to suppress sensitization of a welded zone. In addition, this element concentrates at a temper color of a welded zone in combination with Si and Al and thereby enhances the protection function of an oxide layer. This effect is obtained when the content of Ti is 0.05% or more. However, if the content of Ti exceeds 0.50%, the workability of steel is degraded and the size of a Ti carbonitride is increased, which causes surface defects. Therefore, the Ti content is set to 0.05% to 0.50%, preferably set to 0.08% to 0.38%, and more preferably set to 0.25% to 0.35%.

N: 0.001% to 0.030%

[0033] N is an element that is inevitably contained in steel and has an effect of increasing the strength of steel due to solid-solution strengthening similarly to C. This effect is obtained when the N content is 0.001% or more. However, if precipitation of a Cr nitride occurs, corrosion resistance is degraded. Thus, an appropriate N content is 0.030% or less. Therefore, the N content is set to 0.001% to 0.030%, preferably set to 0.002% to 0.018%, and more preferably set to 0.007% to 0.011%.

Nb: less than 0.05%

[0034] Generally, Nb is considered to be an element that preferentially combines to C and N and thereby suppresses degradation of corrosion resistance caused by precipitation of a Cr carbonitride. The element also precipitates in the form of a film in a double-welded zone and thereby causes weld cracking in the double-welded zone. Thus, the content of Nb is preferably set low. Significant weld cracking occurs if the content of Nb is 0.05% or more. Therefore, the Nb content is set to less than 0.05% and preferably set to less than 0.02%.

$\text{Nb} \times \text{P}$: 0.0005 or less

[0035] where each element symbol represents the content (by mass%) of the element.

[0036] Nb precipitates in the form of a film in a double-welded zone, which causes weld cracking to occur. The precipitation of Nb mainly depends on the product of the Nb content and the P content. As shown in Fig. 1, significant weld cracking occurs if $\text{Nb} \times \text{P}$ exceeds 0.0005. Therefore, $\text{Nb} \times \text{P}$ is set to 0.0005 or less.

[0037] Fundamental chemical composition according to the present invention is described above, and the balance is Fe and inevitable impurities. Furthermore, Zr, W, REM, Co, and B may be added to steel as optional elements in order to enhance corrosion resistance and the toughness of steel.

Zr: 1.0% or less

[0038] Zr combines to C and N and thereby produces an effect of suppressing sensitization. This effect is obtained when the content of Zr is 0.01% or more. However, an excessive addition of Zr degrades the workability of steel and leads to an increase in the cost because Zr is a very expensive element. Therefore, when Zr is added to steel, the Zr content is preferably set to 1.0% or less and more preferably set to 0.2% or less.

W: 1.0% or less

[0039] W has an effect of enhancing corrosion resistance similarly to Mo. This effect is obtained when the content of W is 0.01% or more. However, an excessive addition of W increases the strength of steel, which degrades the manufacturability of steel. Therefore, when W is added to steel, the W content is preferably set to 1.0% or less and more preferably set to 0.5% or less.

REM: 0.1% or less

[0040] A REM (rare-earth element) enhances oxidation resistance and thereby suppresses formation of oxidation scale. This suppresses formation of a Cr-depletion region immediately below a temper color of a welded zone. This effect is obtained when the content of REM is 0.001% or more. However, an excessive addition of REM degrades the manufacturability of steel, such as ease of acid-pickling, and leads to an increase in the cost. Therefore, when an REM is added to steel, the REM content is preferably set to 0.1% or less.

Co: 0.3% or less

[0041] Co is an element that enhances the toughness of steel. This effect is obtained when the content of Co is 0.001%

or more. However, an excessive addition of Co degrades the manufacturability of steel. Therefore, when Co is added to steel, the Co content is preferably set to 0.3% or less and more preferably set to 0.1% or less.

B: 0.1% or less

[0042] B is an element that improves resistance to secondary working embrittlement. The B content of 0.0001% or more is appropriate in order to obtain the effect. However, an excessively high B content causes degradation of ductility due to solid-solution strengthening. Therefore, when B is contained in steel, the B content is preferably set to 0.1% or less and is more preferably set to 0.01% or less.

