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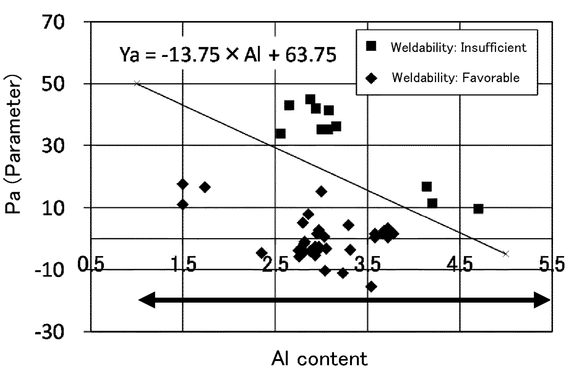
(54) **STEEL PRODUCT USED IN CONTACT WITH STEEL MATERIAL**

(57) The present invention provides a steel product that has excellent oxidation resistance on a surface thereof that is to come into contact with a steel material and that also has excellent weldability. The steel product for use in contact with a steel material according to the present invention is a steel product for use in contact with a steel material, the steel product including a centrifugally-cast portion formed on a surface of the steel product that is to come into contact with the steel material, the centrifugally-cast portion being made through centrifugal casting, and a statically-cast portion to which the centrifugally-cast portion is welded, the statically-cast portion being formed through static casting, the centrifugally-cast portion containing, in terms of mass%, C: 0.2% to 0.7%; Si: more than 0% and 2.0% or less; Mn: more than 0% and 3.0% or less; Cr: 15.0% to 40.0%; Ni: 18.0% to 55.0%; Al: 1.0% to 5.5%; and at least one type selected from the group consisting of Ti: 0.01% to 0.6% and/or Nb: 0.1% to 1.8%, the balance being composed of Fe and inevitable impurities.

FIG.1



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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to steel products, such as hearth rolls and coiler drums, for use in contact with steel materials such as slabs, blooms, and billets, as well as steel sheets and plates.

2. Description of Related Art

[0002] Steel products, such as a hearth roll that conveys a steel sheet or strip in a coil in an annealing furnace in which the steel sheet or strip in a coil is subjected to continuous heat treatment and a coiler drum around which a steel sheet or plate is wound during rolling within a high-temperature furnace, are employed in steelmaking plants and the like.
[0003] Such steel products are used in direct contact with steel materials such as slabs, blooms, and billets, as well as steel sheets and plates under high-temperature atmospheric environments, and thus, metals in the base material are oxidized and a Cr oxide mainly composed of Cr (and also containing Fe and Ni) is formed on the surface thereof. A Cr oxide is likely to exfoliate as a result of coming into contact with the steel material, and the exfoliation may result in damage to the steel material. Moreover, due to the exfoliation of the Cr oxide, or polishing or the like that is performed in order to remove the Cr oxide so as to suppress the exfoliation, reduction in the thickness of the steel product itself may be accelerated.
[0004] To address these issues, a product has also been proposed in which a thermal sprayed layer is formed on the outer circumference of a hearth roll by thermal spraying a CoCrAlY alloy or the like (see Patent Document 1: JP 2008-240072A, for example).

CITATION LIST

Patent Document

[0005] [Patent Document 1] JP 2008-240072
[0006] However, since a thermal sprayed layer also oxidizes, there is a risk that an oxide film formed on the thermal sprayed layer will exfoliate, resulting in a deterioration in oxidation resistance, and also the exfoliated oxide film will damage the steel material. Furthermore, since a large amount of Al (about 10 mass%) is added in the thermal sprayed layer, there is a risk that mechanical properties, such as tensile ductility, of the thermal sprayed layer will deteriorate, and furthermore, the weldability will deteriorate.

SUMMARY OF THE INVENTION

[0007] An object of the present invention is to provide a steel product that has excellent oxidation resistance on a surface thereof that is to come into contact with a steel material and that also has excellent weldability.
[0008] A steel product for use in contact with a steel material according to an aspect of the present invention is a steel product for use in contact with a steel material, the steel product including:

a centrifugally-cast portion formed on a surface of the steel product that is to come into contact with the steel material, the centrifugally-cast portion being made through centrifugal casting; and
a statically-cast portion to which the centrifugally-cast portion is welded, the statically-cast portion being formed through static casting,
the centrifugally-cast portion containing, in terms of mass%:

C: 0.2% to 0.7%;
Si: more than 0% and 2.0% or less;
Mn: more than 0% and 3.0% or less;
Cr: 15.0% to 40.0%;
Ni: 18.0% to 55.0%;
Al: 1.0% to 5.5%; and
at least one type selected from the group consisting of Ti: 0.01% to 0.6% and/or Nb: 0.1% to 1.8%,
the balance being composed of Fe and inevitable impurities.

[0009] It is possible that the centrifugally-cast portion further contains, in terms of mass%, rare earth elements (REMs): more than 0% and 0.4% or less.

