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(54) **AUSTENITIC STAINLESS STEEL FOR APPARATUS FOR HIGH-TEMPERATURE USE HAVING WELDED TUBULAR STRUCTURE**

AUSTENITISCHER EDELSTAHL FÜR VORRICHTUNG ZUR HOCHTEMPERATURVERWENDUNG MIT GESCHWEISSTER RÖHRENFÖRMIGER STRUKTUR

ACIER INOXYDABLE AUSTÉNITIQUE POUR UN APPAREIL DESTINÉ À UNE UTILISATION À HAUTE TEMPÉRATURE PRÉSENTANT UNE STRUCTURE TUBULAIRE SOUDEÉ

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Description

Technical Field

[0001] The present invention relates to an austenitic stainless steel for an article having a welded tubular structure, which is to be used at a high temperature, **an article having a tubular structure comprising said austenitic stainless steel, and a method for producing a welded structural body involving TIG welding using said austenitic stainless steel.**

Background Art

[0002] A fuel reformer for producing a hydrogen gas, including a fuel cell, may be an apparatus for producing hydrogen gas from a fuel such as city gas, kerosene and gasoline, by using a fuel reforming catalyst. The catalyst operating temperature for producing hydrogen may be a high temperature of about 700°C or more and therefore, the catalyst-holding structure material should be required to have excellent oxidation resistance and high-temperature strength. The oxidation resistance and high-temperature strength of the catalyst-holding structure material should be necessary so as to ensure the long-term durability thereof as a structure or construction. A partial fracture or deformation due to oxidative damage or lack of strength at a high temperature may deteriorate the performance as a hydrogen gas generator. The performance deterioration of the hydrogen gas generator may in turn deteriorate the performance of a fuel cell body for generating electricity, to thereby cause performance reduction of the system. For this reason, SUS310S (JIS Standards), which is an austenitic stainless steel excellent in oxidation resistance and high-temperature strength may be often used, particularly at a site to be subjected to a high temperature.

[0003] As the fuel reformer, there has been developed a fuel reformer having an integral cylindrical structure, which has been fabricated by welding a thin sheet of austenitic stainless steel including SUS310S into a tubular shape, and then being stacked into a multiple tubular form (Patent Document 1). The cylindrically structured fuel reformer may have a much complicated structure, where the stacked tubes are function-separated. In the production of such a cylindrical structure, the welding is conducted not only at the time of the welding into a tubular shape, but also at the time of the formation of a gas passage, wherein tubes are joined with each other by girth welding. Accordingly, an austenitic stainless steel which is excellent not only in weldability but also in high-temperature characteristics may be demanded. Herein, the term "excellent in weldability" means that the high-temperature cracking may be less liable to occur mainly at the time of welding.

[0004] The high-temperature cracking capable of occurring during the welding of an austenitic stainless steel, may be cracking which is attributable to the segregation of a low-melting point compound such as P, S, Si and Nb on the austenite grain boundary or columnar crystal grain boundary in the solidification process, and may also be referred to as "solidification cracking". In the austenitic stainless steel (for example, SUS304 (JIS Standards) or SUS316 (JIS Standards)), the high-temperature cracking may be prevented by incorporating several % of ferrite into the weld metal. The reason why ferrite is effective may be, for example, that the solid solubility of S and P is higher in ferrite, the wettability of a liquid is reduced so as to make a liquid film difficult to be spread, and a ferrite/austenite interface is solidified while retaining a complicated configuration thereof, to thereby provide an austenite grain boundary, whereby the cracking is less liable to be propagated. However, in the case of an austenitic stainless steel wherein a ferrite phase cannot be formed even when component adjustment is conducted as in the case of SUS310S, it is known to be effective to reduce the amount of a low-melting point metal-producing element such as P, S and Si.

[0005] Further, as an austenitic stainless steel for a high-temperature apparatus, having high-temperature characteristics, which are substantially equal to those of SUS310S, there has been developed a material wherein the Si content is increased so as to improve the oxidation resistance thereof. However, as described above, an increase in the Si content is liable to cause high-temperature cracking and therefore, the component adjustment may be performed so as incorporate therein several % of ferrite at the time of solidification thereof (for example, as shown in Patent Documents 1 to 4).

[0006] On the other hand, for solving the high-temperature cracking during the welding not only from the aspect of material but also from the aspect of workability thereof, it may be important to reduce the strain during welding. In this connection, when the strain is reduced by decreasing the welding heat input and the material is surely constrained during the welding work, the strain due to residual stress may be suppressed and the high-temperature cracking may be prevented.

Prior Art Documents

Patent Documents

[0007]

[Patent Document 1] JP-A (Japanese Unexamined Patent Publication; KOKAI) No. 2003-286005

[Patent Document 2] JP-A No. 2003-160843

[Patent Document 3] JP-A No. 2003-160841

[Patent Document 4] JP-A No. 8-319541

[0008] JP H03-61322 describes that a hot rolling stock of austenitic stainless steel which has a composition containing, by weight,
C: 0.005-0.10%, Si: 0.2-1.0%, Mn: 0.2-2.5%, P: ≤ 0.045%, S: ≤ 0.020%,
Ni: 6-20%, Cr: 15-25%, N: 0.01-0.10%, Al: 0.0005-0.005%, Ca: 0.0001-0.002%,
Mg: 0.0001-0.001%, and O: ≤ 0.0025% or further containing Mo and/or Cu: 0.5-3.5%; is heated at 1000-1300°C for ≥ 10 min to undergo hot rolling. The hot rolled stock is annealed, pickled, and cold-drawn or cold-rolled into an extra fine wire or foil shape. By this method, an extra fine wire or foil of the stainless steel free from breaking of wire and fracture can be produced.

Summary of Invention

[Problems to be Solved by the Invention]

[0009] However, as described above, in the case of a much complicated welded structure such as fuel reformer, in many cases, it may be difficult to constrain all of the welding areas thereof. Therefore, the welding needs to be conducted in parts a plurality of times during the production thereof. Further, there may be caused a problem such that strain is concentrated on the final welding area, to thereby cause solidification cracking.

[0010] In an article having a welded structure, it may be important to surely achieve the welding joint. However, when the welded structure is complicated, the welding conditions are liable to be varied. When the welding heat input is low and in turn, the amount (or depth) of welding penetration is small, a joint failure may be caused. On the other hand, when the welding is conducted by raising the welding heat input so as to surely achieve the melting and joint, the amount of welding penetration may be increased. As described hereinabove, when the amount of welding penetration is large, the strain due to residual stress may become large, so as to cause a problem such that high-temperature cracking is liable to occur.