2. Manufacturing Conditions

[0043] Next, a preferred method for manufacturing the steel according to the present invention is described. Steel having the above-described composition is produced by melting by a known method using a converter furnace, an electric furnace, a vacuum melting furnace, or the like and formed into a steel raw material (slab) by continuous casting or ingot casting-slabbing. Subsequently, the steel raw material is heated to 1100°C to 1300°C and then hot-rolled at a finishing temperature of 700°C to 1000°C and a coiling temperature of 500°C to 850°C. Thus, a steel strip having a thickness of 2.0 to 5.0 mm is prepared. The hot-rolled strip thus prepared is annealed at 800°C to 1200°C, subjected to acid pickling, and then cold-rolled. The cold-rolled sheet is annealed at 700°C to 1000°C. After being annealed, the cold-rolled sheet is subjected to acid pickling to remove scale. Optionally, the cold-rolled steel strip, from which scale has been removed, may be subjected to skin pass rolling.

Example 1

[0044] Hereafter, the present invention is described on the basis of Examples.

[0045] The stainless steels shown in Table 1 were prepared by melting in vacuum and then heated to 1200°C. Subsequently, the stainless steels were hot-rolled to a thickness of 4 mm, annealed at 800°C to 1000°C, and then subjected to acid pickling to remove scale. The resulting stainless steels were cold-rolled to a thickness of 0.8 mm, annealed at 800°C to 1000°C, and subjected to acid pickling. Thus, test materials were prepared.

[0046] [Table 1]

[Table 1] Chemical compositions of test materials (mass%)

No	C	Si	Mn	P	S	Cr	Ni	Mo	Al	V	Nb	Ti	N	Cu	Other elements	Nb×P	Remark
1	0.005	0.36	0.15	0.027	0.001	22.5	0.11	1.08	0.27	0.10	0.011	0.32	0.009	-		0.00030	Invention example
2	0.008	0.38	0.14	0.021	0.001	21.0	0.09	1.08	0.27	0.10	0.001	0.32	0.009	0.01		0.00002	Invention example
3	0.006	0.38	0.15	0.012	0.001	21.0	0.10	1.07	0.27	0.10	0.040	0.35	0.010	0.01		0.00048	Invention example
4	0.008	0.33	0.14	0.011	0.002	23.6	0.09	1.08	0.26	0.21	0.010	0.28	0.011	-		0.00011	Invention example
5	0.008	0.67	0.14	0.018	0.001	23.6	0.10	1.07	0.26	0.19	0.001	0.28	0.010	-		0.00002	Invention example
6	0.007	0.34	0.14	0.020	0.001	23.7	0.10	0.79	0.18	0.19	0.002	0.28	0.010	-		0.00004	Invention example
7	0.008	0.33	0.15	0.022	0.001	23.8	0.10	0.82	0.77	0.19	0.001	0.29	0.010	-		0.00002	Invention example
8	0.006	0.34	0.15	0.022	0.001	23.7	0.11	0.84	0.50	0.05	0.001	0.39	0.011	-		0.00002	Invention example
9	0.005	0.34	0.15	0.020	0.001	23.7	0.09	0.84	0.49	0.29	0.018	0.18	0.009	-		0.00036	Invention example
10	0.005	0.33	0.16	0.019	0.001	23.7	0.09	0.83	0.50	0.42	0.019	0.18	0.008	-		0.00036	Invention example
11	0.005	0.37	0.16	0.020	0.001	21.9	0.08	1.31	0.50	0.12	0.001	0.47	0.009	-		0.00002	Invention example
12	0.006	0.37	0.21	0.028	0.001	21.9	0.08	1.32	0.32	0.12	0.012	0.27	0.009	0.02	Zr:0.04, W:0.2	0.00034	Invention example
13	0.007	0.42	0.21	0.025	0.001	21.8	0.08	1.32	0.32	0.11	0.001	0.27	0.008	-	Zr:0.02, REM:0.02	0.00003	Invention example
14	0.007	0.44	0.21	0.026	0.001	21.9	0.11	1.32	0.17	0.11	0.001	0.32	0.008	0.06	Co:0.04	0.00003	Invention example
15	0.008	0.44	0.20	0.025	0.001	21.8	0.10	1.32	0.17	0.11	0.001	0.31	0.010	0.01	W:0.1, REM:0.001, B:0.0005	0.00003	Invention example
16	0.008	0.42	0.15	0.029	0.002	22.1	0.10	1.05	0.18	0.15	0.243	0.23	0.012	-		0.00705	Comparative example
18	0.008	0.35	0.14	0.022	0.001	22.3	0.09	1.04	0.09	0.14	0.001	0.19	0.010	0.6		0.00002	Comparative example
19	0.007	0.35	0.13	0.023	0.001	22.3	0.09	1.05	0.31	0.01	0.001	0.19	0.009	-		0.00002	Comparative example
20	0.007	0.36	0.13	0.063	0.001	22.1	0.09	1.05	0.31	0.15	0.002	0.32	0.009	-		0.00013	Comparative example
21	0.007	0.36	0.13	0.028	0.001	22.1	0.09	1.05	0.31	0.15	0.030	0.29	0.009	-		0.00084	Comparative example
22	0.004	0.09	0.32	0.016	0.001	24.7	0.10	1.01	0.23	0.07	0.008	0.28	0.007	-	B:0.0005	0.00013	Invention example
23	0.008	0.18	0.29	0.017	0.001	25.0	0.09	1.01	0.22	0.07	0.010	0.25	0.010	-		0.00017	Invention example
Underlined portions are out of the range of the Invention																	

