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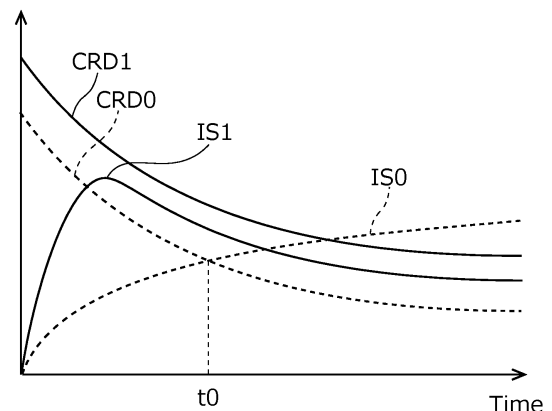
(54) **ALLOY MATERIAL**

(57) There is provided an alloy that has sufficient creep strength in a high temperature environment, and that is capable of achieving both excellent stress relaxation cracking resistance and excellent weld hot cracking resistance. An alloy according to the present disclosure consists of, in mass%, C: 0.050 to 0.100%, Si: 1.00% or less, Mn: 1.50% or less, P: 0.035% or less, S: 0.0015% or less, Cr: 19.00 to 23.00%, Ni: 30.00 to 35.00%, N: 0.100% or less, Al: 0.15 to 0.70%, Ti: 0.15 to 0.70%, and B: 0.0010 to 0.0050%, with the balance being Fe and impurities, and satisfies Formula (1) and Formula (2).

$$0.60 < \text{Al} + \text{Ti} < 1.20 \quad (1)$$

$$1.12 \leq \text{Ti}/\text{Al} \quad (2)$$

FIG. 1



Description

TECHNICAL FIELD

- 5 **[0001]** The present disclosure relates to an alloy, and more particularly relates to an alloy which can be utilized in a high temperature environment.

BACKGROUND ART

- 10 **[0002]** Alloys that are used in steam methane reformers, ethylene cracking furnaces, heating furnace pipes for petroleum refining and petrochemical plants, and polycrystalline silicon manufacturing equipment and the like are used in high temperature environments of 500 to 1000°C. Therefore, alloys that are used in such high temperature environments are required to have high creep strength and excellent corrosion resistance in a high temperature environment. Alloy 800, Alloy 800H, and Alloy 800HT are known as alloys for use in such high temperature environments.
- 15 **[0003]** Alloy 800, Alloy 800H, and Alloy 800HT each contain large amounts of Cr and Ni. Therefore, it is known that these alloys are excellent in corrosion resistance at high temperature. These alloys also contain Al and Ti. Therefore, in these alloys, a gamma-prime (γ') phase ($\text{Ni}_3(\text{Al}, \text{Ti})$) is formed in the alloy during use in a high temperature environment. Because these alloys are precipitation-strengthened by formation of the γ' phase, these alloys have excellent creep strength.
- 20 **[0004]** However, in the case of Alloy 800, Alloy 800H, and Alloy 800HT, weld hot cracking is likely to occur in a heat affected zone (HAZ) during welding. In addition, as is also introduced in Non Patent Literatures 1 and 2, when using these alloys, stress relaxation cracking may occur during use in a high temperature environment. Therefore, alloys that have chemical compositions equivalent to Alloy 800, Alloy 800H, and Alloy 800HT are required to have excellent weld hot cracking resistance and excellent stress relaxation cracking resistance.
- 25 **[0005]** In order to improve the stress relaxation cracking resistance of the alloys mentioned above, a method in which the total content of Al and Ti is limited, and a method in which a heat treatment is performed after welding and the like have been proposed. However, if the total content of Al and Ti is limited, sufficient creep strength cannot be obtained. Further, when a heat treatment is performed after welding, there may be cases where the fabrication cost increases, or where a heat treatment is not possible after welding due to the equipment design.
- 30 **[0006]** International Application Publication No. WO2018/066579 (Patent Literature 1) discloses a technique for increasing the stress relaxation cracking resistance of an alloy containing Al and Ti. In order to achieve excellent stress relaxation cracking resistance in a high temperature environment, Patent Literature 1 focuses on the γ' phase that forms in an alloy during use in a high temperature environment. According to Patent Literature 1, the chemical composition of the alloy is adjusted in order to form an appropriate amount of γ' phase during use in a high temperature environment. It is described in Patent Literature 1 that by this means, excellent stress relaxation cracking resistance is obtained during use in
- 35 a high temperature environment.

CITATION LIST

PATENT LITERATURE

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- [0007]** Patent Literature 1: International Application Publication No. WO2018/066579

NON PATENT LITERATURE

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[0008]

Non Patent Literature 1: Hans van Wortel: "Control of Relaxation Cracking in Austenitic High Temperature Components", CORROSION 2007 (2007), NACE, Paper No. 07423

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Non Patent Literature 2: Richard Colwell and Cathleen Shargay: "Alloy 800H: Material and fabrication challenges associated with the mitigation of stress relaxation cracking", ASME Pressure Vessels & Piping Conference 2020, Paper No.2020-21842

SUMMARY OF INVENTION

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TECHNICAL PROBLEM

- [0009]** Excellent stress relaxation cracking resistance in a high temperature environment can be obtained with the alloy described in Patent Literature 1. However, excellent stress relaxation cracking resistance in a high temperature

environment may also be obtained by other means. In addition, in Patent Literature 1, there is no discussion whatsoever regarding achieving both excellent stress relaxation cracking resistance and excellent weld hot cracking resistance.

[0010] An objective of the present disclosure is to provide an alloy which has sufficient creep strength in a high temperature environment and which is capable of achieving both excellent stress relaxation cracking resistance and excellent weld hot cracking resistance.