[0011] The present invention has been made by taking into account such a problem. An object of the present invention is to provide an austenitic stainless steel which is excellent in profitability and excellent in weldability for providing an article having a complicated tubular structure.

[Means for Solving the Problem]

[0012] In order to attain the above object, the present inventors have conducted reproducibility tests on the high-temperature cracking by using stainless steels, which have been changed in various components thereof, and by changing the welding heat input, to thereby study the high-temperature cracking during the welding. As a result, the present inventors have found that, for the purpose of improving the high-temperature cracking, it may be important to attain a proper amount of welding penetration by studying appropriate material components thereof. The present invention has been accomplished based on the resultant discovery. Herein, the following descriptions should not be construed as limiting the present invention by any means.

[0013] In the case of a high C amount, high-temperature cracking is liable to occur during the welding of the austenitic stainless steel. The reason therefor may be because the C promotes the segregation of low-melting point S in the melting part thereof. Further, excess Si may reduce the weldability. Each of P and S may be segregated on the grain boundary so as to reduce the weldability.

[0014] The inventors have made tests and evaluations on the welding conditions, components and compositions, with which the amount of welding penetration due to appropriate welding can be ensured, even when the welding heat input is lowered so as to prevent the high-temperature cracking, while controlling the amount of low-melting point element such as Si, P and S for inhibiting the high-temperature cracking during the welding.

[0015] Tests were conducted by changing the welding heat input so as to examine the relationship of the bead width ratio between front and back surfaces after welding with high heat input (that is, the bead width of back surface/bead width of front surface), and the high-temperature cracking property, and examine the welding penetration at the time of low heat input. The present inventors have found that, during the welding with high heat input, when the bead width ratio of front and back surfaces exceeds 0.8, the high-temperature cracking is liable to occur. The present inventors have clarified that a specific relationship of Al and Ca contents in the steel affects the bead width ratio of front and back surfaces. That is, Al is usually added as a deoxidizing element and Ca is added to reduce the S content, but both elements have been found to be an element necessary for achieving an adequate amount of welding penetration during the welding. As a result of analysis by the present inventors, it has been found that the "weldability index" represented by the following formula (1) may have a suitable range, and within such a suitable range, the bead width ratio of front and back surfaces may be 0.8 or less, to thereby make it possible to keep good weldability.

$$0.015 \leq 0.29\ (\%\ Al) + 17.92\ (\%\ Ca) \leq 0.093 \qquad \text{Formula (1)}$$

[0016] If the weldability index is less than 0.015, the amount of welding penetration may become large, and the high-temperature cracking is liable to occur. On the other hand, when the weldability index of formula (1) is 0.015 or more, the amount of welding penetration may be decreased, even at the time of high heat input, and the bead width ratio of front and back surfaces may become 0.8 or less. As a result, the occurrence of high-temperature cracking may be reduced. The weldability index may preferably be 0.03 or more. If the weldability index exceeds 0.093, the welding penetration during the welding with low heat input may be reduced so as to deteriorate the weldability. The upper limit of the weldability index may preferably be 0.079, more preferably 0.068.

[0017] The present inventors have gained the above-described knowledge relating to the test results, and have provided a useful measure for solving the technical problem in the welding of an austenitic stainless steel.

[0018] The present invention provides an austenitic stainless steel for an article having a tubular structure, consisting of, in mass%,

C: from 0.001 to 0.2%,
Si: from 0.01 to 1.5%,
Mn: from 0.01 to 1.5%,
Cr: from 20.0 to 26.0%,
Ni: from 15.0 to 23.0%,
N: from 0.001 to 0.07%,
Al: from 0.003 to 0.05%, and
Ca: from 0.0003 to 0.005%, and

optionally further one member or two or more members of, in mass%,

Cu: from 0.001 to 0.3%,
Mo: from 0.001 to 0.3%,
Sn: from 0.001 to 0.05%,
W: from 0.001 to 0.10%,
Co: from 0.001 to 0.10%,
Ti: from 0.001 to 0.03%,
Nb: from 0.001 to 0.03%,
V: from 0.001 to 0.2%,
Zr: from 0.001 to 0.03%,
B: from 0.00001 to 0.001%,
Mg: from 0.00001 to 0.001%, and
REM: from 0.00001 to 0.01%,
with the balance being Fe and unavoidable impurities,
wherein the contents of P and S as impurities are limited to, in mass%,
P: ≤0.022%, and
S: ≤0.004%, and
A1 and Ca satisfy the following formula:

$$0.015 \leq 0.29\ (\%\ Al) + 17.92\ (\%\ Ca) \leq 0.093 \qquad \text{formula (1).}$$

The present invention also provides a method for producing a welded structural body, wherein the welded structural body is produced by a method involving TIG welding using the above austenitic stainless steel for an article having a tubular structure.
The present invention also provides an article having a tubular structure, wherein said tubular structure comprises an austenitic stainless steel as described above.

[Effect of the Invention]

[0019] The invention is defined in the claims.
[0020] Even in the case of a member having a complicated configuration, the austenitic stainless steel excellent in weldability for a tubular structure according to the present invention can be stably welded with an appropriate amount of welding penetration, so that the high-temperature cracking due to an increase in the welding heat input can be reduced, and an austenitic stainless steel excellent in weldability for a tubular structure can be provided at a low cost.

Brief Description of Drawings

[0021] [Fig. 1] Fig. 1 is a view showing a relationship among Al and Ca contents, welding cracking and welding workability.