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[0047] Cross welding as shown in Fig. 2 was performed on the prepared test materials by bead-on-plate TIG welding at a welding current of 90 A and a welding speed of 60 cm/min. The shielding gas used was 100% Ar gas both on the face side (torch side) and on the back side. The flow rate was set to 15 L/min on the face side and 10 L/min on the back side. The width of a welding bead on the face side was approximately 4 mm.

[0048] Presence or absence of weld cracks in double-welded zones of the prepared welding beads was examined using an optical microscope. Table 2 shows the results.

[0049] [Table 2]

[Table 2] Evaluation results of properties of test materials

No	Presence or absence of weld cracks	Pitting potential Vc'100 at welding bead	Presence or absence of corrosion determined by neutral salt spray cyclic corrosion test	Remark
		mV vs SCE		
1	Absent	22	Absent	Invention example
2	Absent	24	Absent	Invention example
3	Absent	27	Absent	Invention example
4	Absent	14	Absent	Invention example
5	Absent	38	Absent	Invention example
6	Absent	12	Absent	Invention example
7	Absent	52	Absent	Invention example
8	Absent	41	Absent	Invention example
9	Absent	28	Absent	Invention example
10	Absent	28	Absent	Invention example
11	Absent	49	Absent	Invention example
12	Absent	23	Absent	Invention example
13	Absent	28	Absent	Invention example
14	Absent	22	Absent	Invention example
15	Absent	21	Absent	Invention example
16	Present	-	Present	Comparative example
18	Absent	-197	Present	Comparative example
19	Absent	-202	Present	Comparative example

(continued)

No	Presence or absence of weld cracks	Pitting potential $V_{c'100}$ at welding bead	Presence or absence of corrosion determined by neutral salt spray cyclic corrosion test	Remark
		mV vs SCE		
20	Present	-	Present	Comparative example
21	Present	-	Present	Comparative example
22	Absent	13	Absent	Invention example
23	Absent	32	Absent	Invention example

[0050] Weld cracking did not occur in Test material Nos. 1 to 15, 22, and 23, which are Invention examples. However, among Test material Nos. 16 and 18 to 21, which are Comparative examples, weld cracks were present in Test material No. 16 in which the Nb content and $Nb \times P$ were out of the range of the invention, Test material No. 20 in which the P content was out of the range of the invention, and Test material No. 21 in which $Nb \times P$ was out of the range of the invention. Weld-cracked portions of these test materials were cut out and their fracture surfaces were observed with a SEM. A film-like precipitation of Nb was observed in each sample.

