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(54) **CAST AUSTENITIC STAINLESS STEEL**

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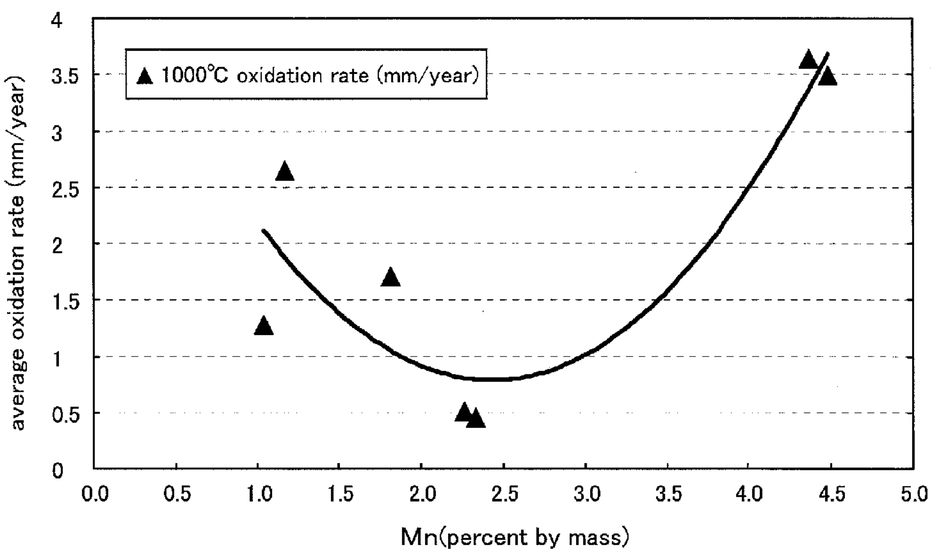
(57) **ABSTRACT**

An austenitic stainless cast steel having a volume fraction of a ferrite phase of 0.1-5.0%.

*Fig. 1*


▲ 1000°C oxidation rate (mm/year)
average oxidation rate (mm/year)
4
3.5
3
2.5
2
1.5
1
0.5
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Mn(percent by mass)

# CAST AUSTENITIC STAINLESS STEEL

## TECHNICAL FIELD

**[0001]** The present invention relates to an austenitic stainless cast steel.

## BACKGROUND ART

**[0002]** An austenitic stainless cast steel exhibits excellent properties especially in corrosion resistance, strength, weldability and the like, and has been widely used for piping, valves and the like in chemical plants and power plants. The austenitic stainless cast steel is formed of, for example from metallurgical viewpoint, two phases including approximately 10-20% of an alpha phase and approximately 90-80% of a gamma phase (austenitic phase).

**[0003]** As for steel castings of the austenitic stainless steel, CF8C has been known. For example, a CF8C austenitic stainless steel casting includes: up to 0.08 percent by mass of C (carbon); up to 2.0 percent by mass of Si (silicon); up to 1.5 percent by mass of Mn (manganese); 18.0-21.0 percent by mass of Cr (chromium); 9.0-12.0 percent by mass of Ni (nickel); and up to 1.0 percent by mass of Nb (niobium).

**[0004]** CF8C includes approximately 12.0% of a ferrite phase. The ferrite phase can be, for example, measured as ferrite content in the austenitic stainless steel with a known ferrite scope, or calculated using a Schaeffler diagram based on component elements, and is indicated with volume fraction (percent (%)).

**[0005]** The ferrite phase is considered effective for preventing weld cracking and reducing stress corrosion cracking. However, if a ferrite phase content is large, for example, exposure of CF8C to high temperature for a long period of time may transform the ferrite phase into a sigma phase ($\sigma$ phase), which is a compound of iron and chromium. This may lead to embrittlement of the steel casting.