Modes for Carrying Out the Invention

[0022] The austenitic stainless steel for a tubular structure of the present invention will be described below. In the following, "%" means "mass %".
[0023] C: C may be an element which is effective in stabilizing the austenite structure. However, if the content is increased, this element may promote high-temperature cracking due to the segregation of S. For this reason, the upper limit thereof is set to 0.2%. Further, for suppressing the occurrence of high-temperature cracking, the upper limit value may preferably be 0.15%, more preferably 0.1%. On the other hand, the lower limit is set to 0.001% in view of production cost. For this reason, the lower limit may preferably be 0.002%, more preferably 0.003%.
[0024] Si: Si may be used as a deoxidizing element and its content may preferably be larger in view of the oxidation resistance but if added in excess, this element may seriously deteriorate the weldability. Therefore, the upper limit is set to 1.5%. For this reason, the upper limit may preferably be 1.0%, more preferably 0.8%. The lower limit is set to 0.01% in view of production cost. For this reason, the lower limit value may preferably be 0.015%, more preferably 0.02%.
[0025] Mn: Mn may be an element which is necessary for stabilizing the austenite structure, and may also be an element for fixing S during the welding so as to suppress the reduction in the high-temperature cracking. However, the excessive addition thereof may reduce the oxidation resistance and therefore, the upper limit is set to 1.5% or less. In view of the oxidation resistance, the upper limit may preferably be 1.3%, more preferably 1.0%. In order not to raise the production cost, the lower limit is set to 0.01%. For this reason, the lower limit may preferably be 0.015%, more preferably 0.02%.
[0026] P: P may be an element which is segregated on the grain boundary at the time of the solidification, to thereby reduce the weldability. Therefore, the upper limit is set to 0.022% or less. The upper limit may preferably be 0.020%, more preferably 0.015%. P may be an element which is unavoidably contained in the steel, but in view of the weldability, it may be preferred that P is not present.
[0027] S: S may also be an element which is segregated on the grain boundary at the time of the solidification, to thereby reduce the weldability. Therefore, the upper limit is set to 0.004% or less. The upper limit may preferably be 0.0015%, more preferably 0.0001%. S may be an element which is unavoidably contained in the steel, but in view of weldability, it may be preferred that S is not present.
[0028] Cr: Cr may be an element which is necessary for ensuring the corrosion resistance, which is a basic characteristic of a stainless steel, and for ensuring the oxidation resistance and strength in a high-temperature environment, which are important in the present invention. Therefore, its content should be 20.0% or more. For this reason, the lower limit may preferably be 22.0%, more preferably 23.0%. The upper limit is set to 26.0% so as not to reduce the formability, raise the production cost or deteriorate the productivity. For this reason, the upper limit may preferably be 25.5%, more preferably 24.0%.
[0029] Ni: Ni may be an element which is necessary for stabilizing the austenite structure, to thereby ensure the strength at a high temperature. Therefore, the lower limit is set to 15.0%. For this reason, the lower limit may preferably

be 16.0%, more preferably 17.0%. However, if the content is increased, the high-temperature cracking due to the segregation of S may be promoted, the production cost may be raised, or the productivity may be deteriorated, and therefore, the upper limit is set to 23.0%. For this reason, the upper limit may preferably be 21.0%, more preferably 19.0%.

[0030] N: N may be an element which is effective in stabilizing the austenite structure. However, if the content is increased, the formability may be deteriorated or the hot working productivity may be reduced, and therefore, the upper limit is set to 0.07%. For this reason, the upper limit may preferably be 0.06%, more preferably 0.05%. On the other hand, in view of the production cost, the lower limit is set to 0.001%. For this reason, the lower limit may preferably be 0.002%, more preferably 0.003%.

[0031] Al: Al may be a deoxidizing element, and may be an element which is effective in achieving an adequate amount of welding penetration during the welding. However, if the amount thereof to be added is too large, the welding penetration property (amount of welding penetration, or width or depth of welding penetration) may be decreased so as to deteriorate the weldability. Therefore, the upper limit is set to 0.05%. For this reason, the upper limit may preferably be 0.045%, more preferably 0.035%. Further, the lower limit is set to 0.003% in view of the production cost. The lower limit may preferably be 0.004%, more preferably 0.005%.

[0032] Ca: Ca may be an element which is necessary for achieving an adequate amount of welding penetration during the welding by decreasing the content of S which may deteriorate the weldability. However, if the amount thereof to be added is too large, the weldability may be conversely reduced so as to deteriorate the weldability. Therefore, the upper limit is set to 0.005% or less. For this reason, the upper limit may preferably be 0.004%, more preferably 0.003%.

[0033] Further, the lower limit is 0.0003% in consideration of the production cost. For this reason, the lower limit may preferably be 0.0005%, more preferably 0.0008%.

[0034] Weldability Index:
As the weldability index for an adequate amount of welding penetration so as to inhibit the high-temperature cracking, formula (1) which is a relational expression of Al and Ca contents has been developed.

[0035] This may be a formula for determining the relationship of Al and Ca contents by evaluating the welding penetration based on the bead width ratio between the front and back surfaces after welding.

$$0.015 \le 0.29\ (\%\ Al) + 17.92\ (\%\ Ca) \le 0.093 \qquad \text{formula (1)}$$

[0036] Tests were conducted by changing the welding heat input so as to examine the relationship among the bead width ratio (bead width of back surface/bead width of front surface) of front and back surfaces after welding with high heat input, and the high-temperature cracking, so as to study the welding penetration at the time of low heat input. As a result, formula (1) has been found. First, the present inventors have found that, during the welding with high heat input (for example, 705 J/cm or more), when the bead width ratio of front and back surfaces exceeds 0.8, the high-temperature cracking is liable to occur. It has also been clarified that a specific relationship of Al and Ca contents in the steel may affect the above bead width ratio of front and back surfaces. As a result of analysis by the present inventors, it has been found that the "weldability index" represented by formula (1) may have a suitable range, and within such a suitable range, the bead width ratio of front and back surfaces may be 0.8 or less, so as to make it possible to keep good weldability. In this way, the present inventors have developed formula (1). It has been found that, although Al is usually added as a deoxidizing element and Ca is added to reduce the S content, each of these elements is an element which is necessary for achieving an adequate amount of welding penetration during the welding. If the weldability index is less than 0.015, the amount of welding penetration may become large, and the high-temperature cracking is liable to occur. On the other hand, when the weldability index of formula (1) is 0.015 or more, the amount of welding penetration may be decreased also at the time of high heat input, and the bead width ratio of front and back surfaces may become 0.8 or less. As a result, the occurrence of high-temperature cracking may be reduced. The weldability index may preferably be 0.03 or more. On the other hand, if the weldability index exceeds 0.093, the welding penetration during the welding with low heat input may be reduced so as to deteriorate the weldability.

[0037] As described hereinabove, in the case of an article having a much complicated welded structure such as a fuel reformer, the welding conditions are liable to be varied because of the complicated structure. When the heat input during the welding is low and the amount of welding penetration is small, a joint failure may be generated. Then, when the welding is conducted by raising the heat input during the welding so as to surely achieve the melting and joint thereby, the amount of welding penetration may be readily increased to an excessive extent. The austenitic stainless steel according to the present invention may be characterized in that the high-temperature cracking hardly occurs, even when the welding heat input is increased, and on the other hand, the weldability is not deteriorated, even when the welding heat input is decreased.