[0051] A 20-mm square test piece including a double-welded zone of the prepared welding bead was taken from each test material except for Test material Nos. 16, 20, and 21 in which weld cracks were present. Each test piece was covered with a seal material so that a 10-mm square plane to be measured is not covered with the seal material. The pitting potential of each test piece was measured in a 3.5-mass% aqueous NaCl solution at 30°C without removing a temper color formed by welding from the test piece. The test pieces were not subjected to polishing or a passivation treatment. Steps of the measurement method other than those described above adhered to JIS G 0577 (2005). Table 2 shows the measured pitting potentials $V_{c'100}$. In Test materials Nos. 1 to 15, 22, and 23, which are Invention examples, $V_{c'100}$ was 0 mV vs SCE or more. On the other hand, in Test materials Nos. 18 and 19, which are Comparative examples, $V_{c'100}$ was less than 0 mV vs SCE. Thus, it was confirmed that high corrosion resistance was achieved in Invention examples.

[0052] A 40×40-mm test piece including a double-welded zone of the welding bead was taken from each of Test material Nos. 1 to 23 shown in Table 1. A neutral salt spray cyclic corrosion test according to JIS H 8502 (1999) was conducted using the face side of the test piece as a plane to be examined. The number of cycles was set to three. After the test was finished, presence or absence of the corrosion of the welding bead was visually examined. Table 2 shows the results. In Test materials Nos. 1 to 15, 22, and 23, which are Invention examples, corrosion was absent. On the other hand, in Test materials Nos. 16 and 18 to 21, which are Comparative examples, corrosion was present. Thus, it was confirmed that the welding beads of Invention examples had high corrosion resistance.

Industrial Applicability

[0053] The ferritic stainless steel according to the present invention is suitably used in applications where a structure is fabricated by welding, for example, automobile exhaust system materials such as muffler materials, hot-water storage tank materials for electric water heaters, or building materials such as fitting materials, ventilation opening materials, and duct materials.

Claims

1. Ferritic stainless steel containing, by mass%, C: 0.001% to 0.030%, Si: 0.03% to 0.80%, Mn: 0.05% to 0.50%, P: 0.03% or less, S: 0.01% or less, Cr: 19.0% to 28.0%, Ni: 0.01% to less than 0.30%, Mo: 0.2% to 3.0%, Al: more than 0.15% to 1.2%, V: 0.02% to 0.50%, Cu: less than 0.1%, Ti: 0.05% to 0.50%, N: 0.001% to 0.030%, and Nb: less than 0.05%,
wherein Expression (1) is satisfied and the balance is Fe and inevitable impurities,

$$Nb \times P \leq 0.0005 \dots (1)$$

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where each element symbol represents the content (by mass%) of the element.

2. The ferritic stainless steel according to Claim 1 or 2 further containing, by mass%, one or more elements selected from Zr: 1.0% or less, W: 1.0% or less, REM: 0.1% or less, Co: 0.3% or less, and B: 0.1% or less.