[0010] It is possible that the centrifugally-cast portion further contains, in terms of mass%:

W: more than 0% and 5.0% or less; and/or
Mo: more than 0% and 2.0% or less.

[0011] It is desirable that the centrifugally-cast portion satisfies Pa<Ya, where

$$Pa = -11.1+28.1\times C+29.2\times Si-0.25\times Ni-45.6\times Ti+18.0\times REMs-16.6\times Nb,$$

and

$$Ya = -13.75\times Al+63.75.$$

[0012] It is desirable that the statically-cast portion does not contain Al.

[0013] It is possible that the steel product further has a ceramic thermal sprayed layer on the surface of the centrifugally-cast portion.

[0014] It is possible that the steel product is a hearth roll or a coiler drum.

[0015] According to the present invention, since the centrifugally-cast portion formed in the steel product has the above-described composition, Al forms an Al oxide with priority over Cr, and the formation of a Cr oxide can be suppressed and problems such as the exfoliation of the Cr oxide can be suppressed. Moreover, since the amount of Al added is as small as 1.0% to 5.5%, a deterioration in mechanical properties can be suppressed.

[0016] Moreover, since the amount of Al added to the centrifugally-cast portion is small, weldability thereof can also be ensured, and thus, the centrifugally-cast portion can be suitably welded to the statically-cast portion.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017]

FIG. 1 is a graph showing the results of regression analysis of tested centrifugally-cast portions based on weldability, where the vertical axis represents a Pa value and the horizontal axis represents an Al content; and
FIG. 2 is criteria for judging the beads that were formed using the method A and the method B.

DETAILED DESCRIPTION OF THE INVENTION

[0018] Hereinafter, an embodiment of the present invention will be described in detail. Note that, in the following description, "%" means mass% unless otherwise specified.

[0019] A steel product according to the present invention is suitably applied to a product, such as a hearth roll or a coiler drum, for use in direct contact with a steel material, such as a slab, a bloom, or a billet, or a steel sheet or plate, under a high-temperature atmospheric environment.

[0020] The steel product has a centrifugally-cast portion that contains:

C: 0.2% to 0.7%;
Si: more than 0% and 2.0% or less;
Mn: more than 0% and 3.0% or less;
Cr: 15.0% to 40.0%;
Ni: 18.0% to 55.0%;
Al: 1.0% to 5.5%; and
at least one type selected from the group consisting of Ti: 0.01% to 0.6% and/or Nb: 0.1% to 1.8%,
the balance being composed of Fe and inevitable impurities.

[0021] The centrifugally-cast portion can be made through centrifugal casting, and the reasons for the limitation on components will be described below.

C: 0.2% to 0.7%

[0022] C has the effect of imparting favorable castability and increasing high-temperature creep rupture strength. Also, C combines with Ti, Nb, Cr, or the like to form a carbide and has the effect of increasing high-temperature strength. Therefore, C is contained in an amount of at least 0.2%. However, if the C content is excessively high, a primary carbide Cr_7C_3 is likely to be widely formed. Then, the transfer of Al to the surface of the centrifugally-cast portion is inhibited, resulting in a shortage of Al, and thus, formation of an Al oxide such as Al_2O_3 is suppressed. Moreover, excessive secondary carbide precipitation occurs, and this leads to a deterioration in ductility and toughness. Therefore, the upper limit of the C content is 0.7%. Note that it is more desirable that the lower limit of the C content is 0.35% or more and the upper limit of the C content is 0.6% or less.

Si: more than 0% and 2.0% or less

[0023] Si is contained as a deoxidizer for a molten metal alloy and also for the purpose of increasing the fluidity of molten metal alloy and improving oxidation resistance. However, the addition of an excessively large amount of Si leads to a deterioration in ductility, a deterioration in high-temperature creep rupture strength, a deterioration in surface quality after casting, and a deterioration in weldability. Therefore, the upper limit of the Si content is 2.0%. Note that the Si content is desirably 1.5% or less and more desirably 1.0% or less.

Mn: more than 0% and 3.0% or less

[0024] Mn is contained so as to serve as a deoxidizer for a molten metal alloy and also improve weldability by fixing S in the molten alloy and improve ductility. However, the addition of an excessively large amount of Mn leads to a deterioration in high-temperature creep rupture strength and a deterioration in oxidation resistance. Therefore, the upper limit of the Mn content is 3.0%. Note that it is more desirable that the Mn content is 1.0% or less.

Cr: 15.0% to 40.0%

[0025] Cr contributes to an improvement in high-temperature strength and cyclic oxidation resistance. Also, Cr exhibits excellent heat resistance together with Ni and Fe in a high-temperature range exceeding 1000°C, and generates a primary carbide with C and N and improves high-temperature creep rupture strength. Moreover, Cr forms an oxide layer together with Al, and imparts excellent characteristics in terms of oxidation resistance and corrosion resistance to the centrifugally-cast portion. Therefore, Cr is contained in an amount of at least 15.0% or more. On the other hand, excessive generation of a Cr carbide and a Cr nitride leads to a deterioration in ductility, and therefore the upper limit of the Cr content is 40.0%. Note that it is more desirable that the lower limit of the Cr content is 22.0% or more and the upper limit of the Cr content is 35.0% or less.