[0038] Hereinbelow, there will be described elements which may further be added positively, or elements which may be mixed as an impurity.

Cu, Mo, Sn, W and Co:

[0039] Cu, Mo, Sn, W and Co may be mixed from a scrap of the raw material. These elements may be effective in enhancing the corrosion resistance, but if added in an excess amount, the cost may be raised, or the productivity may be reduced. Therefore, the upper limits of those elements **are** Cu: 0.3%, Mo: 0.3%, Sn: 0.05%, W: 0.10% and Co: 0.10%; preferably Cu: 0.25%, Mo: 0.25%, Sn: 0.04%, W: 0.08% and Co: 0.06%; more preferably Cu: 0.20%, Mo: 0.20%, Sn: 0.03%, W: 0.05% and Co: 0.05%. The lower limits of these components are set to 0.001% as an unavoidable level.

Ti, Nb, V and Zr:

[0040] Ti, Nb, V and Zr may be effective in enhancing the grain boundary corrosion resistance by combining with C and N so as to form a precipitate, to thereby reduce the amounts of C and N capable of forming a solid solution in the steel. On the other hand, an excessive addition of these elements may allow a liquid phase film due to the production of carbide so as to promote the high-temperature cracking and deteriorate the weldability. **Therefore,** the upper limits of the elements above **are** Ti: 0.03%, Nb: 0.03%, V: 0.2% and Zr: 0.03%; preferably Ti: 0.02%, Nb: 0.02%, V: 0.1% and Zr: 0.01%; more preferably Ti: 0.015%, Nb: 0.015%, V: 0.05% and Zr: 0.005%. The lower limits of those elements **are** set all to 0.001% as an unavoidable level.

B and Mg:

[0041] B and Mg may be elements which are effective in improving the hot formability, but their excessive addition may deteriorate the weldability. Therefore, the contents thereof **are** B: from 0.00001 to 0.001% and Mg: from 0.00001 to 0.001%; preferably B: from 0.00001 to 0.0008% and Mg: from 0.00001 to 0.0006%; more preferably B: from 0.00001 to 0.0005% and Mg: from 0.00001 to 0.0004%.

REM:

[0042] REM may include La, Ce, Y, etc. REM may be an element which is effective in enhancing the hot formability, but an excessive addition thereof may deteriorate the weldability. Therefore, the content thereof is REM: from 0.00001 to 0.01%; suitably REM: from 0.00001 to 0.005%; more preferably REM: from 0.00001 to 0.003%.

[Examples]

[0043] Hereinbelow, the present invention will be described in more detail with reference to examples. Incidentally, the following descriptions should not be construed as limiting the present invention by any means.

[0044] Each of austenitic stainless steels composed of components shown in Tables 1 and 2 was melted in a vacuum melting furnace, cast into a steel ingot of 50 kg, and cut out in a block shape. Thereafter, the block which had been cut out was subjected to hot rolling, annealing/pickling, cold rolling, and annealing/pickling, to thereby produce a steel plate having a thickness of 0.8 mm. Then, each of the resultant steel plates was evaluated. In Tables 1 and 2, each of P, S, O and N may be contained as an impurity. Further, the blank column in the Tables indicates that the element was not added. In the Tables, the numerical value outside the scope of the present invention is underlined.

[Table 1]

[0045]

Table 1

Section	No	Component Content (mass%)																	
		C	Si	Mn	P	S	Ni	Cr	Mo	Cu	Sn	W	Co	Ti	Nb	V	Zr	B	Mg
Example of Invention	1	0.042	0.51	0.95	0.020	0.0010	19.22	25.19											
	2	0.034	0.52	1.14	0.016	0.0009	19.31	24.18											
	3	0.040	1.20	0.88	0.017	0.0007	19.20	24.55											
	4	0.058	0.81	0.75	0.015	0.0017	19.25	25.32											
	5	0.036	0.50	1.00	0.013	0.0008	19.28	25.11											
	6	0.037	0.75	1.05	0.015	0.0010	19.35	25.08											
	7	0.041	0.78	1.15	0.018	0.0008	19.55	25.12											
	8	0.045	0.91	1.18	0.015	0.0005	19.18	24.48											
	9	0.039	0.89	0.98	0.014	0.0009	19.25	24.82											
	10	0.065	0.78	0.82	0.015	0.0002	21.02	24.96	0.12										
	11	0.057	0.79	0.80	0.016	0.0005	18.73	24.82		0.18									
	12	0.049	0.77	0.83	0.013	0.0004	19.08	22.68						0.01					
	13	0.053	0.80	1.05	0.012	0.0006	19.75	25.46							0.005				
	14	0.049	0.50	1.03	0.016	0.0009	20.54	23.76								0.07			
	15	0.053	0.55	1.20	0.014	0.0009	19.69	24.29										0.0003	
	16	0.039	0.92	1.22	0.018	0.0008	19.36	24.71											
	17	0.054	0.76	0.82	0.014	0.0011	19.28	24.89											
	18	0.038	0.53	0.97	0.016	0.0009	20.32	25.32											
	19	0.042	0.90	1.11	0.020	0.0010	20.05	24.99											
	20	0.041	0.75	0.98	0.017	0.0012	19.58	25.45											
	21	0.039	1.01	1.12	0.016	0.0005	19.26	24.68											
	22	0.035	0.75	0.82	0.015	0.0010	19.56	25.14			0.02								
	23	0.038	0.70	0.85	0.014	0.0012	20.05	25.22				0.04							
	24	0.041	1.01	1.05	0.019	0.0009	20.10	24.98					0.05						
	25	0.038	0.98	1.06	0.018	0.0008	19.85	24.66									0.004		
	26	0.045	0.99	1.12	0.015	0.0012	19.54	25.55											0.0002
	27	0.055	0.6	1.02	0.018	0.0018	19.77	24.87											

(continued)