SOLUTION TO PROBLEM

[0011] An alloy according to the present disclosure has a chemical composition consisting of, in mass%,

C: 0.050 to 0.100%,
 Si: 1.00% or less,
 Mn: 1.50% or less,
 P: 0.035% or less,
 S: 0.0015% or less,
 Cr: 19.00 to 23.00%,
 Ni: 30.00 to 35.00%,
 N: 0.100% or less,
 Al: 0.15 to 0.70%,
 Ti: 0.15 to 0.70%,
 B: 0.0010 to 0.0050%,
 Nb: 0 to 0.30%,
 Ta: 0 to 0.50%,
 V: 0 to 1.00%,
 Zr: 0 to 0.10%,
 Hf: 0 to 0.10%,
 Cu: 0 to 1.00%,
 Mo: 0 to 1.00%,
 W: 0 to 1.00%,
 Co: 0 to 1.00%,
 Ca: 0 to 0.0200%,
 Mg: 0 to 0.0200%, and
 rare earth metal: 0 to 0.1000%,
 with the balance being Fe and impurities, and
 satisfies Formula (1) and Formula (2):

$$0.60 < \text{Al} + \text{Ti} < 1.20 \quad (1)$$

$$1.12 \leq \text{Ti}/\text{Al} \quad (2)$$

where, a content of a corresponding element in the chemical composition of the alloy is substituted in percent by mass for each symbol of an element in Formula (1) and Formula (2).

ADVANTAGEOUS EFFECTS OF INVENTION

[0012] The alloy according to the present disclosure has sufficient creep strength in a high temperature environment, and is capable of achieving both excellent stress relaxation cracking resistance and excellent weld hot cracking resistance.

BRIEF DESCRIPTION OF DRAWINGS

[0013] [FIG. 1] FIG. 1 is a view for describing a mechanism by which stress relaxation cracking occurs during use in a high temperature environment in an alloy in which the content of each element in the chemical composition is within the range of the present embodiment.

DESCRIPTION OF EMBODIMENTS

[0014] The present inventors initially conducted studies from the viewpoint of the chemical composition with regard to an alloy which has sufficient creep strength in a high temperature environment, and which is capable of achieving both excellent stress relaxation cracking resistance and excellent weld hot cracking resistance. As a result, the present inventors considered that if an alloy has a chemical composition consisting of, in mass%, C: 0.050 to 0.100%, Si: 1.00% or less, Mn: 1.50% or less, P: 0.035% or less, S: 0.0015% or less, Cr: 19.00 to 23.00%, Ni: 30.00 to 35.00%, N: 0.100% or less, Al: 0.15 to 0.70%, Ti: 0.15 to 0.70%, B: 0.0010 to 0.0050%, Nb: 0 to 0.30%, Ta: 0 to 0.50%, V: 0 to 1.00%, Zr: 0 to 0.10%, Hf: 0 to 0.10%, Cu: 0 to 1.00%, Mo: 0 to 1.00%, W: 0 to 1.00%, Co: 0 to 1.00%, Ca: 0 to 0.0200%, Mg: 0 to 0.0200%, and rare earth metal: 0 to 0.1000%, with the balance being Fe and impurities, there is a possibility that the alloy will have sufficient creep strength in a high temperature environment and will be capable of achieving both excellent stress relaxation cracking resistance and excellent weld hot cracking resistance.

[0015] The present inventors also investigated means for increasing creep strength in a high temperature environment in an alloy having the aforementioned chemical composition. As a result, the present inventors discovered that in an alloy in which the content of each element in the chemical composition is within the aforementioned range, if the following Formula (1) is satisfied, the creep strength in a high temperature environment sufficiently increases:

$$0.60 < \text{Al} + \text{Ti} < 1.20 \quad (1)$$

where, a content of a corresponding element in the chemical composition of the alloy is substituted in percent by mass for each symbol of an element in Formula (1).

[0016] The present inventors also conducted studies regarding compatibly achieving both excellent stress relaxation cracking resistance and excellent weld hot cracking resistance. Specifically, first, the present inventors investigated the mechanism by which stress relaxation cracking occurs during use of an alloy having the aforementioned chemical composition in a high temperature environment. As a result, the present inventors obtained the following findings.

[0017] FIG. 1 is a view for describing a mechanism by which stress relaxation cracking occurs during use in a high temperature environment in an alloy in which the content of each element in the chemical composition is within the range of the present embodiment. The abscissa in FIG. 1 represents time. The ordinate in FIG. 1 represents the amount of elongation or strain. A curve CRD0 in FIG. 1 represents creep rupture elongation. A curve IS0 represents the amount of strain that is accumulated in Cr-depleted zones in grains accompanying creep deformation.

[0018] Generally, an alloy to be used in a high temperature environment is subjected to a solution treatment during the process for producing the alloy, to thereby dissolve precipitates in the alloy. Since precipitates are sufficiently dissolved in the alloy during the production process, a γ' phase is formed during use in a high-temperature environment. A high creep strength is obtained by precipitation strengthening by the γ' phase.

[0019] When such kind of an alloy is used in a high temperature environment, as illustrated in FIG. 1, the creep rupture elongation CRD0 gradually decreases with the passage of time from the initial stage of use in the high temperature environment. On the other hand, from the initial stage of use in the high temperature environment (that is, the initial stage of the stress relaxation process), the aforementioned γ' phase forms within the alloy.