Ni: 18.0% to 55.0%

[0026] Ni is an element that is necessary to ensure cyclic oxidation resistance and metallographic stability, ensure high-temperature creep strength, and stabilize the austenitization of the centrifugally-cast portion. Moreover, Ni contributes to an improvement in high-temperature strength and oxidation resistance together with Cr. Furthermore, if the Ni content is low, the Fe content becomes relatively high, which inhibits the generation of an Al oxide. Therefore, Ni is contained in an amount of at least 18.0% or more. On the other hand, even if an excessively large amount of Ni is added, its effects become saturated, and also this is economically disadvantageous. Therefore, the upper limit of the Ni content is 55.0%. Note that it is more desirable that the lower limit of the Ni content is 29.0% or more and the upper limit of the Ni content is 46.0% or less.

Al: 1.0% to 5.5%

[0027] Al is an essential element for forming an Al oxide on the centrifugally-cast portion. The formation of an Al oxide improves the carburization resistance of the centrifugally-cast portion together with the Cr oxide. Also, Al forms a γ' phase together with Ni and reinforces the austenitic phase of the centrifugally-cast portion. Therefore, Al is contained in an amount of 1.5% or more. However, the addition of an excessively large amount of Al leads to a deterioration in ductility, and makes the γ' phase unstable, which results in the generation of an embrittled phase. Furthermore, the addition of an excessively large amount of Al leads to a deterioration in castability and reduces the cleanliness of the centrifugally-cast portion. Therefore, the upper limit of the Al content is 5.5%. Note that it is more desirable that the lower limit of the Al content is 2.0% or more and the upper limit of the Al content is 4.5% or less.

At least one type selected from the group consisting of Ti:0.01% to 0.6% and/or Nb:0.1% to 1.8%

[0028] Ti and Nb are elements that are likely to form a carbide and contribute to an improvement in creep rupture strength and high-temperature tensile strength. Moreover, Nb also contributes to an improvement in aging ductility. Therefore, at least one type of Ti in an amount of 0.01% or more and Nb in an amount of 0.1% or more is contained. On the other hand, the addition of an excessively large amount of these elements leads to a deterioration in ductility. Also, Nb causes a deterioration in the exfoliation resistance of the Al oxide layer and also causes a deterioration in oxidation resistance. Moreover, addition of an excessively large amount of Ti promotes the generation of a Ti oxide and causes a deterioration in the cleanliness of the centrifugally-cast portion. Therefore, the upper limit of the Ti content is 0.6%, and the upper limit of the Nb content is 1.8%. Note that it is more desirable that the lower limit of the Ti content is 0.05% or more and the upper limit of the Ti content is 0.30% or less and the lower limit of the Nb content is 0.1% or more and the upper limit of the Nb content is 1.3% or less.
[0029] In addition, the following elements may be contained in the centrifugally-cast portion.

Rare-earth elements (REMs): more than 0% and 0.4% or less

[0030] An REM means one of a set of eighteen elements in the periodic table including the fifteen lanthanides from La to Lu as well as Y, Hf, and Sc. The REMs contained in the centrifugally-cast portion are mainly Ce, La, and Nd, and the total amount of these three elements accounts for preferably about 80% or more, and more preferably about 90% or more, of the total amount of all the rare earth elements contained. The REMs contribute to the stabilization of the Al oxide layer, and can improve the adhesion of the oxide film since the REMs are reactive metals. Moreover, the REMs prevent spalling breakdown of the oxide layer due to temperature changes in the furnace, and furthermore, form a solid solution with the base material and contribute to an improvement in oxidation resistance, and therefore, it is desirable that the REMs are contained. On the other hand, the REMs preferentially form oxides and cause a deterioration in the cleanliness of the base material and the ductility, and therefore, the upper limit of the REM content is 0.4%. Note that it is more desirable that the lower limit of the REM content is 0.01% or more and the upper limit of the REM content is 0.30% or less.