Section	No	Component Content (mass%)					Weldability Index*1	Evaluation of Weld Cracking		Evaluation of Weld Workability	Oxidation Resistance (g/m2)
		REM	Al	Ca	O	N		Evaluation of Weld Cracking (%)	Bead Width Ratio of Front and Back Surfaces	Bead Width Ratio of Front and Back Surfaces	
Example of Invention	1		0.025	0.0028	0.0024	0.0182	0.057	0	0.76	0.65	2.5
	2		0.019	0.0026	0.0018	0.0195	0.052	0	0.77	0.68	3.2
	3		0.008	0.0009	0.0025	0.0277	0.018	30	0.80	0.71	2.2
	4		0.006	0.0025	0.0031	0.0321	0.047	0	0.75	0.63	2.6
	5		0.014	0.0018	0.0038	0.0189	0.036	10	0.78	0.70	2.5
	6		0.012	0.0012	0.0035	0.0276	0.025	20	0.79	0.72	2.7
	7		0.007	0.0023	0.0030	0.0201	0.043	10	0.76	0.68	2.4
	8		0.024	0.0020	0.0039	0.0363	0.043	10	0.77	0.66	3.4
	9		0.018	0.0012	0.0025	0.0277	0.027	20	0.79	0.70	3.1
	10		0.022	0.0025	0.0035	0.0270	0.051	0	0.76	0.68	2.8
	11		0.008	0.0025	0.0018	0.0194	0.047	10	0.76	0.66	3.2
	12		0.019	0.0025	0.0022	0.0299	0.050	0	0.75	0.67	4.3
	13		0.045	0.0025	0.0021	0.0352	0.058	0	0.74	0.58	2.3
	14		0.017	0.0025	0.0033	0.0275	0.050	0	0.75	0.66	3.9
	15		0.026	0.0025	0.0029	0.0311	0.052	0	0.76	0.63	2.9
	16	0.002	0.024	0.0025	0.0030	0.0218	0.052	0	0.76	0.65	3.1
	17		0.033	0.0015	0.0022	0.0312	0.036	10	0.78	0.58	2.3
	18		0.042	0.0037	0.0020	0.0295	0.078	0	0.75	0.56	2.2
	19		0.009	0.0035	0.0045	0.0256	0.065	0	0.74	0.68	2.4
	20		0.014	0.0043	0.0033	0.0308	0.081	0	0.75	0.70	2.1
	21		0.027	0.0038	0.0028	0.0254	0.076	0	0.74	0.66	3.3
	22		0.024	0.0021	0.0025	0.0351	0.045	0	0.75	0.66	2.4
	23		0.025	0.0022	0.0030	0.0320	0.047	0	0.75	0.66	2.2
	24		0.018	0.0015	0.0035	0.0282	0.032	10	0.77	0.68	2.8
	25		0.030	0.0010	0.0022	0.0335	0.027	10	0.77	0.68	3.1
	26		0.019	0.0032	0.0038	0.0305	0.063	0	0.73	0.65	2.5
	27		0.042	0.0005	0.0033	0.0265	0.0211	10	0.78	0.7	2.4

*1 Weldability index: 0.29 (% Al)+17.92 (% Ca)

[Table 2]

[0046]

Table 2

Section	No	Component Content (mass%)																
		C	Si	Mn	P	S	Ni	Cr	Mo	Cu	Sn	W	Co	Ti	Nb	V	Zr	B	Mg
Comparative Example	1	0.035	0.58	1.04	0.025	0.0008	19.43	24.80											
	2	0.050	0.85	1.05	0.015	0.0050	19.51	24.75											
	6	0.041	0.55	0.80	0.015	0.0009	19.10	18.83											
	7	0.043	0.50	1.21	0.016	0.0010	19.32	25.32											
	8	0.051	0.67	1.19	0.017	0.0011	19.41	24.69											
	9	0.040	1.12	1.24	0.015	0.0012	19.15	23.87											
	10	0.041	0.98	1.03	0.015	0.0005	19.41	25.14											
	11	0.038	0.50	1.20	0.015	0.0004	19.23	24.79						0.04					
	12	0.037	0.56	1.19	0.015	0.0007	19.08	24.86							0.032				
	13	0.041	0.88	1.11	0.015	0.0008	19.19	24.82								0.30			
	14	0.035	0.55	1.08	0.018	0.0010	19.88	24.85									0.05		
	15	0.036	0.77	1.16	0.015	0.0005	19.07	24.93										0.0025	
	16	0.048	0.95	0.75	0.015	0.0009	20.12	25.14											0.002
	17	0.048	0.80	1.18	0.015	0.0010	19.66	24.82											
	18	0.042	0.56	0.98	0.018	0.0009	20.02	25.03											
	19	0.052	0.71	0.90	0.019	0.0002	19.04	24.54											
	20	0.036	0.62	1.01	0.017	0.001	20.08	25.12											
	22	0.051	0.88	1.11	0.02	0.002	19.5	25.15											

(continued)

Section	No	Component Content (mass%)					Weldability Index*1	Evaluation of Weld Cracking		Evaluation of Weld Workability	Oxidation Resistance (g/m2)
		REM	Al	Ca	O	N		Evaluation of Weld Cracking (%)	Bead Width Ratio of Front and Back Surfaces	Bead Width Ratio of Front and Back Surfaces	
Comparative Example	1		0.023	0.0025	0.0033	0.0388	0.051	100	0.76	0.66	3.2
	2		0.006	0.0016	0.0026	0.0394	0.030	100	0.79	0.70	3.0
	6		0.025	0.0027	0.0028	0.0201	0.056	20	0.74	0.66	15.1
	7		0.025	0.0054	0.0026	0.0191	0.104	30	0.70	0.48	2.5
	8		0.055	0.0010	0.0030	0.0211	0.034	30	0.71	0.47	2.2
	9		0.001	0.0006	0.0035	0.0276	0.011	100	0.82	0.75	2.4
	10		0.013	0.0005	0.0031	0.0325	0.013	100	0.81	0.76	2.3
	11		0.019	0.0025	0.0027	0.0266	0.050	60	0.76	0.65	2.5
	12		0.016	0.0025	0.0039	0.0379	0.049	50	0.75	0.68	2.8
	13		0.023	0.0025	0.0026	0.0259	0.051	50	0.75	0.67	2.6
	14		0.022	0.0027	0.0031	0.0308	0.055	60	0.77	0.68	2.6
	15		0.027	0.0025	0.0027	0.0362	0.053	100	0.75	0.64	2.7
	16		0.025	0.0038	0.0028	0.0285	0.075	100	0.82	0.71	2.2
	17	0.020	0.020	0.0025	0.0031	0.0314	0.051	60	0.76	0.65	2.5
	18		0.041	0.0046	0.0033	0.0317	0.094	30	0.71	0.48	2.3
	19		0.011	0.0004	0.0026	0.0382	0.010	100	0.85	0.72	2.5
	20		0.008	0.0055	0.0041	0.0329	0.1009	20	0.7	0.48	2.6
	22		0.031	0.0002	0.0035	0.0284	0.0126	100	0.82	0.75	2.3