**[0006]** Patent Document 1 discloses CF8C-Plus, which is an alloy modified from CF8C, and describes that CF8C-Plus does not contain ferrite phase. Patent Document 1 also describes that CF8C-Plus includes: 0.05-0.15 percent by mass of C; 0.2-1.0 percent by mass of Si; 0.5-10.0 percent by mass of Mn; 18.0-25.0 percent by mass of Cr; 10.0-15.0 percent by mass of Ni; 0.1-1.5 percent by mass of Nb; and 0.05-0.5 percent by mass of N.

**[0007]** In Patent Document 1, an absence of the ferrite phase from CF8C-Plus is considered important for retaining the properties imparted at casting of materials during a life of the component part produced from the materials.

**[0008]** When CF8C is exposed to high temperature for a long period of time under usage environment, the sigma phase is precipitated to cause aging embrittlement, and thus aging ductility may become poor. Also in the case of CF8C-Plus described in Patent Document 1, further improvement has been demanded in oxidation resistance.

**[0009]** Therefore, it has been desired to provide an austenitic stainless cast steel exhibiting excellent aging ductility and oxidation resistance.

## CITATION LIST

### Patent Literature

**[0010]** Patent Document 1: Japanese translation of a PCT application Kohyo No. 2009-545675

## SUMMARY OF INVENTION

**[0011]** In order to provide such an austenitic stainless cast steel, the inventions of the following items (1)-(6) are provided.

**[0012]** (1) An austenitic stainless cast steel having a volume fraction of a ferrite phase of 0.1-5.0%.

**[0013]** (2) The austenitic stainless cast steel according to item (1), including: 0.01-0.10 percent by mass of C; 0.6-1.0 percent by mass of Si; 2.0-2.8 percent by mass of Mn; and 0.1-0.4 percent by mass of N.

**[0014]** (3) The austenitic stainless cast steel according to item (1) or (2), including: 18.0-24.0 percent by mass of Cr; 8.0-15.0 percent by mass of Ni; and 0.2-0.7 percent by mass of Nb.

**[0015]** (4) An austenitic stainless cast steel, wherein a volume fraction of the ferrite phase is 0.1-5.0%, and the cast steel includes: 0.01-0.10 percent by mass of C; 0.6-1.0 percent by mass of Si; 2.0-2.8 percent by mass of Mn; 0.1-0.4 percent by mass of N; 18.0-24.0 percent by mass of Cr; 8.0-15.0 percent by mass of Ni; 0.2-0.7 percent by mass of Nb; and the balance is Fe and inevitable impurities. (5) The austenitic stainless cast steel according to any one of items (1)-(4), obtained by performing cooling from a temperature range of 1,150-1,350° C. to a temperature range of 600-800° C. at a cooling rate of 30° C./min or more. (6) A valve formed of austenitic stainless cast steel according to any one of items (1)-(5).

**[0016]** The austenitic stainless cast steel of the present invention is excellent in, for example, aging ductility, tensile strength and oxidation resistance, as will be described in Examples. Especially, the aging ductility in Examples of the present invention was approximately 2.4 times as high as that in Comparative Examples. Likewise, oxidation resistance in Examples of the present invention was approximately 9.5 times as high as that in Comparative Examples.

**[0017]** The reason that the austenitic stainless cast steel exhibits such excellent properties seems to be that the volume fraction of the ferrite phase is 0.1-5.0%, and the contents of the components C, Si, Mn, Cr, Ni, Nb and N seem to play important roles. Hereinbelow, each component will be described in detail.

**[0018]** By setting the volume fraction of the ferrite phase to 0.1-5.0%, even when the cast steel is exposed to high temperature for a long period of time, a precipitation amount of the sigma phase can be suppressed low. Since the precipitation amount of the sigma phase is low, the austenitic stainless cast steel is unlikely to be embrittled, and exhibits excellent aging ductility.