W: more than 0% and 5.0% or less and/or Mo: more than 0% and 2.0% or less

[0031] W and Mo form a solid solution with the base material, reinforce the austenitic phase of the base material, and improve creep rupture strength, and therefore, it is desirable that either one or both of them are contained. However, an excessively high W or Mo content leads to a deterioration in ductility and carburization resistance, and also inhibits the formation of an Al oxide in particular if the Al oxide is to be generated at a temperature of 1050°C or lower. Moreover, an excessively high W or Mo content leads to a deterioration in the oxidation resistance of the base material. Therefore, the upper limit of the W content is 5.0% and the upper limit of the Mo content is 2.0%. Note that it is more desirable that the upper limit of the W content is 3.0% and the upper limit of the Mo content is 1.0%.
[0032] Moreover, as shown in FIG. 1, it is desirable that the various elements contained in the centrifugally-cast portion satisfy $Pa<Ya$, where $Pa = -11.1+28.1\times C+29.2\times Si-0.25\times Ni-45.6\times Ti+18.0\times REMs-16.6\times Nb$, and $Ya = -13.75\times Al+63.75$. Note that, with respect to the Pa value, if any of the elements shown above is not contained, the value of that element is taken as 0.
[0033] If the Pa value and the Ya value satisfy the above-described expression, the weldability and the oxidation resistance (formation of an Al oxide layer) of the centrifugally-cast portion can be ensured.
[0034] The above-described Pa value is related to the amounts of the elements C, Si, Ni, Ti, REMs, and Nb contained. Centrifugally-cast portions to be tested containing varying amounts of these elements and Al were produced. Then, the centrifugally-cast portions to be tested were subjected to a bead-on-plate test of Examples, which will be described later, and data on the weldability of the tested centrifugally-cast portions were acquired. The influence coefficients of elements that influence the weldability were obtained from the acquired data through regression analysis.
[0035] With regard to the Pa value, referring to the influence coefficients, C, Si, and REMs whose influence coefficients are positive numbers are the elements that each adversely influence the weldability, and a greater numerical value (absolute value) means a greater degree of the adverse influence. On the other hand, Ni, Ti, and Nb whose influence coefficients are negative numbers are the elements that improve the weldability, and a greater numerical value (absolute value) means a greater degree of the favorable influence.
[0036] FIG. 1 is a plot of the Pa value on the vertical axis versus the Al content on the horizontal axis with respect to the tested centrifugally-cast portions, and cases with favorable weldability are plotted as rhombuses and cases with insufficient weldability are plotted as squares.
[0037] In order for a tested centrifugally-cast portion to have a favorable Al oxide layer formed thereon and have oxidation resistance, it is necessary to satisfy the above-described range of the Al content (Al: 1.0% to 5.5%). The graph

in FIG. 1 shows this range of the Al content in an enlarged manner. Referring to FIG. 1, it can be found that the boundary between a group with excellent weldability and a group with insufficient weldability is distinctly delineated with respect to the Pa values and the Al contents with which favorable Al oxide layers are formed. It can be seen from this graph that the correlation with the Ya value, which includes the Al content, could be clearly analyzed based on the weldability.

[0038] Then, the linear Ya value that separates these groups and that is based on the Al content was determined to be $Ya = -13.75 \times Al + 63.75$. That is to say, it can be seen that a centrifugally-cast portion with excellent oxidation resistance and excellent weldability can be obtained by satisfying $Pa < Ya$ within the range of Al: 1.0% to 5.0%.

[0039] The centrifugally-cast portion is formed into a tubular shape, for example, through centrifugal casting, and the steel product can be produced by welding the centrifugally-cast portion to a base member such as an axle or a shaft portion that constitutes the steel product. Since the centrifugally-cast portion has excellent weldability, welding to the base member can be suitably performed, and a sufficient joining strength can be ensured.

[0040] The base member can be made through static casting, for example, and this statically-cast portion is suitably made from a material that does not contain Al, in order to suppress a deterioration in mechanical properties and weldability.

[0041] In the steel product, the centrifugally-cast portion can be formed on a surface thereof that is to come into contact with a steel material. In this case, it is necessary to perform an Al oxide layer forming treatment for forming an Al oxide layer on the surface of the centrifugally-cast portion. The Al oxide layer forming treatment can be performed as an independent step by heat-treating the steel product in an oxidizing atmosphere, or can also be performed in the same high-temperature atmosphere as that in which the steel product is to be used, by placing the steel product in a heating furnace.

[0042] Preferably, the Al oxide layer forming treatment is performed by heat-treating the steel product at a temperature of 900°C, desirably 1000°C, and more desirably 1050°C or more, in an oxidizing atmosphere in which an oxidizing gas that contains oxygen in an amount of 1 vol% or more, steam, and CO2 are mixed. The heat treatment time is preferably 1 hour or longer.

[0043] As a result of the steel product being subjected to the Al oxide layer forming treatment, the centrifugally-cast portion comes into contact with oxygen, and Al, Cr, Ni, Si, Fe, and the like that are diffused on the surface of the base material are oxidized to form an oxide layer. At this time, due to the heat treatment being performed in the above-described temperature range, Al forms an oxide with priority over Cr, Ni, Si, and Fe. Moreover, Al in the base material also moves to the surface and constitutes the oxide, and thus, an Al oxide layer mainly composed of Al_2O_3 is formed.

[0044] In the obtained steel product, since the centrifugally-cast portion has excellent weldability, the centrifugally-cast portion is firmly joined to the base member without causing weld cracking or the like, and thus the steel product has excellent mechanical characteristics. Moreover, the centrifugally-cast portion has excellent mechanical characteristics, and the Al oxide layer formed on the surface thereof allows the steel product to exhibit excellent oxidation resistance when used in a high-temperature atmosphere. Therefore, the steel product can be suitably used as a hearth roll or a coiler drum that is to come into contact with a steel material in a high-temperature atmosphere.