[0020] During use of the alloy in a high temperature environment, TiC is also formed, and not just the aforementioned γ' phase. Formation of the TiC causes Cr-depleted zones to arise in the vicinity of grain boundaries. In the Cr-depleted zones, the strength is low compared to other regions in the grains. Consequently, in the stress relaxation process, creep strain tends to concentrate in the Cr-depleted zones. Dislocations that constitute strain are trapped by TiC within the Cr-depleted zones. As time passes, the amount of TiC formed in the Cr-depleted zones increases. Therefore, the amount of dislocations trapped by TiC also increases. Consequently, the creep strain amount IS0 in the Cr-depleted zones also increases. At a time t_0 at which the increased creep strain amount IS0 becomes more than the creep rupture elongation CRD0, stress relaxation cracking occurs in the alloy.

[0021] As described above, an increase in the amount of creep strain which causes the occurrence of stress relaxation cracking occurs in Cr-depleted zones, and Cr-depleted zones arise due to the formation of TiC. Thus, the present inventors considered that TiC influences stress relaxation cracking more than the γ' phase. Therefore, the present inventors focused their attention on the TiC in the alloy during the stress relaxation process.

[0022] Initially the present inventors thought that it would suffice to suppress the formation of TiC in the stress relaxation process. It suffices to decrease the content of Ti in the alloy in order to suppress TiC. However, unless the content of Ti satisfies Formula (1), the γ' phase will not be sufficiently formed during use in a high temperature environment. In such case, sufficient creep strength will not be obtained in a high temperature environment.

[0023] Therefore, the present inventors turned their original idea around and came up with the idea of, rather than suppressing the formation of TiC, to instead cause TiC to form to a certain extent in advance in the alloy prior to use in a high temperature environment. The present inventors then investigated the stress relaxation cracking resistance when using

such kind of alloy. As a result, the present inventors have discovered that the stress relaxation cracking resistance increases.

[0024] In a case where an alloy contains a certain amount of TiC in advance prior to being used in a high temperature environment, a certain amount of TiC is formed in the process for producing the alloy. Due to the pinning effect of the TiC, the grains in the alloy become fine. When the grains in the alloy are fine, the creep rupture elongation increases from CRD0 to CRD1.

[0025] Furthermore, in the initial stage of the stress relaxation process, as in the previous case, TiC forms in Cr-depleted zones. However, a certain amount of TiC is already present in the alloy prior to being used in a high temperature environment. Therefore, formation of TiC is saturated in the initial stage of the stress relaxation process. Further, after the formation of TiC is saturated, the TiC that has already been formed coarsens. As a result of the TiC coarsening, dislocations that had been trapped by the TiC are removed from the TiC. As a result, the creep strain amount accumulated in the Cr-depleted zones decreases. Therefore, a curve of the creep strain amount accumulated in the Cr-depleted zones becomes like a curve IS1 shown in FIG. 1.

[0026] The peak of the creep strain amount IS1 is formed in the initial stage of the stress relaxation process. The time point of the peak of the creep strain amount IS1 corresponds to a time point at which the formation of TiC is saturated. In the initial stage of the stress relaxation process, the creep rupture elongation CRD1 is higher than the peak of the creep strain amount IS1. Then, when the creep strain amount IS1 exceeds the peak, the creep strain amount IS1 gradually decreases over time. Therefore, the time at which the creep rupture elongation CRD1 and the creep strain amount IS1 intersect is later than the time t0. As a result, the stress relaxation cracking resistance increases.

[0027] Furthermore, as mentioned above, because the alloy includes a certain amount of TiC, the grains in the alloy become fine. Therefore, the weld hot cracking resistance during welding also increases. It is thus possible to achieve both excellent stress relaxation cracking resistance and excellent weld hot cracking resistance.

[0028] Note that, when the grains become fine, there is a possibility that the creep strength will decrease. However, as mentioned above, the alloy includes a certain amount of TiC in advance, and TiC is further formed during use in a high temperature environment, and not just a γ' phase. The TiC that has already been present and the TiC that is newly formed during use in a high temperature environment precipitation-strengthen the alloy. Therefore, sufficient creep strength can be maintained in a high temperature environment.

[0029] Based on the above findings, the present inventors conducted studies to determine the appropriate amount of TiC in an alloy in order to have sufficient creep strength in a high temperature environment and to also enable both excellent stress relaxation cracking resistance and excellent weld hot cracking resistance to be achieved. As a result, the present inventors obtained the following finding.

[0030] In an alloy in which the content of each element in the chemical composition is within the aforementioned range, the content of Ti must be higher than the content of Al in order to cause a certain amount of TiC to be formed. Specifically, the content of Ti and the content of Al are set so as to satisfy Formula (2):

$$1.12 \leq \text{Ti/Al} \quad (2)$$

where, the content of the corresponding element in the chemical composition of the alloy is substituted in percent by mass for each symbol of an element in Formula (2).

[0031] If the content of each element in the chemical composition is within the aforementioned range, and Formula (1) and Formula (2) are satisfied, an appropriate amount of TiC will be present in the alloy. In this case, the stress relaxation cracking resistance can be increased, and the weld hot cracking resistance during welding also increases. In addition, during use in a high temperature environment, sufficient creep strength is obtained by the formation of a γ' phase and TiC.

[0032] The alloy according to the present embodiment, which has been completed based on the above findings, is as follows.

[1] An alloy having a chemical composition consisting of, in mass%,

C: 0.050 to 0.100%,
Si: 1.00% or less,
Mn: 1.50% or less,
P: 0.035% or less,
S: 0.0015% or less,
Cr: 19.00 to 23.00%,
Ni: 30.00 to 35.00%,
N: 0.100% or less,
Al: 0.15 to 0.70%,

Ti: 0.15 to 0.70%,
 B: 0.0010 to 0.0050%,
 Nb: 0 to 0.30%,
 Ta: 0 to 0.50%,
 V: 0 to 1.00%,
 Zr: 0 to 0.10%,
 Hf: 0 to 0.10%,
 Cu: 0 to 1.00%,
 Mo: 0 to 1.00%,
 W: 0 to 1.00%,
 Co: 0 to 1.00%,
 Ca: 0 to 0.0200%,
 Mg: 0 to 0.0200%, and
 rare earth metal: 0 to 0.1000%,
 with the balance being Fe and impurities, and
 satisfying Formula (1) and Formula (2):

$$0.60 < \text{Al} + \text{Ti} < 1.20 \quad (1)$$

$$1.12 \leq \text{Ti}/\text{Al} \quad (2)$$

where, a content of a corresponding element in the chemical composition of the alloy is substituted in percent by mass for each symbol of an element in Formula (1) and Formula (2).