**[0019]** C has an effect of lowering a melting point and improving fluidity, i.e. castability of molten metal. In addition, it is preferable that the amount of C is low from the viewpoint of corrosion resistance, and if a large amount is added, the corrosion resistance of the base metal is reduced. In view of these, in order to improve high-temperature ductility, an additive amount of C in the present invention is set to 0.01-0.10 percent by mass.

**[0020]** Si serves as deoxidizing agent for molten metal, and is effective for improving fluidity, oxidation resistance, and weldability. However, an excessive addition will make the austenitic structure unstable, leading to deterioration of castability, hinder workability and weldability, and promotion of weld cracking. Therefore, an additive amount of Si in the present invention is set to 0.6-1.0 percent by mass.

**[0021]** Mn is effective as deoxidizing agent for molten metal, and enhances fluidity during the casting to thereby improve productivity. In addition, it is also effective for reducing weld cracking. Since an excessive addition will deteriorate oxidation resistance, an additive amount of Mn in the present invention is set to 2.0-2.8 percent by mass. When Mn is in this range, the austenitic stainless cast steel exhibiting excellent oxidation resistance can be obtained, as will be described in Examples.

**[0022]** N improves high-temperature strength and thermal fatigue resistance, and is a strong austenite forming element which stabilizes an austenitic matrix. In addition, N is an element effective for grain refining. With this grain refining, ductility of the material which is important as structure can be secured, and in addition, a drawback of poor machinability, which is specific in the austenitic stainless cast steel, can be improved. Especially, N renders excellent perforation machinability to a member to be perforated for connecting parts. When N is added in a large amount, embrittlement is promoted, while an effective Cr amount is reduced and thus oxidation resistance is deteriorated. Therefore, an additive amount of N in the present invention is set to 0.1-0.4 percent by mass.

**[0023]** Cr improves oxidation resistance and stabilizes the ferrite structure. In order to reliably attain this effect, the amount of Cr is set to 18.0 percent by mass or more. On the other hand, an excessive addition will lower the aging ductility of the steel due to excessive precipitation of Cr carbide when the case steel is used at high temperature, and thus the upper limit of the Cr amount is set to 24.0 percent by mass.

**[0024]** Ni facilitates the formation of the stable austenitic matrix, stabilizes the austenitic phase, and enhances high-temperature strength and oxidation resistance of the steel. Taking excellent castability, corrosion resistance and weldability into consideration, an additive amount of Ni in the present invention is set to 8.0-15.0 percent by mass.

**[0025]** Nb binds with C to form fine carbide, and improves high-temperature strength. In addition, the formation of Cr carbide is suppressed, and thus oxidation resistance can be improved. In order to effectively exert these effects, the content of 0.2% or more is required. However, when Nb is added in an excessive amount, heat cracking susceptibility is notably enhanced, and inner quality will be deteriorated. Therefore, an additive amount of Nb in the present invention is set to 0.2-0.7 percent by mass.

**[0026]** In addition, the austenitic stainless cast steel of the present invention can be produced by performing cooling from a temperature range of 1,150-1,350° C. to a temperature range of 600-800° C. at a cooling rate of 30° C./min or more. By producing the austenitic stainless cast steel of the present invention under the above-described conditions, even when the cast steel is left as-cast, excellent strength property can be obtained, and thus solution heat treatment can be omitted.

**[0027]** The produced austenitic stainless cast steel is used as, for example, materials for piping, valves and the like in chemical plants and power plants.

## BRIEF DESCRIPTION OF DRAWINGS

**[0028]** FIG. **1** is a graph showing results of oxidation resistance (mm/year) examined with respect to the austenitic stainless cast steel.

## DESCRIPTION OF EMBODIMENTS

**[0029]** Hereinbelow, embodiments of the present invention will be described with reference to the drawings.

**[0030]** The austenitic stainless cast steel of the present invention is formed in such a manner that the volume fraction of the ferrite phase becomes 0.1-5.0%, preferably 0.5-3.0%. The austenitic stainless cast steel of the present invention includes C, Si, Mn, Cr, Ni, Nb, N and the like as components thereof.