[0045] Note that a ceramic thermal sprayed layer may also be formed on the surface of the centrifugally-cast portion, if necessary, by thermal spraying a ceramic onto the surface of the centrifugally-cast portion.

Examples

[0046] Test pieces of centrifugally-cast portions having alloy compositions shown in Table 1 (unit: mass%, the balance being Fe and inevitable impurities) (test pieces for an oxidation resistance test: thickness 25 mm × 3 pieces, and test pieces for a bead-on-plate test for confirming the weldability (for only examples of the invention): thicknesses 25 mm or less and 25 mm or greater) were made through centrifugal casting. Examples of the invention were sample Nos. 101 to 110, and comparative examples were sample Nos. 201 to 206. In Table 1, "REMs" indicates the total amount of Ce, La, and Y. Note that, although the examples of the invention satisfied the composition range of the present invention, the sample Nos. 201 to 204 of the comparative examples contained no Al and the sample Nos. 205 and 206 of the comparative examples each contained an excessively small amount of Al, and the relevant portions are denoted by an asterisk "*".

Table 1

Sample No.	C	Si	Mn	Cr	Ni	Al	Ti	Nb	Ce	La	Y	REM (sum)	W	Mo	Pa	Ya	Pa<Ya	Oxidation resistance	Evaluation	Cracking resistance	Overall judgment
101	0.42	0.29	0.17	23.1	33.3	3.09	0.08	0.03		0.03		0.03	1.02		−2.75	21.26	√	0.174	B	A	B
102	0.46	0.34	0.2	22.5	32.8	3.93	0.11					0			−1.45	9.71	√	0.014	A	A	A
103	0.51	0.28	0.18	22.1	31.7	5.02	0.12					0	0.99		−1.99	−5.27		0.031	A	B	B
104	0.52	0.34	0.19	27.9	33.4	2.97	0.11					0	1.07		0.08	22.91	√	0.274	B	A	B
105	0.53	0.35	0.19	32.2	33.6	2.88	0.15			0.03		0.03	1.15		−0.69	24.15	√	0.247	B	A	B
106	0.38	0.37	0.19	23.0	41.2	2.93	0.06					0			−2.64	23.46	√	0.072	A	A	A
107	0.46	0.4	0.21	27.7	41.5	2.83	0.08				0.03	0.03	0.92		0.02	24.84	√	0.270	B	A	B
108	0.47	0.39	0.2	27.6	41.7	3.04	0.08	0.6		0.03		0.03	0.96		−10.00	21.95	√	0.046	A	A	A
109	0.43	0.51	0.52	23.6	33.5	4.5	0.12					0	0.3	0.2	2.03	1.88		0.027	A	B	B
110	0.45	1.21	0.74	24.3	34.9	5.3	0.15		0.25	0.11		0.36	0.1		27.79	−9.13		0.021	A	B	B
201	0.45	0.36	0.19	24.1	35.2	*	0.02					0	1.02		2.34	63.75	√	2.252	D		C
202	0.45	0.45	0.18	23.7	42.8	*	0.02					0			3.08	63.75	√	0.494	C		C
203	0.52	1.85	0.82	23.9	35.2	*	0.04	0.47				0			39.10	63.75	√	0.638	C		C
204	0.57	1.75	1.05	30.6	43.0	*	0.04	0.77				0			30.66	63.75	√	0.487	C		C
205	0.65	1.78	1.19	19.8	23.8	*0.8	0.11			0.32		0.32	0.3		53.94	52.75		1.526	D		C
206	0.63	1.87	0.84	22.4	27.0	*0.57	0.05			0.38		0.38	0.2	0.1	59.02	55.91		1.138	D		C

[0047] Moreover, with respect to each test piece in Table 1, Pa and Ya were calculated and compared to each other to determine the relationship in magnitude therebetween. In Table 1, for each test piece that satisfies Pa<Ya, a check mark is placed in the "Pa<Ya" column. Referring to Table 1, it can be seen that all of the sample Nos. 103, 109, 110, 205, and 206 are test pieces that do not satisfy Pa<Ya.

Oxidation resistance test

[0048] The test pieces were weighed. After that, the test pieces were kept in a heating furnace at 1000°C (in the atmosphere), and scales on the surfaces of the heated test pieces were removed using an acid solution. Then, the test pieces were weighed again. Based on the amount of change in weight before and after heating of each test piece, the amount of weight reduction due to oxidation was calculated, and an average amount of weight reduction due to oxidation per hour (mg/cm^2•h) was obtained. The results are shown in "Oxidation resistance" in Table 1. Moreover, with respect to the oxidation resistance, as shown in "Evaluation" in Table 1, test pieces with an amount of weight reduction due to oxidation of 0.1 mg/cm^2•h or less were evaluated as "A", those with 0.3 mg/cm^2•h or less were evaluated as "B", those with 1 mg/cm^2•h or less were evaluated as "C", and those with greater than 1 mg/cm^2•h were evaluated as "D".