[2] The alloy according to [1], wherein:

when a content of Ti in percent by mass in a residue obtained by an electrolytic extraction method is defined as $[\text{Ti}]_R$, the alloy further satisfies Formula (3):

$$0.050 < [\text{Ti}]_R < 0.72\text{Ti} - 0.01(\text{Ti}/\text{Al}) - 0.11 \quad (3)$$

where, a content of a corresponding element in the chemical composition of the alloy is substituted in percent by mass for each symbol of an element in Formula (3).

[3] The alloy according to [1] or [2], containing one or more elements selected from a group consisting of:

Nb: 0.01 to 0.30%,
 Ta: 0.01 to 0.50%,
 V: 0.01 to 1.00%,
 Zr: 0.01 to 0.10%,
 Hf: 0.01 to 0.10%,
 Cu: 0.01 to 1.00%,
 Mo: 0.01 to 1.00%,
 W: 0.01 to 1.00%,
 Co: 0.01 to 1.00%,
 Ca: 0.0001 to 0.0200%,
 Mg: 0.0001 to 0.0200%, and
 rare earth metal: 0.001 to 0.1000%.

[0033] Hereunder, the alloy of the present embodiment is described in detail. Note that, the symbol "%" in relation to elements means mass percent unless otherwise stated.

[Features of alloy of present embodiment]

[0034] The alloy of the present embodiment has the following features.

(Feature 1)

[0035] The chemical composition consists of, in mass%, C: 0.050 to 0.100%, Si: 1.00% or less, Mn: 1.50% or less, P: 0.035% or less, S: 0.0015% or less, Cr: 19.00 to 23.00%, Ni: 30.00 to 35.00%, N: 0.100% or less, Al: 0.15 to 0.70%, Ti: 0.15 to 0.70%, B: 0.0010 to 0.0050%, Nb: 0 to 0.30%, Ta: 0 to 0.50%, V: 0 to 1.00%, Zr: 0 to 0.10%, Hf: 0 to 0.10%, Cu: 0 to 1.00%, Mo: 0 to 1.00%, W: 0 to 1.00%, Co: 0 to 1.00%, Ca: 0 to 0.0200%, Mg: 0 to 0.0200%, and rare earth metal: 0 to 0.1000%, with the balance being Fe and impurities.

(Feature 2)

[0036] The chemical composition of Feature 1 also satisfies Formula (1):

$$0.60 < \text{Al} + \text{Ti} < 1.20 \quad (1)$$

where, the content of the corresponding element in the chemical composition of the alloy is substituted in percent by mass for each symbol of an element in Formula (1).

(Feature 3)

[0037] The chemical composition of Feature 1 also satisfies Formula (2):

$$1.12 \leq \text{Ti}/\text{Al} \quad (2)$$

where, the content of the corresponding element in the chemical composition of the alloy is substituted in percent by mass for each symbol of an element in Formula (2).

[0038] The alloy of the present embodiment satisfies the aforementioned Feature 1 to Feature 3. Therefore, the alloy of the present embodiment has sufficient creep strength in a high temperature environment, and enables the achievement of both excellent stress relaxation cracking resistance and excellent weld hot cracking resistance. Hereunder, Feature 1 to Feature 3 are described.

[(Feature 1) Regarding chemical composition]

[0039] The chemical composition of the alloy of the present embodiment contains the following elements.

C: 0.050 to 0.100%

[0040] Carbon (C) increases the creep strength of the alloy in a high temperature environment. If the content of C is less than 0.050%, the aforementioned advantageous effect will not be sufficiently obtained even if the contents of other elements are within the range of the present embodiment.

[0041] On the other hand, if the content of C is more than 0.100%, even if the contents of other elements are within the range of the present embodiment, C will form M_{23}C_6 -type Cr carbides at grain boundaries. In such case, Cr-depleted zones will form at the grain boundaries. Consequently, the stress relaxation cracking resistance of the alloy will decrease.

[0042] Therefore, the content of C is 0.050 to 0.100%.

[0043] A preferable lower limit of the content of C is 0.053%, more preferably is 0.055%, further preferably is 0.057%, and further preferably is 0.060%.

[0044] A preferable upper limit of the content of C is 0.095%, more preferably is 0.090%, further preferably is 0.085%, and further preferably is 0.080%.

Si: 1.00% or less

[0045] Silicon (Si) is unavoidably contained. In other words, the content of Si is more than 0%. Si deoxidizes the alloy in the steelmaking process. Si also increases the oxidation resistance of the alloy in a high temperature environment. If even a small amount of Si is contained, the aforementioned advantageous effects will be obtained to a certain extent even when the contents of other elements are within the range of the present embodiment. However, if the content of Si is more than 1.00%, the weld hot cracking resistance will decrease even if the contents of other elements are within the range of the present embodiment. Therefore, the content of Si is 1.00% or less.

[0046] A preferable lower limit of the content of Si is 0.01%, more preferably is 0.05%, further preferably is 0.10%, further

preferably is 0.12%, and further preferably is 0.15%.