*1 Weldability index: 0.29 (% Al)+17.92 (% Ca)

[0047] Next, each of the above steel plates was subjected to a welding test. In the present invention, the welding method should not be limited, and welding may be conducted by using a filler material (or filler metal), or without using a filler material or a welding rod. Although this may not be limited in the present invention, the test was conducted by TIG welding in this Example. That is, on the surface of a 50 mm-square test material which had been cut out from the steel plate as described above, TIG welding was applied in a ring configuration with a diameter of 35 mm. Further, TIG welding (without using a welding rod) was applied linearly from a corner to the opposing corner of the test material so as to intersect the welded part having the ring configuration. The welding by TIG welding was conducted at a welding speed of 50 cm/min under argon gas sealing. The welding heat input in the TIG welding was 720 J/cm for TIG welding in a ring configuration and 600 J/cm for TIG welding (without a welding rod) in a linear configuration. The occurrence of high-temperature cracking during the welding was evaluated by increasing the welding heat gain in TIG welding so as to set up the conditions such that the amount of welding penetration was excessively increased and high-temperature cracking was liable to occur.

[0048] In the evaluation of weld cracking (evaluation of the occurrence of high-temperature cracking during the welding), the occurrence or no occurrence of the cracking in the finally solidified part after the TIG welding (without a welding rod) in a linear configuration was observed on both front and back surfaces by using a magnifier (magnification of 10 times). The score of the weld cracking was 0.5, when the cracking was observed on either the front or back surface, and the score was 1 (one), when the cracking was observed on both the front and back surfaces. The evaluations were conducted by using 5 test materials, the incidence of the cracking was determined from the score of the occurrence of the cracking. The test material, of which the incidence of cracking exceeded 30%, was judged as "failed" because of bad weldability. The evaluation results of bead width of the back surface/bead width of front surface, which had been determined by measuring the bead width on front and back surfaces by using a ruler are shown together.

[0049] Further, as the evaluation of weld workability (welding penetration), the welding penetration when the welding heat input is low and the amount of welding penetration is liable to be excessively decreased was evaluated. For this purpose, TIG welding (without a welding rod) in a linear configuration was conducted with a welding heat input of 480 J/cm, the bead width was measured on the front and back surfaces by using a ruler. The test material where bead width of back surface/bead width of front surface < 0.5 was judged as "failed" because of bad welding penetration.

(Oxidation Resistance Test)

[0050] A continuous oxidation test was conducted at 1,000°C for 200 hours in the atmosphere by using a test piece of 20 mm × 30 mm, and the oxidation resistance was evaluated in terms of the oxidation increment. The test piece where the oxidation increment exceeded 5 g/m^2 was judged as "failed".

[0051] As shown in Table 1, in the evaluation of weld cracking, in Examples 1 to 27 of the present invention where the composition was in the scope of the present invention, the content of each component and the weldability index represented by formula (1) were in preferred ranges. In these Examples of the present invention, the bead width ratio of front and back surfaces in the evaluation of weld cracking was 0.8 or less, the amount of welding penetration was not excessively increased, and the incidence of cracking was 30% or less. It was confirmed that in Examples 1 to 27 of the present invention where the composition was in the scope of the present invention, the performance in terms of weld cracking is excellent. On the other hand, as shown in Table 2, in Comparative Examples 1 and 2 where the amounts of P, S, C and Si were respectively outside the scope of the present invention, in Comparative Examples 9, 10 and 17 where the weldability index represented by formula (1) was below the lower limit of the scope of the present invention, and in Comparative Examples 11 to 17 where the amounts of Ti, Nb, V, Zr, B, Mg and REM were respectively outside the scope of the present invention, the incidence of the occurrence of cracking exceeded 30%, and it was confirmed that the weldability were poor. Particularly, in Comparative Examples 9, 10 and 19 where the weldability index was below the lower limit of the present invention, the bead width of front and back surfaces exceeded 0.8.

[0052] As the evaluation of weld workability, an evaluation was conducted by decreasing the welding heat input for the purpose of confirming a welding penetration failure due to variation of the welding current. As a result, in Examples 1 to 27 where the composition was in the scope of the present invention, the bead width ratio of front and back surfaces in the evaluation of welding workability showed a value of 0.5 or more, and it was confirmed that the weldability had no problem. On the other hand, in Comparative Examples 7 and 8 where the amounts of Al and Ca were respectively outside the scope of the present invention, and in Comparative Examples 7 and 18 where the weldability index was over the upper limit of the present invention, it was found that when the welding heat input is lowered, the bead width ratio of front and back surfaces was reduced, the welding penetration was poor, and the welding workability was deteriorated.

[0053] Fig. 1 shows a relationship among the amounts added of Al and Ca, which are features of the present invention, and the weldability index. In Fig. 1, the region where the solidification cracking at the time of excessive welding heat input may be suppressed by adding appropriate amounts of Al and Ca, is shown by a region above the lower limit line of formula (1) in the Figure. On the other hand, the region where the excessive addition of Al and Ca may decrease the welding penetration is shown by a region below the upper limit line of formula (1), the upper limit line of Al, and the upper limit line of Ca. In Examples where the components was in the scope of implementation of the present invention, the solidification cracking at the time of excessive heat input did not occur and the performance in terms of the weld cracking was good. Further, in Examples of the present invention, the insufficient welding penetration at the time of low heat input was not caused and the welding workability was good. On the other hand, in Comparative Examples outside the scope of the present invention, the solidification cracking or insufficient welding penetration was observed.

[0054] Further, in an oxidation resistance test assuming the use in a high-temperature condition, in Examples 1 to 27 where the composition was in the scope of the present invention, the oxidation increment was 5 g/m^2 or less. On the other hand,

[0055] in Comparative Example 6 where the Cr amount was smaller than the range, the oxidation increment was more than 5 g/m^2, and it was found that the oxidation resistance was poor in view of the application thereof to a high-temperature condition.

Industrial Applicability

[0056] As described hereinabove, the present invention may provide an austenitic stainless steel with excellent weldability for an article having a tubular structure. Therefore, the present invention may greatly enhance the welding workability at the time of producing an article with a tubular structure having a complicated shape, and may be of great industrial value.