[0049] Referring to Table 1, it can be seen that all of the examples of the invention were evaluated as "A" or "B", and had smaller amounts of weight reduction due to oxidation and had superior oxidation resistance, compared with the comparative examples, which were evaluated as "C" or "D". The reason for this is that, in each of the test pieces of the examples of the invention, an Al oxide was generated on the surface thereof and suppressed further oxidation. On the other hand, in each of the test pieces of the comparative examples, a Cr oxide and a Si oxide were generated on the surface thereof, and these oxides were less dense than the Al oxide, did not have a sufficient function of preventing the entry of oxygen, and was not able to suppress oxidation.

[0050] A comparison between the examples of the invention shows that the sample Nos. 102, 103, 106, and 108 to 110 were evaluated as "A" and had particularly excellent oxidation resistance. It is assumed that this is because a particularly excellent Al oxide layer was formed due to the high Al concentration, the relatively low concentration of Cr, which is likely to form an oxide layer, and the like.

Bead-on-plate test

[0051] The test pieces (two types with a thickness of 25 mm or less and a thickness of 25 mm or more) of the examples of the invention shown in Table 1 were subjected to a bead-on-plate test in the following manner, and resistance to cracking due to welding was judged.

[0052] Prior to the bead-on-plate test, a test surface of each test piece was machined using a grinder and smoothed. The test surface refers to a portion that was to constitute a weld groove and a portion that was to be heat-affected by welding.

[0053] Moreover, the test surface of each test piece was subjected to a liquid penetrant test, and it was confirmed that no crack was present in the test surface.

[0054] With respect to the test pieces whose test surfaces were confirmed to have passed the test, the bead-on-plate test was performed through TIG welding under the conditions shown in Table 2. The bead was a straight bead, and the bead length was 50 to 100 mm.

Table 2

Order	Filler metal	Thickness of material tested	Current	Speed	Other conditions
Method A	Not used	25 mm or less	150 A	150-200 mm/min.	Straight bead 50-100 mm
		25 mm or more	200 A	150-200 mm/min.	
Method B	Used	25 mm or less	150 A	150-200 mm/min.	Straight bead 50-100 mm
		25 mm or more	200 A	150-200 mm/min.	

[0055] Note that this test was conducted in the following order: a test was performed using the method A, followed by a liquid penetrant test, and if a defect was found in the liquid penetrant test, a test was performed using the method B.

[0056] FIG. 2 and Table 3 show criteria for judging the beads that were formed using the method A (filler metal (welding rod) was not used) and the method B (filler metal was used). Note that, in the method B, even a minute crack was judged as "OUT".

Table 3

Defect type	Criterion for judgement	Method A	Method B
Cracks	Within Bead	OK	OUT
	Spanning between bead and base material	OUT	OUT
	Occurring in base material	OUT	OUT
	Within crater	OK	OUT
Point defects at lateral side of bead		OK	OK

[0057] As a result of the above-described test, the cracking resistance of test pieces with respect to which no defects were found in all of the test pieces with a thickness of 25 mm or less and a thickness of 25 mm or more using the method A was evaluated as "A", the cracking resistance of test pieces with respect to which defects were found using the method A, but no defects were found using the method B was evaluated as "B", and the cracking resistance of test pieces with respect to which defects were found using the method A and were also found using the method B was evaluated as "C". The results are shown in "Cracking resistance" in Table 1.

[0058] Referring to Table 1, with regard to the test pieces of the examples of the invention, the sample Nos. 101, 102, and 104 to 108 were evaluated as "A" and the sample Nos. 103, 109, and 110 were evaluated as "B".

[0059] If the examples of the invention are examined, it is found that all of the test pieces whose cracking resistance was evaluated as "A" each had a Ya value greater than the Pa value and satisfied $Pa<Ya$.

Overall judgment

[0060] Each test piece that was evaluated as "A" in both the oxidation resistance test and the bead-on-plate test was judged to be "A" overall. On the other hand, each test piece that was evaluated as "A" in one of the tests and "B" in the other test was judged to be "B" overall, and each test piece whose evaluation results contained "C" or "D" was judged to be "C" overall. The results are shown in "Overall judgment" in Table 1. Referring to Table 1, all of the test pieces of the examples of the invention were judged to be "A" or "B", and all of the test pieces of the comparative examples were judged to be "C". That is to say, in the test pieces of the examples of the invention, cracking is less likely to occur during welding, and it is thus found that the test pieces of the examples of the invention have superior oxidation resistance to the test pieces of the comparative examples. Therefore, the steel product of the present invention is extremely suitable for application to a hearth roll, a coiler drum, and the like that are used in contact with a steel material such as slabs, blooms, and billets, as well as steel sheets and plates.

[0061] The foregoing description is solely intended to illustrate the invention and should not be construed as limiting the present invention as set forth in the claims or restricting the scope of the claims. It goes without saying that the configuration of each part of the present invention is not limited to the foregoing examples, and various modifications are possible within the technical scope indicated by the claims.