[0047] A preferable upper limit of the content of Si is 0.90%, more preferably is 0.80%, further preferably is 0.70%, further preferably is 0.65%, further preferably is 0.60%, further preferably is 0.55%, and further preferably is 0.50%.

5 Mn: 1.50% or less

[0048] Manganese (Mn) is unavoidably contained. In other words, the content of Mn is more than 0%. Mn deoxidizes a weld zone of the alloy during welding. Mn also stabilizes austenite. If even a small amount of Mn is contained, the aforementioned advantageous effects will be obtained to a certain extent. However, if the content of Mn is more than 1.50%, even if the contents of other elements are within the range of the present embodiment, sigma phase (σ phase) will easily form during use in a high temperature environment. The σ phase will reduce the toughness and creep ductility of the alloy in a high temperature environment. Therefore, the content of Mn is 1.50% or less.

[0049] A preferable lower limit of the content of Mn is 0.01%, more preferably is 0.05%, further preferably is 0.10%, further preferably is 0.40%, further preferably is 0.50%, and further preferably is 0.60%.

[0050] A preferable upper limit of the content of Mn is 1.45%, more preferably is 1.40%, further preferably is 1.35%, further preferably is 1.30%, further preferably is 1.25%, and further preferably is 1.20%.

P: 0.035% or less

[0051] Phosphorus (P) is unavoidably contained. That is, the content of P is more than 0%. P segregates to grain boundaries of the alloy during welding with large heat input. If the content of P is more than 0.035%, even if the contents of other elements are within the range of the present embodiment, the aforementioned segregation will occur and the stress relaxation cracking resistance will decrease. Therefore, the content of P is 0.035% or less.

[0052] The content of P is preferably as low as possible. However, excessively reducing the content of P will raise the production cost of the alloy. Therefore, when normal industrial manufacturing is taken into consideration, a preferable lower limit of the content of P is 0.001%, more preferably is 0.002%, and further preferably is 0.005%.

[0053] A preferable upper limit of the content of P is 0.030%, more preferably is 0.025%, further preferably is 0.020%, and further preferably is 0.015%.

30 S: 0.0015% or less

[0054] Sulfur (S) is unavoidably contained. In other words, the content of S is more than 0%. S segregates to grain boundaries of the alloy during welding with large heat input. If the content of S is more than 0.0015%, even if the contents of other elements are within the range of the present embodiment, the aforementioned segregation will occur and the stress relaxation cracking resistance will decrease. Therefore, the content of S is 0.0015% or less.

[0055] The content of S is preferably as low as possible. However, excessively reducing the content of S will raise the production cost of the alloy. Therefore, when normal industrial manufacturing is taken into consideration, a preferable lower limit of the content of S is 0.0001%, and more preferably is 0.0002%.

[0056] A preferable upper limit of the content of S is 0.0012%, more preferably is 0.0010%, further preferably is 0.0008%, and further preferably is 0.0006%.

Cr: 19.00 to 23.00%

[0057] Chromium (Cr) increases the corrosion resistance of the alloy in a high temperature environment. If the content of Cr is less than 19.00%, the aforementioned advantageous effect will not be sufficiently obtained even if the contents of other elements are within the range of the present embodiment. On the other hand, if the content of Cr is more than 23.00%, the stability of austenite in a high temperature environment will decrease even if the contents of other elements are within the range of the present embodiment. In such case, the creep strength of the alloy will decrease. Therefore, the content of Cr is 19.00 to 23.00%.

[0058] A preferable lower limit of the content of Cr is 19.20%, more preferably is 19.40%, and further preferably is 19.60%.

[0059] A preferable upper limit of the content of Cr is 22.50%, more preferably is 22.00%, further preferably is 21.50%, further preferably is 21.00%, further preferably is 20.50%, and further preferably is 20.00%.

55 Ni: 30.00 to 35.00%

[0060] Nickel (Ni) stabilizes austenite and increases the creep strength of the alloy in a high temperature environment. If the content of Ni is less than 30.00%, the aforementioned advantageous effect will not be sufficiently obtained even if the

contents of other elements are within the range of the present embodiment. On the other hand, if the content of Ni is more than 35.00%, the aforementioned advantageous effect will be saturated. In addition, the raw material cost will increase. Therefore, the content of Ni is 30.00 to 35.00%.

[0061] A preferable lower limit of the content of Ni is 30.20%, more preferably is 30.40%, further preferably is 30.60%, further preferably is 30.80%, further preferably is 31.20%, further preferably is 31.40%, and further preferably is 31.60%.

[0062] A preferable upper limit of the content of Ni is 34.50%, more preferably is 34.00%, further preferably is 33.50%, and further preferably is 33.00%.

N: 0.100% or less

[0063] Nitrogen (N) is unavoidably contained. In other words, the content of N is more than 0%. N dissolves in the matrix (parent phase) and stabilizes austenite. The dissolved N also forms fine nitrides in the alloy during use in a high temperature environment. The fine nitrides strengthen Cr-depleted zones, and therefore increase the stress relaxation cracking resistance of the alloy. The fine nitrides that are formed during use in a high temperature environment also increase the creep strength by precipitation strengthening. If even a small amount of N is contained, the aforementioned advantageous effects will be obtained to a certain extent. However, if the content of N is more than 0.100%, coarse TiN will form even if the contents of other elements are within the range of the present embodiment. The coarse TiN will decrease the toughness of the alloy. Therefore, the content of N is 0.100% or less.

[0064] A preferable lower limit of the content of N is 0.001%.

[0065] A preferable upper limit of the content of N is 0.090%, more preferably is 0.080%, further preferably is 0.070%, further preferably is 0.060%, further preferably is 0.050%, further preferably is 0.040%, further preferably is 0.030%, further preferably is 0.020%, and further preferably is 0.010%.