Claims

1. An austenitic stainless steel for an article having a tubular structure, consisting of, in mass%,
C: from 0.001 to 0.2%,
Si: from 0.01 to 1.5%,
Mn: from 0.01 to 1.5%,
Cr: from 20.0 to 26.0%,
Ni: from 15.0 to 23.0%,
N: from 0.001 to 0.07%,
Al: from 0.003 to 0.05%, and
Ca: from 0.0003 to 0.005%, and
optionally further one member or two or more members of, in mass%,
Cu: from 0.001 to 0.3%,
Mo: from 0.001 to 0.3%,
Sn: from 0.001 to 0.05%,
W: from 0.001 to 0.10%,
Co: from 0.001 to 0.10%,
Ti: from 0.001 to 0.03%,
Nb: from 0.001 to 0.03%,
V: from 0.001 to 0.2%,
Zr: from 0.001 to 0.03%,
B: from 0.00001 to 0.001%,
Mg: from 0.00001 to 0.001%, and
REM: from 0.00001 to 0.01%,
with the balance being Fe and unavoidable impurities,
wherein the contents of P and S as impurities are limited to, in mass%,
P: ≤ 0.022%, and
S: ≤ 0.004%, and
Al and Ca satisfy the following formula:

$$0.015 \leq 0.29\ (\%\ Al) + 17.92\ (\%\ Ca) \leq 0.093 \qquad \text{formula (1).}$$

2. The austenitic stainless steel for an article having a tubular structure according to claim 1, wherein Al and Ca satisfy the following formula:

$$0.03 \leq 0.29\ (\%\ Al) + 17.92\ (\%\ Ca) \leq 0.093 \quad \text{formula (1).}$$

3. The austenitic stainless steel for an article having a tubular structure according to claim 1 or 2, wherein the tubular structure is a welded structural body.

4. The austenitic stainless steel for an article having a tubular structure according to claim 1 or 2, wherein a bead width ratio of front and back surfaces (bead width of back surface/bead width of front surface) is 0.5 or more, when TIG welding in a linear configuration is conducted at a welding speed of 50 cm/min and with a welding heat input of 480 J/cm, and the bead width ratio of front and back surfaces is 0.8 or less, when TIG welding in a linear configuration is conducted at a welding speed of 50 cm/min and with a welding heat input of 600 J/cm, wherein the TIG welding is without a welding rod.

5. A method for producing a welded structural body, wherein the welded structural body is produced by a method involving TIG welding using the austenitic stainless steel for an article having a tubular structure according to any one of claims 1 to 3.

6. An article having a tubular structure, wherein said tubular structure comprises an austenitic stainless steel according to any one of claims 1 to 4.

Patentansprüche

1. Ein austenitischer rostfreier Stahl für einen Gegenstand mit einer röhrenförmigen Struktur, bestehend aus, in Massen-%,
C: von 0,001 bis 0,2%,
Si: von 0,01 bis 1,5%,
Mn: von 0,01 bis 1,5%,
Cr: von 20,0 bis 26,0%,
Ni: von 15,0 bis 23,0%,
N: von 0,001 bis 0,07%,
Al: von 0,003 bis 0,05%, und
Ca: von 0,0003 bis 0,005%, und
gegebenenfalls weiter ein Element oder zwei oder mehrere Elemente aus, in Massen-%,
Cu: von 0,001 bis 0,3%,
Mo: von 0,001 bis 0,3%,
Sn: von 0,001 bis 0,05%,
W: von 0,001 bis 0,10%,
Co: von 0,001 bis 0,10%,
Ti: von 0,001 bis 0,03%,
Nb: von 0,001 bis 0,03%,
V: von 0,001 bis 0,2%,
Zr: von 0,001 bis 0,03%,
B: von 0,00001 bis 0,001%,
Mg: von 0,00001 bis 0,001%, und
Seltenerdmetalle: 0,00001 bis 0,01%,
wobei der Rest aus Fe und unvermeidbaren Verunreinigungen besteht,
wobei die Anteile an P und S als Verunreinigungen begrenzt sind auf, in Massen-%,
P: ≤ 0,022%, und
S: ≤ 0,004%, und
Al und Ca die folgende Formel erfüllen:

$$0{,}015 \leq 0{,}29\ (\%\ Al) + 17{,}92\ (\%\ Ca) \leq 0{,}093 \qquad \text{Formel (1).}$$

2. Der austenitische rostfreie Stahl für einen Gegenstand mit einer röhrenförmigen Struktur nach Anspruch 1, wobei Al und Ca die folgende Formel erfüllen:

$$0{,}03 \leq 0{,}29\ (\%\ Al) + 17{,}92\ (\%\ Ca) \leq 0{,}093 \text{ Formel (1).}$$

3. Der austenitische rostfreie Stahl für einen Gegenstand mit einer röhrenförmigen Struktur nach Anspruch 1 oder 2, wobei die röhrenförmige Struktur ein geschweißter strukturierter Körper ist.

4. Der austenitische rostfreie Stahl für einen Gegenstand mit einer röhrenförmigen Struktur nach Anspruch 1 oder 2, wobei ein Wulstbreitenverhältnis von Vorder- und Rückfläche (Wulstbreite der Rückfläche/Wulstbreite der Vorderfläche) 0,5 oder mehr beträgt, wenn das TIG-Schweißen in einer linearen Konfiguration mit einer Schweißgeschwindigkeit von 50 cm/min und mit einem Schweißwärmeinput von 480 J/cm durchgeführt wird, und das Wulstbreitenverhältnis von Vorder- und Rückseite 0,8 oder weniger beträgt, wenn das TIG-Schweißen in einer linearen Konfiguration mit einer Schweißgeschwindigkeit von 50 cm/min und mit einem Schweißwärmeinput von 600 J/cm durchgeführt wird, wobei das TIG-Schweißen ohne Schweißdraht erfolgt.

5. Ein Verfahren zur Herstellung eines geschweißten strukturierten Körpers, wobei der geschweißte strukturierte Körper durch ein Verfahren hergestellt wird, das TIG-Schweißen unter Verwendung des austenitischen rostfreien Stahls für einen Gegenstand mit einer röhrenförmigen Struktur nach einem der Ansprüche 1 bis 3 umfasst.

6. Ein Gegenstand mit einer röhrenförmigen Struktur, wobei die röhrenförmige Struktur einen austenitischen rostfreien Stahl nach einem der Ansprüche 1 bis 4 umfasst.