**[0031]** The contents are as follows:

**[0032]** C: 0.01-0.10 percent by mass, preferably 0.02-0.04 percent by mass;

**[0033]** Si: 0.6-1.0 percent by mass, preferably 0.7-0.9 percent by mass;

**[0034]** Mn: 2.0-2.8 percent by mass, preferably 2.2-2.4 percent by mass;

**[0035]** N: 0.1-0.4 percent by mass, preferably 0.15-0.25 percent by mass;

**[0036]** Cr: 18.0-24.0 percent by mass, preferably 19.5-21.5 percent by mass;

**[0037]** Ni: 8.0-15.0 percent by mass, preferably 10.5-12.5 percent by mass; and

**[0038]** Nb: 0.2-0.7 percent by mass, preferably 0.2-0.4 percent by mass.

**[0039]** The compositions (percent by mass) of the austenitic stainless cast steel of the present invention, and of CF8C and CF8C-Plus for comparison, are shown in Table 1.

TABLE 1

| | Austenitic stainless cast steel of the present invention | CF8C | CF8C-Plus |
|---|---|---|---|
| Ferrite (volume fraction (%)) | 0.1-5.0 | 12.0 | — |
| C (percent by mass) | 0.01-0.10 | Up to 0.08 | 0.05-0.15 |
| Si (percent by mass) | 0.6-1.0 | Up to 2.0 | 0.2-1.0 |
| Mn (percent by mass) | 2.0-2.8 | Up to 1.5 | 0.5-10.0 |
| Cr (percent by mass) | 18.0-24.0 | 18.0-21.0 | 18.0-25.0 |
| Ni (percent by mass) | 8.0-15.0 | 9.0-12.0 | 10.0-15.0 |
| Nb (percent by mass) | 0.2-0.7 | Up to 1.0 | 0.1-1.5 |
| N (percent by mass) | 0.1-0.4 | — | 0.05-0.5 |

**[0040]** In the austenitic stainless cast steel of the present invention, by setting the volume fraction of the ferrite phase to 0.1-5.0%, even when the cast steel is exposed to high temperature for a long period of time, the precipitation amount of the sigma phase can be suppressed low. Therefore, the austenitic stainless cast steel of the present invention is unlikely to be embrittled, and exhibits excellent aging ductility.

**[0041]** In addition, the austenitic stainless cast steel of the present invention has a higher Mn content and a lower C content than those of CF8C. With this configuration, the strength and oxidation resistance at high temperature can be improved.

**[0042]** In addition to the components described above, the austenitic stainless cast steel of the present invention may further include W, B, Al, Mo, Co, Ti, Zr, Cu, rare-earth element (La, Ce, Y, Pd, Nd and the like) or the like, and the balance is Fe and inevitable impurities.

**[0043]** The austenitic stainless cast steel of the present invention can be produced by melting the above-described metal components in a melting furnace and performing cooling from a temperature range of 1,150-1,350° C. to a temperature range of 600-800° C. at a cooling rate of 30° C./min or more. By producing the austenitic stainless cast steel of the present invention under the above-described conditions, even when the cast steel is left as-cast, excellent strength property can be obtained, and thus solution heat treatment can be omitted.

**[0044]** The produced austenitic stainless cast steel is used, for example, for piping, valves and the like in chemical plants and power plants.

## Example 1

**[0045]** Example of the present invention will be described. The main components (percent by mass) of the austenitic stainless cast steel of the present invention (Examples 1-1-1-6) and CF8C (Comparative Examples 1-1-1-5) are shown in Tables 2 and 3, respectively.