Al: 0.15 to 0.70%

[0066] Aluminum (Al) deoxidizes the alloy in the steelmaking process. Al also increases the oxidation resistance of the alloy in a high temperature environment. In addition, Al forms a γ' phase in high temperature environments and thereby increases the creep strength of the alloy in high temperature environments. If the content of Al is less than 0.15%, the aforementioned advantageous effect will not be sufficiently obtained even if the contents of other elements are within the range of the present embodiment.

[0067] On the other hand, if the content of Al is more than 0.70%, even if the contents of other elements are within the range of the present embodiment, a large amount of γ' phase will be formed during the process for producing the alloy. In this case, the hot workability during the process for producing the alloy will decrease. Furthermore, if the content of Al is more than 0.70%, TiC will not be sufficiently formed. In such case, the grains in the alloy will not become sufficiently fine because of TiC. Consequently, during welding of the alloy, the weld hot cracking resistance in a heat affected zone of the alloy will decrease. In addition, since the Ti amount satisfying Formula (1) will decrease, the amount of TiC acting to perform precipitation strengthening at 700°C will decrease and the creep strength of the alloy will not sufficiently increase. Furthermore, TiC will not sufficiently form in the initial stage of the stress relaxation process. Consequently, the stress relaxation cracking resistance in a high temperature environment will decrease.

[0068] Therefore, the content of Al is 0.15 to 0.70%.

[0069] A preferable lower limit of the content of Al is 0.17%, more preferably is 0.19%, further preferably is 0.21%, and further preferably is 0.23%.

[0070] A preferable upper limit of the content of Al is 0.65%, more preferably is 0.60%, further preferably is 0.57%, further preferably is 0.55%, further preferably is 0.53%, further preferably is 0.51%, further preferably is 0.45%, and further preferably is 0.40%.

[0071] Note that, the term "content of Al" means the content (mass%) of so-called "total Al".

Ti: 0.15 to 0.70%

[0072] Titanium (Ti) combines with Ni and Al in a high temperature environment to form a γ' phase, and thereby increases the creep strength of the alloy in a high temperature environment. If the content of Ti is less than 0.15%, the aforementioned advantageous effect will not be sufficiently obtained even if the contents of other elements are within the range of the present embodiment. On the other hand, if the content of Ti is more than 0.70%, coarse TiC will form even if the contents of other elements are within the range of the present embodiment. In this case, during welding of the alloy, the weld hot cracking resistance in a heat affected zone of the alloy will decrease. In addition, if the content of Ti is more than 0.70%, a large amount of γ' phase will be formed during the process for producing the alloy. In such case, the hot workability during the process for producing the alloy will decrease. Therefore, the content of Ti is 0.15 to 0.70%.

[0073] A preferable lower limit of the content of Ti is 0.17%, more preferably is 0.19%, further preferably is 0.21%, and

further preferably is 0.25%.

[0074] A preferable upper limit of the content of Ti is 0.65%, more preferably is 0.60%, further preferably is 0.59%, further preferably is 0.57%, further preferably is 0.55%, further preferably is 0.50%, and further preferably is 0.45%.

B: 0.0010 to 0.0050%

[0075] Boron (B) segregates to grain boundaries in a high temperature environment, and thereby increases the grain boundary strength. Thus, B increases the stress relaxation cracking resistance of the alloy. If the content of B is less than 0.0010%, the aforementioned advantageous effect will not be sufficiently obtained even if the contents of other elements are within the range of the present embodiment. On the other hand, if the content of B is more than 0.0050%, even if the contents of other elements are within the range of the present embodiment, B will promote the formation of Cr carbides at the grain boundaries. In such case, the stress relaxation cracking resistance of the alloy will decrease. Therefore, the content of B is 0.0010 to 0.0050%.

[0076] A preferable lower limit of the content of B is 0.0012%, more preferably is 0.0014%, and further preferably is 0.0015%.

[0077] A preferable upper limit of the content of B is 0.0045%, more preferably is 0.0040%, further preferably is 0.0035%, and further preferably is 0.0030%.

[0078] The balance of the chemical composition of the alloy according to the present embodiment is Fe and impurities. Here, the term "impurities" means substances which are mixed in from ore and scrap used as the raw material or from the production environment or the like when industrially producing the alloy, and which are not intentionally contained but are permitted within a range that does not adversely affect the alloy of the present embodiment. Representative examples of impurities include Sn, As, Zn, Pb and Sb. The total content of these impurities is 0.1% or less.

[Optional Elements]

[0079] The chemical composition of the alloy of the present embodiment may further contain, in lieu of a part of Fe, one or more elements selected from the group consisting of:

Nb: 0 to 0.30%,
Ta: 0 to 0.50%,
V: 0 to 1.00%,
Zr: 0 to 0.10%,
Hf: 0 to 0.10%,
Cu: 0 to 1.00%,
Mo: 0 to 1.00%,
W: 0 to 1.00%,
Co: 0 to 1.00%,
Ca: 0 to 0.0200%,
Mg: 0 to 0.0200%, and
rare earth metal: 0 to 0.1000%.

[0080] Hereunder, these optional elements are described.

[First group: Regarding Nb, Ta, V, Zr and Hf]

[0081] The chemical composition of the alloy according to the present embodiment may further contain one or more elements selected from the group consisting of Nb, Ta, V, Zr and Hf in lieu of a part of Fe. Each of these elements combines with C to form carbides, thereby lowering the amount of dissolved C. By this means, the formation of Cr carbides at grain boundaries in a high temperature environment is suppressed. Therefore, the formation of Cr-depleted zones is suppressed. As a result, the stress relaxation cracking resistance of the alloy in a high temperature environment is further increased.