List of Reference Numerals

[0062]

10 bead
12 crater
14 crack
16 point defect

Claims

1. A steel product for use in contact with a steel material, the steel product comprising:

   a centrifugally-cast portion formed on a surface of the steel product that is to come into contact with the steel material, the centrifugally-cast portion being made through centrifugal casting; and
   a statically-cast portion to which the centrifugally-cast portion is welded, the statically-cast portion being formed through static casting,
   the centrifugally-cast portion containing, in terms of mass%:

C: 0.2% to 0.7%;
Si: more than 0% and 2.0% or less;
Mn: more than 0% and 3.0% or less;
Cr: 15.0% to 40.0%;
Ni: 18.0% to 55.0%;
Al: 1.0% to 5.5%; and
at least one type selected from the group consisting of Ti: 0.01% to 0.6% and/or Nb: 0.1% to 1.8%,
the balance being composed of Fe and inevitable impurities.

2. The steel product according to claim 1,
wherein the centrifugally-cast portion further contains, in terms of mass%,
rare earth elements (REMs): more than 0% and 0.4% or less.

3. The steel product according to claim 1 or 2,
wherein the centrifugally-cast portion further contains, in terms of mass%:

W: more than 0% and 5.0% or less; and/or
Mo: more than 0% and 2.0% or less.

4. The steel product according to any one of claims 1 to 3,
wherein the centrifugally-cast portion satisfies $Pa<Ya$, where

$$Pa = -11.1+28.1\times C+29.2\times Si-0.25\times Ni-45.6\times Ti+18.0\times REMs-16.6\times Nb,$$

and

$$Ya = -13.75\times Al+63.75.$$

5. The steel product according to any one of claims 1 to 4,
wherein the statically-cast portion does not contain Al.

6. The steel product according to any one of claims 1 to 5, further comprising:
a ceramic thermal sprayed layer on the surface of the centrifugally-cast portion.

7. The steel product according to any one of claims 1 to 6, which is a hearth roll or a coiler drum.

FIG.1

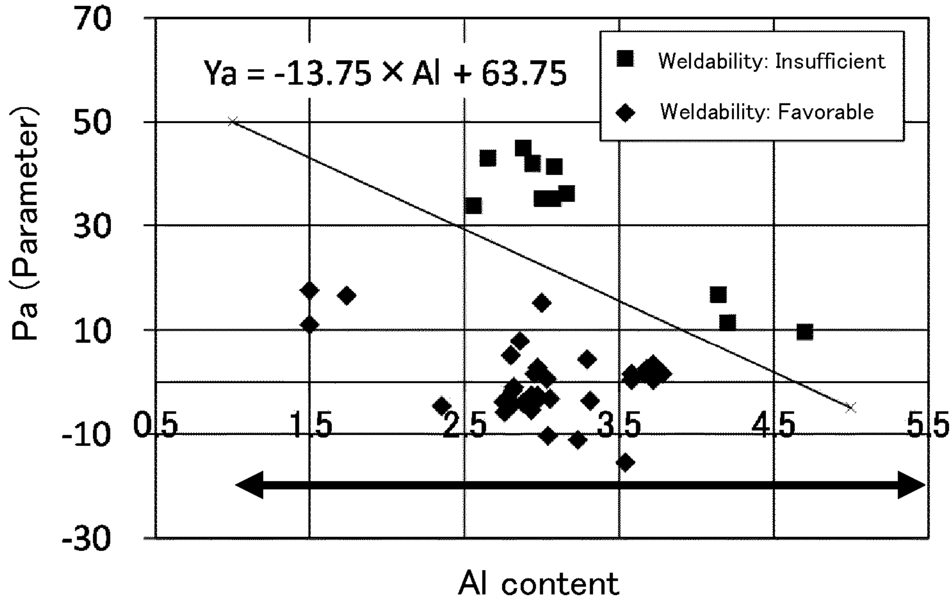
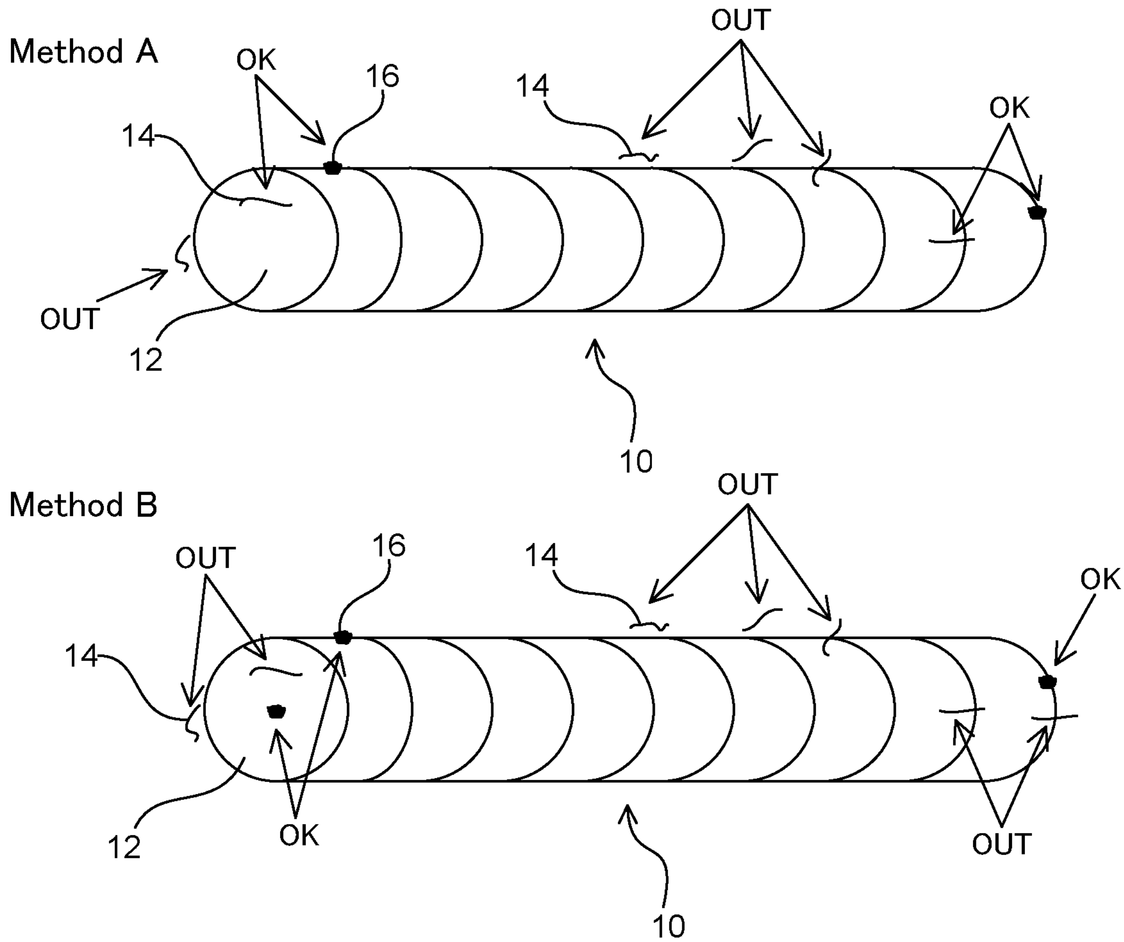