Revendications

1. Acier inoxydable austénitique pour un article présentant une structure tubulaire consistant en, en % en masse,
C : de 0,001 à 0,2 %,
Si : de 0,01 à 1,5 %,
Mn : de 0,01 à 1,5 %,
Cr : de 20,0 à 26,0 %,
Ni : de 15,0 à 23,0 %,
N : de 0,001 à 0,07 %,
Al : de 0,003 à 0,05 %, et
Ca : de 0,0003 à 0,005 %, et
éventuellement de plus un élément ou deux éléments ou plus de, en % en masse,
Cu : de 0,001 à 0,3 %,
Mo : de 0,001 à 0,3 %,
Sn : de 0,001 à 0,05 %,
W : de 0,001 à 0,10 %,
Co : de 0,001 à 0,10 %,
Ti : de 0,001 à 0,03 %,
Nb : de 0,001 à 0,03 %,
V : de 0,001 à 0,2 %,
Zr : de 0,001 à 0,03 %,
B : de 0,00001 à 0,001 %,
Mg : de 0,00001 à 0,001 %, et
REM : de 0,00001 à 0,01 %,
avec le reste étant Fe et des impuretés inévitables,
dans lequel les teneurs en P et S comme impuretés sont limitées à, en % en masse,
P : ≤ 0,022 %, et
S : ≤ 0,004 %, et
Al et Ca satisfont la formule suivante :

$$0{,}015 \leq 0{,}29\ (\%\ Al) + 17{,}92\ (\%\ Ca) \leq 0{,}093 \qquad \text{formule (1).}$$

2. Acier inoxydable austénitique pour un article présentant une structure tubulaire selon la revendication 1, dans lequel Al et Ca satisfont la formule suivante :

$$0,03 \leq 0,29\ (\%\ Al) + 17,92\ (\%\ Ca) \leq 0,093 \qquad \text{formule (1).}$$

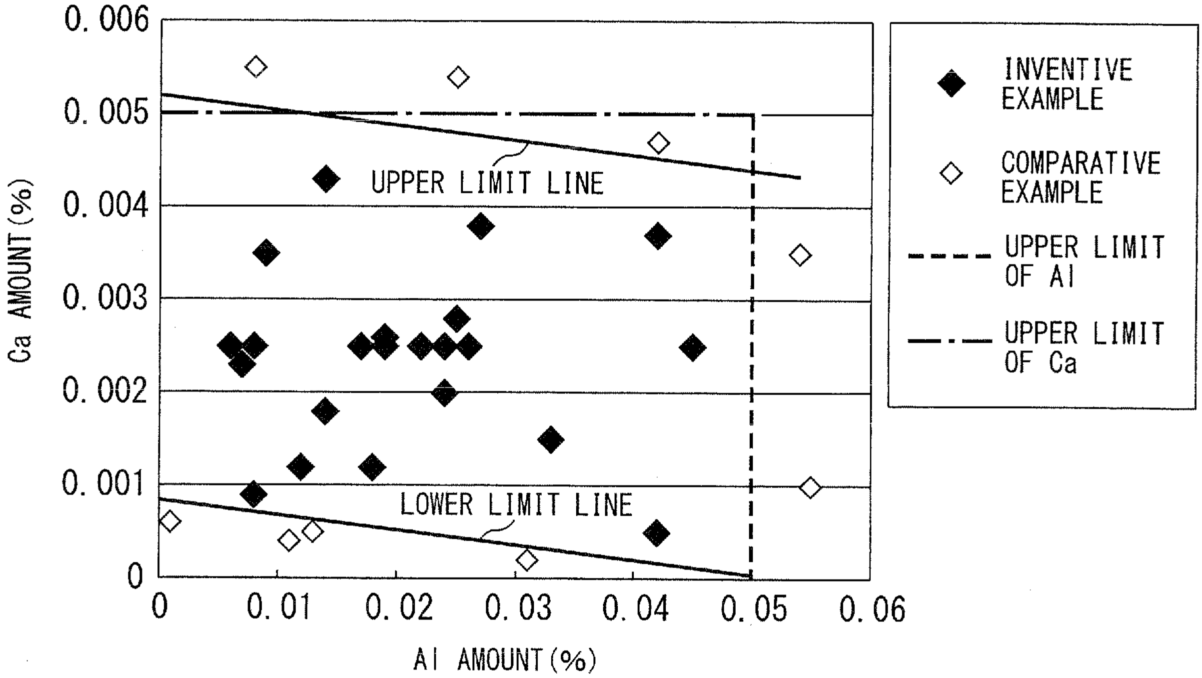
3. Acier inoxydable austénitique pour un article présentant une structure tubulaire selon la revendication 1 ou 2, dans lequel la structure tubulaire est un corps structurel soudé.

4. Acier inoxydable austénitique pour un article présentant une structure tubulaire selon la revendication 1 ou 2, dans lequel un rapport de largeur de cordon de soudure de surfaces avant et arrière (largeur de cordon de soudure de surface arrière/largeur de cordon de soudure de surface avant) est de 0,5 ou supérieur, lorsqu'un soudage TIG dans une configuration linéaire est réalisé à une vitesse de soudage de 50 cm/min et avec une entrée de chaleur de soudage de 480 J/cm, et le rapport de largeur de cordon de soudure de surfaces avant et arrière est de 0,8 ou inférieur, lorsqu'un soudage TIG dans une configuration linéaire est réalisé à une vitesse de soudage de 50 cm/min et avec une entrée de chaleur de soudage de 600 J/cm, dans lequel le soudage TIG se fait sans baguette de soudure.

5. Procédé de production d'un corps structurel soudé, dans lequel le corps structurel soudé est produit par un procédé impliquant un soudage TIG utilisant l'acier inoxydable austénitique pour un article présentant une structure tubulaire selon l'une quelconque des revendications 1 à 3.

6. Article présentant une structure tubulaire, dans lequel ladite structure tubulaire comprend un acier inoxydable austénitique selon l'une quelconque des revendications 1 à 4.

FIG. 1


0.006
0.005
0.004
0.003
0.002
0.001
0
Ca AMOUNT (%)
UPPER LIMIT LINE
LOWER LIMIT LINE
0
0.01
0.02
0.03
0.04
0.05
0.06
Al AMOUNT (%)
INVENTIVE EXAMPLE
COMPARATIVE EXAMPLE
UPPER LIMIT OF Al
UPPER LIMIT OF Ca

REFERENCES CITED IN THE DESCRIPTION

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