TABLE 2

| | Example | | | | | |
|---|---|---|---|---|---|---|
| | 1-1 | 1-2 | 1-3 | 1-4 | 1-5 | 1-6 |
| Ferrite (volume fraction (%)) | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| C (percent by mass) | 0.04 | 0.03 | 0.04 | 0.03 | 0.08 | 0.06 |
| Si (percent by mass) | 0.76 | 0.86 | 0.76 | 0.86 | 0.89 | 0.86 |
| Mn (percent by mass) | 2.07 | 2.15 | 2.07 | 2.15 | 2.07 | 2.12 |
| Cr (percent by mass) | 20.55 | 19.90 | 20.55 | 19.90 | 22.35 | 22.10 |
| Ni (percent by mass) | 11.38 | 11.12 | 11.38 | 11.12 | 10.50 | 10.34 |
| Nb (percent by mass) | 0.27 | 0.26 | 0.27 | 0.26 | 0.29 | 0.32 |
| N (percent by mass) | 0.21 | 0.20 | 0.21 | 0.20 | 0.19 | 0.21 |

TABLE 3

| | Comparative Example | | | | |
|---|---|---|---|---|---|
| | 1-1 | 1-2 | 1-3 | 1-4 | 1-5 |
| Ferrite (volume fraction (%)) | 12.0 | 9.0 | 0 | 0 | 0 |
| C (percent by mass) | 0.03 | 0.03 | 0.017 | 0.08 | 0.06 |
| Si (percent by mass) | 0.47 | 0.63 | 0.37 | 0.48 | 0.57 |
| Mn (percent by mass) | 1.04 | 4.48 | 1.83 | 1.02 | 2.02 |
| Cr (percent by mass) | 19.98 | 19.93 | 19.93 | 19.35 | 19.60 |
| Ni (percent by mass) | 9.92 | 9.45 | 11.63 | 11.49 | 11.55 |
| Nb (percent by mass) | 0.59 | 0.42 | 0.43 | 0.69 | 0.71 |
| N (percent by mass) | 0.03 | 0.10 | 0.24 | 0.25 | 0.24 |

**[0046]** In these Examples and Comparative Examples, aging ductility (700° C.-620 hours), tensile strength (900° C.), 0.2% proof stress (900° C.) and oxidation resistance (1,000° C.) were examined, and further a high-temperature low-cycle fatigue test (alternate triangular waves, strain rate of 0.1%/sec, 700° C., total strain of 0.5%) was performed.

**[0047]** It should be noted that both in Examples and Comparative Examples, casting was performed using normal static casting method. In Examples 1 and 2, the cast steel was left as-cast, while in the other Examples and Comparative Examples, the cast steel was subjected to SHT (solution heat treatment). Aging ductility, tensile strength, 0.2% proof stress, and oxidation resistance were examined and the results are shown in Table 4.

TABLE 4

| | Aging ductility (%) | Tensile strength (Mpa) | 0.2% proof stress (Mpa) | Oxidation resistance (mm/year) | High-temperature low-cycle fatigue test (times) |
|---|---|---|---|---|---|
| Example 1-1 | 24.4 | 120 | 90 | 0.300 | — |
| Example 1-2 | 28.8 | 125 | 87 | 0.370 | 6200 |
| Example 1-3 | 24.0 | 113 | 91 | 0.066 | 3400 |
| Example 1-4 | 29.2 | 134 | 89 | 0.122 | 2420 |
| Example 1-5 | 20.4 | 131 | 91 | 0.489 | — |
| Example 1-6 | 22.1 | 129 | 88 | 0.394 | — |
| Comparative Example 1-1 | 17.2 | 93 | 70 | 1.278 | 2388 |
| Comparative Example 1-2 | 6.8 | 101 | 75 | 3.494 | — |
| Comparative Example 1-3 | 8.6 | 127 | 84 | 1.854 | — |
| Comparative Example 1-4 | 11.2 | 98 | 73 | 4.101 | — |
| Comparative Example 1-5 | 8.2 | 104 | 77 | 3.124 | — |

**[0048]** As a result, regarding aging ductility, Examples exhibited 20.4% or more, while Comparative Examples exhibited 17.2% or less.