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FIG. 1

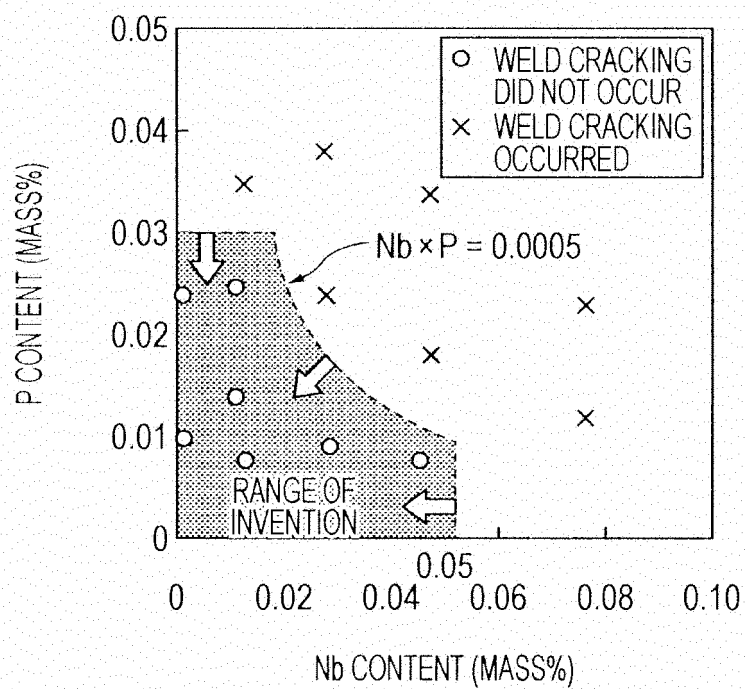
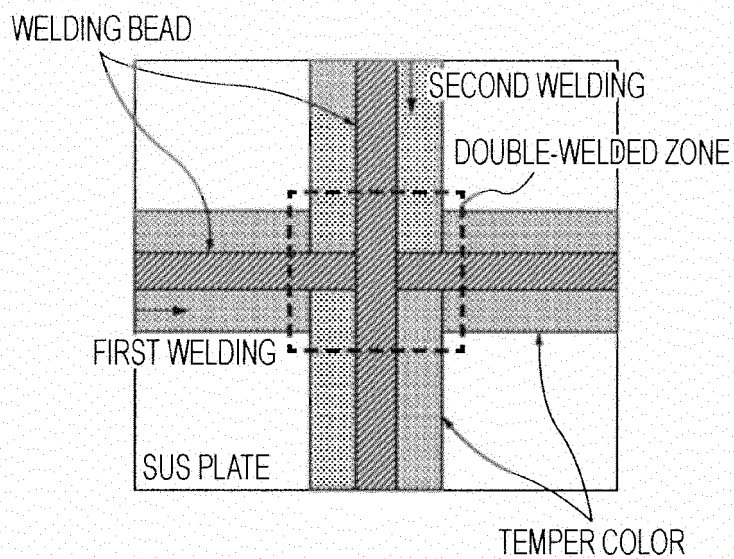


FIG. 2



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/007972

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00(2006.01) i, C21D9/46(2006.01) i, C22C38/50(2006.01) i, C22C38/54(2006.01) i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/00-38/60, C21D9/46-9/48

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	1996-2013
Kokai Jitsuyo Shinan Koho	1971-2013	Toroku Jitsuyo Shinan Koho	1994-2013

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2011-190524 A (Nisshin Steel Co., Ltd.),	2
A	29 September 2011 (29.09.2011), table 1, A12; paragraph [0028] (Family: none)	1
A	JP 2008-38183 A (Nippon Steel & Sumikin Stainless Steel Corp.), 21 February 2008 (21.02.2008), table 1 & US 2010/0150770 A1 & WO 2007/129703 A1 & CA 2650469 A1 & KR 10-2008-0110662 A & CN 101437974 A	1, 2

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

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Date of the actual completion of the international search
09 January, 2013 (09.01.13)Date of mailing of the international search report
22 January, 2013 (22.01.13)Name and mailing address of the ISA/
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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/007972

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2007-77496 A (JFE Steel Corp.), 29 March 2007 (29.03.2007), table 1 & US 2009/0056838 A1 & EP 1918399 A1 & WO 2007/020826 A1 & KR 10-2007-0108559 A & CN 101151389 A	1, 2
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A	K.E.PINNOW et al., A New High-Chromium Ferritic Stainless Steel, METALS ENGINEERING QUARTERLY, Vol.15 No.3, 1975, Page.32-41	1, 2

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REFERENCES CITED IN THE DESCRIPTION

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- JP 2009091654 A [0007]