Ya = -13.75 × Al + 63.75
Weldability: Insufficient
Weldability: Favorable
Pa (Parameter)
70
50
30
10
-10
-30
0.5
1.5
2.5
3.5
4.5
5.5
Al content

FIG.2


Method A
OK
16
14
OUT
14
OK
OUT
12
10
Method B
OUT
16
14
OUT
14
OK
OK
12
OUT
10

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2018/031132

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. C22C38/00(2006.01)i, C22C30/00(2006.01)i, C22C38/58(2006.01)i, C23C4/10(2016.01)i, B22D13/02(2006.01)n, B22D13/10(2006.01)n, C22C19/05(2006.01)n

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. C22C1/00-49/14, C23C4/10, B22D13/02, B22D13/10

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

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2018
Registered utility model specifications of Japan	1996-2018
Published registered utility model applications of Japan	1994-2018

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 02-115351 A (KUBOTA IRON WORKS CO., LTD.) 27 April 1990 (Family: none)	1-7
A	JP 50-093817 A (MITSUBISHI HEAVY INDUSTRIES, LTD.) 26 July 1975 (Family: none)	1-7
A	JP 2016-132019 A (KUBOTA CORPORATION) 25 July 2016 (Family: none)	1-7
A	WO 2015/145896 A1 (KUBOTA CORPORATION) 01 October 2015 & US 2017/0306468 A1 & EP 3124645 A1 & CN 106460144 A	1-7

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

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- "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	Date of mailing of the international search report
02.10.2018	16.10.2018

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/031132

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 2013/141030 A1 (KUBOTA CORPORATION) 26 September 2013 & US 2014/0205802 A1 & EP 2829628 A1 & CN 104204268 A & KR 10-2014-0143744 A	1-7
A	JP 2016-223017 A (KUBOTA CORPORATION) 28 December 2016 (Family: none)	1-7
A	JP 2012-213781 A (KUBOTA CORPORATION) 08 November 2012 (Family: none)	1-7
A	JP 03-072019 A (KUBOTA CORPORATION) 27 March 1991 (Family: none)	1-7
A	WO 2016/104417 A1 (KUBOTA CORPORATION) 30 June 2016 & EP 3239311 A1	1-7
A	JP 2004-052036 A (KUBOTA CORPORATION) 19 February 2004 (Family: none)	1-7
A	JP 09-243284 A (KUBOTA CORPORATION) 19 September 1997 (Family: none)	1-7
A	JP 57-094561 A (KUBOTA IRON WORKS CO., LTD.) 12 June 1982 (Family: none)	1-7

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2008240072 A **[0004] [0005]**