Nb: 0 to 0.30%

[0082] Niobium (Nb) is an optional element, and does not have to be contained. In other words, the content of Nb may be 0%. When Nb is contained, that is, when the content of Nb is more than 0%, Nb combines with C to form carbides. By forming carbides and thereby immobilizing C, the dissolved C amount in the alloy decreases. By this means, in a high temperature environment, formation of Cr carbides at grain boundaries is suppressed. Consequently, the formation of Cr-

depleted zones is suppressed. As a result, the stress relaxation cracking resistance of the alloy increases. In addition, during use in a high temperature environment, Nb forms fine nitrides in the alloy, together with N. The fine nitrides strengthen Cr-depleted zones, and thus the stress relaxation cracking resistance of the alloy increases. The fine nitrides that are formed during use in a high temperature environment also increase the creep strength by precipitation strengthening. If even a small amount of Nb is contained, the aforementioned advantageous effect will be obtained to a certain extent.

[0083] However, if the content of Nb is more than 0.30%, even if the contents of other elements are within the range of the present embodiment, during welding of the alloy, the weld hot cracking resistance in a heat affected zone of the alloy will decrease. Therefore, the content of Nb is 0 to 0.30%.

[0084] A preferable lower limit of the content of Nb is 0.01%, more preferably is 0.02%, further preferably is 0.05%, and further preferably is 0.08%.

[0085] A preferable upper limit of the content of Nb is 0.25%, more preferably is 0.20%, and further preferably is 0.15%.

Ta: 0 to 0.50%

[0086] Tantalum (Ta) is an optional element, and does not have to be contained. In other words, the content of Ta may be 0%. When Ta is contained, that is, when the content of Ta is more than 0%, Ta combines with C to form carbides. By forming carbides and thereby immobilizing C, the dissolved C amount in the alloy decreases. By this means, in a high temperature environment, formation of Cr carbides at grain boundaries is suppressed. Consequently, the formation of Cr-depleted zones is suppressed. As a result, the stress relaxation cracking resistance of the alloy increases. If even a small amount of Ta is contained, the aforementioned advantageous effect will be obtained to a certain extent.

[0087] However, if the content of Ta is more than 0.50%, even if the contents of other elements are within the range of the present embodiment, during welding of the alloy, the weld hot cracking resistance in a heat affected zone of the alloy will decrease. Therefore, the content of Ta is 0 to 0.50%.

[0088] A preferable lower limit of the content of Ta is 0.01%, more preferably is 0.02%, further preferably is 0.05%, and further preferably is 0.08%.

[0089] A preferable upper limit of the content of Ta is 0.45%, more preferably is 0.40%, further preferably is 0.35%, and further preferably is 0.30%.

V: 0 to 1.00%

[0090] Vanadium (V) is an optional element, and does not have to be contained. In other words, the content of V may be 0%. When V is contained, that is, when the content of V is more than 0%, V combines with C to form carbides. By forming carbides and thereby immobilizing C, the dissolved C amount in the alloy decreases. By this means, in a high temperature environment, formation of Cr carbides at grain boundaries is suppressed. Consequently, the formation of Cr-depleted zones is suppressed. As a result, the stress relaxation cracking resistance of the alloy increases. If even a small amount of V is contained, the aforementioned advantageous effect will be obtained to a certain extent.

[0091] However, if the content of V is more than 1.00%, even if the contents of other elements are within the range of the present embodiment, during welding of the alloy, the weld hot cracking resistance in a heat affected zone of the alloy will decrease. Therefore, the content of V is 0 to 1.00%.

[0092] A preferable lower limit of the content of V is 0.01%, more preferably is 0.02%, further preferably is 0.04%, and further preferably is 0.06%.

[0093] A preferable upper limit of the content of V is 0.80%, more preferably is 0.50%, further preferably is 0.40%, further preferably is 0.35%, and further preferably is 0.30%.

Zr: 0 to 0.10%

[0094] Zirconium (Zr) is an optional element, and does not have to be contained. In other words, the content of Zr may be 0%. When Zr is contained, that is, when the content of Zr is more than 0%, Zr combines with C to form carbides. By forming carbides and thereby immobilizing C, the dissolved C amount in the alloy decreases. By this means, in a high temperature environment, formation of Cr carbides at grain boundaries is suppressed. Consequently, the formation of Cr-depleted zones is suppressed. As a result, the stress relaxation cracking resistance of the alloy increases. If even a small amount of Zr is contained, the aforementioned advantageous effect will be obtained to a certain extent.

[0095] However, if the content of Zr is more than 0.10%, even if the contents of other elements are within the range of the present embodiment, during welding of the alloy, the weld hot cracking resistance in a heat affected zone of the alloy will decrease. Therefore, the content of Zr is 0 to 0.10%.

[0096] A preferable lower limit of the content of Zr is 0.01%, and more preferably is 0.02%.

[0097] A preferable upper limit of the content of Zr is 0.09%, more preferably is 0.08%, further preferably is 0.07%, and

further preferably is 0.06%.

Hf: 0 to 0.10%

5 **[0098]** Hafnium (Hf) is an optional element, and does not have to be contained. In other words, the content of Hf may be 0%. When Hf is contained, that is, when the content of Hf is more than 0%, Hf combines with C to form carbides. By forming carbides and thereby immobilizing C, the dissolved C amount in the alloy decreases. By this means, in a high temperature environment, formation of Cr carbides at grain boundaries is suppressed. Consequently, the formation of Cr-depleted zones is suppressed. As a result, the stress relaxation cracking resistance of the alloy increases. If even a small amount of Hf is contained, the aforementioned advantageous effect will be obtained to a certain extent.