**[0049]** Regarding tensile strength, Examples exhibited 113-134 Mpa, while Comparative Examples exhibited 93-127 Mpa.

**[0050]** Regarding 0.2% proof stress, Examples exhibited 87-91 Mpa, while Comparative Examples exhibited 70-84 Mpa.

**[0051]** Regarding oxidation resistance, Examples exhibited 0.489 mm/year or less, while Comparative Examples exhibited 1.278 mm/year or more.

**[0052]** To sum up, though Examples and Comparative Examples were not notably distinguishable in the 0.2% proof stress, it was found that Example exhibited excellent result in aging ductility, tensile strength and oxidation resistance. Especially, an average value of the aging ductility in Examples was 24.8%, while an average value in Comparative Examples was 10.4%, and thus the value in Example was approximately 2.4 times as high as that in Comparative Example. Likewise, an average value of oxidation resistance in Examples was 0.290 mm/year, while an average value in Comparative Examples was 2.770 mm/year, and thus the value in Example was improved approximately 9.5 times as much as that in Comparative Example.

**[0053]** The above-described results shows the case where the volume fraction of the ferrite phase of the austenitic stainless cast steel of the present invention was 0.2%, and it is considered that similar results will be obtained when a lower limit of the volume fraction of the ferrite phase is set to 0.1%.

## Example 2

**[0054]** In Example 1, the volume fraction of the ferrite phase of the austenitic stainless cast steel of the present invention was 0.2% (Examples 1-1-1-6). In addition, also for a case in which the volume fraction of the ferrite phase is 1-3%, aging ductility, tensile strength, 0.2% proof stress and oxidation resistance were examined (Examples 2-1-2-4) under the same condition for Example 1. The components of Examples 2-1-2-4 are shown in Table 5, and the results are shown in Table 6.

TABLE 5

| | Example | | | |
|---|---|---|---|---|
| | 2-1 | 2-2 | 2-3 | 2-4 |
| Ferrite (volume fraction (%)) | 2 | 1 | 3 | 1 |
| C (percent by mass) | 0.014 | 0.013 | 0.020 | 0.013 |
| Si (percent by mass) | 0.67 | 0.72 | 0.62 | 0.72 |
| Mn (percent by mass) | 2.26 | 2.37 | 2.00 | 2.22 |
| Cr (percent by mass) | 21.10 | 21.10 | 21.70 | 22.22 |
| Ni (percent by mass) | 11.29 | 11.38 | 12.09 | 11.54 |
| Nb (percent by mass) | 0.29 | 0.29 | 0.27 | 0.27 |
| N (percent by mass) | 0.22 | 0.23 | 0.16 | 0.23 |

TABLE 6

| | Aging ductility (%) | Tensile strength (Mpa) | 0.2% proof stress (Mpa) | Oxidation resistance (mm/year) |
|---|---|---|---|---|
| Example 2-1 | 27.0 | 128 | 89 | 0.006 |
| Example 2-2 | 24.0 | 123 | 88 | 0.058 |
| Example 2-3 | 27.0 | 95 | 63 | 0.558 |
| Example 2-4 | 20.4 | 137 | 88 | 0.015 |

**[0055]** As a result, an average value of aging ductility in Examples 2-1-2-4 was 24.6%, and an average value of oxidation resistance was 0.159 mm/year. Like in Example 1, these values are recognized as being excellent over the values in Comparative Example. It is considered that similar results will be obtained when an upper limit of the volume fraction of the ferrite phase of the austenitic stainless cast steel of the present invention is set to 5%.

Example 3

**[0056]** With respect to the austenitic stainless cast steel whose Mn content was approximately 1.0-4.5 percent by mass, oxidation resistance (mm/year) was examined. As the austenitic stainless cast steel of the present invention, those with the Mn content of 2.26 percent by mass (Example 3-1) and 2.33 percent by mass (Example 3-2) were used. As the austenitic stainless cast steel of Comparative Example, those with the Mn content of 1.04 percent by mass (Comparative Example 3-1), 1.17 percent by mass (Comparative Example 3-2), 1.81 percent by mass (Comparative Example 3-3), 4.37 percent by mass (Comparative Example 3-4), and 4.48 percent by mass (Comparative Example 3-5) were used. The components for these Examples and Comparative Examples are shown in Table 7. The results are shown in Table 8 and FIG. **1**.

TABLE 7

| | Example | | Comparative Example | | | | |
|---|---|---|---|---|---|---|---|
| | 3-1 | 3-2 | 3-1 | 3-2 | 3-3 | 3-4 | 3-5 |
| Ferrite (volume fraction (%)) | 2 | 3 | 12 | 8 | 0.2 | 10 | 9 |
| C (percent by mass) | 0.03 | 0.03 | 0.03 | 0.03 | 0.017 | 0.03 | 0.03 |
| Si (percent by mass) | 0.65 | 0.64 | 0.47 | 0.61 | 0.36 | 0.62 | 0.63 |
| Mn (percent by mass) | 2.26 | 2.33 | 1.04 | 1.17 | 1.81 | 4.37 | 4.48 |
| Cr (percent by mass) | 20.45 | 20.47 | 19.98 | 20.09 | 19.87 | 19.87 | 19.93 |
| Ni (percent by mass) | 11.35 | 11.33 | 9.92 | 9.92 | 12.49 | 9.35 | 9.45 |
| Nb (percent by mass) | 0.65 | 0.62 | 0.59 | 0.62 | 0.29 | 0.66 | 0.42 |
| N (percent by mass) | 0.14 | 0.12 | 0.03 | 0.12 | 0.20 | 0.10 | 0.10 |

TABLE 8

| | Oxidation resistance (mm/year) |
|---|---|
| Example 3-1 | 0.5062 |
| Example 3-2 | 0.4521 |
| Comparative Example 3-1 | 1.2782 |
| Comparative Example 3-2 | 2.6405 |
| Comparative Example 3-3 | 1.7060 |
| Comparative Example 3-4 | 3.6345 |
| Comparative Example 3-5 | 3.4943 |

**[0057]** As can be seen in FIG. **1**, in the austenitic stainless cast steel of the present invention where the Mn content is 2.0-2.8 percent by mass, oxidation resistance can be reduced to 1 mm/year or less.

Industrial Applicability

**[0058]** The present invention is applicable to the production of the austenitic stainless cast steel.

**1**. An austenitic stainless cast steel having a volume fraction of a ferrite phase of 0.1-5.0%.

**2**. The austenitic stainless cast steel according to claim **1**, comprising: 0.01-0.10 percent by mass of C; 0.6-1.0 percent by mass of Si; 2.0-2.8 percent by mass of Mn; and 0.1-0.4 percent by mass of N.

**3**. The austenitic stainless cast steel according to claim **1** or **2**, comprising: 18.0-24.0 percent by mass of Cr; 8.0-15.0 percent by mass of Ni; and 0.2-0.7 percent by mass of Nb.

**4**. An austenitic stainless cast steel, comprising:

a volume fraction of a ferrite phase is 0.1-5.0%, and 0.1-0.10 percent by mass of C; 0.6-1.0 percent by mass of Si; 2.0-2.8 percent by mass of Mn; 0.1-0.4 percent by mass of N; 18.0-24.0 percent by mass of Cr; 8.0-15.0 percent by mass of Ni; 0.2-0.7 percent by mass of Nb; and the balance is Fe and inevitable impurities.

**5**. The austenitic stainless cast steel according to claim **1**, obtained by cooling a melted metal component from a temperature range of 1,150-1,350° C. to a temperature range of 600-800° C. at a cooling rate of 30° C./min or more.

**6**. A valve formed of comprising the austenitic stainless cast steel of claim **1**.

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