10 **[0099]** However, if the content of Hf is more than 0.10%, even if the contents of other elements are within the range of the present embodiment, during welding of the alloy, the weld hot cracking resistance in a heat affected zone of the alloy will decrease. Therefore, the content of Hf is 0 to 0.10%.

[0100] A preferable lower limit of the content of Hf is 0.01%, and more preferably is 0.02%.

15 **[0101]** A preferable upper limit of the content of Hf is 0.09%, more preferably is 0.08%, further preferably is 0.07%, and further preferably is 0.06%.

[Second group: Regarding Cu, Mo, W, and Co]

20 **[0102]** The chemical composition of the alloy according to the present embodiment may further contain one or more elements selected from the group consisting of Cu, Mo, W, and Co in lieu of a part of Fe. Each of these elements increases the creep strength of the alloy in a high temperature environment.

Cu: 0 to 1.00%

25 **[0103]** Copper (Cu) is an optional element, and does not have to be contained. In other words, the content of Cu may be 0%. When Cu is contained, that is, when the content of Cu is more than 0%, during use of the alloy in a high temperature environment, Cu precipitates as a Cu phase in the grains. The creep strength of the alloy is increased by this precipitation strengthening. If even a small amount of Cu is contained, the aforementioned advantageous effect will be obtained to a certain extent.

30 **[0104]** However, if the content of Cu is more than 1.00%, even if the contents of other elements are within the range of the present embodiment, a Cu phase will excessively precipitate in the grains. In such case, the strength difference between the inside of the grains and the grain boundaries will be large. Consequently, the stress relaxation cracking resistance will decrease. Therefore, the content of Cu is 0 to 1.00%.

35 **[0105]** A preferable lower limit of the content of Cu is 0.01%, more preferably is 0.02%, further preferably is 0.05%, further preferably is 0.10%, further preferably is 0.15%, and further preferably is 0.20%.

[0106] A preferable upper limit of the content of Cu is 0.90%, more preferably is 0.80%, further preferably is 0.70%, further preferably is 0.60%, further preferably is 0.55%, and further preferably is 0.50%.

40 Mo: 0 to 1.00%

[0107] Molybdenum (Mo) is an optional element, and does not have to be contained. In other words, the content of Mo may be 0%. When Mo is contained, that is, when the content of Mo is more than 0%, during use of the alloy in a high temperature environment, Mo increases the creep strength of the alloy by solid-solution strengthening. If even a small amount of Mo is contained, the aforementioned advantageous effect will be obtained to a certain extent.

45 **[0108]** However, if the content of Mo is more than 1.00%, even if the contents of other elements are within the range of the present embodiment, intermetallic compounds such as Laves phases will form within the grains. In such case, secondary induced precipitation hardening will increase and the strength difference between the inside of the grains and the grain boundaries will be large. Consequently, the stress relaxation cracking resistance will decrease. Therefore, the content of Mo is 0 to 1.00%.

50 **[0109]** A preferable lower limit of the content of Mo is 0.01%, more preferably is 0.02%, further preferably is 0.03%, further preferably is 0.04%, further preferably is 0.05%, further preferably is 0.10%, further preferably is 0.20%, and further preferably is 0.30%.

55 **[0110]** A preferable upper limit of the content of Mo is 0.90%, more preferably is 0.80%, further preferably is 0.70%, further preferably is 0.65%, and further preferably is 0.60%.

W: 0 to 1.00%

[0111] Tungsten (W) is an optional element, and does not have to be contained. In other words, the content of W may be 0%. When W is contained, that is, when the content of W is more than 0%, during use of the alloy in a high temperature environment, W increases the creep strength of the alloy by solid-solution strengthening. If even a small amount of W is contained, the aforementioned advantageous effect will be obtained to a certain extent.

[0112] However, if the content of W is more than 1.00%, even if the contents of other elements are within the range of the present embodiment, intermetallic compounds such as Laves phases will form within the grains. In such case, secondary induced precipitation hardening will increase and the strength difference between the inside of the grains and the grain boundaries will be large. Consequently, the stress relaxation cracking resistance will decrease. Therefore, the content of W is 0 to 1.00%.

[0113] A preferable lower limit of the content of W is 0.01%, more preferably is 0.02%, further preferably is 0.03%, further preferably is 0.04%, further preferably is 0.05%, and further preferably is 0.10%.

[0114] A preferable upper limit of the content of W is 0.90%, more preferably is 0.80%, further preferably is 0.70%, further preferably is 0.65%, further preferably is 0.60%, and further preferably is 0.50%.

Co: 0 to 1.00%

[0115] Cobalt (Co) is an optional element, and does not have to be contained. In other words, the content of Co may be 0%. When Co is contained, that is, when the content of Co is more than 0%, Co stabilizes austenite and increases the creep strength of the alloy in a high temperature environment. If even a small amount of Co is contained, the aforementioned advantageous effect will be obtained to a certain extent.

[0116] However, if the content of Co is more than 1.00%, the raw material cost will increase. Therefore, the content of Co is 0 to 1.00%.

[0117] A preferable lower limit of the content of Co is 0.01%, more preferably is 0.02%, further preferably is 0.03%, further preferably is 0.05%, and further preferably is 0.10%.

[0118] A preferable upper limit of the content of Co is 0.90%, more preferably is 0.80%, further preferably is 0.70%, further preferably is 0.60%, and further preferably is 0.50%.

[Third group: Regarding Ca, Mg, and rare earth metal (REM)]

[0119] The chemical composition of the alloy according to the present embodiment may further contain one or more elements selected from the group consisting of Ca, Mg, and rare earth metal (REM) in lieu of a part of Fe. Each of these elements increases the hot workability of the alloy.

Ca: 0 to 0.0200%

[0120] Calcium (Ca) is an optional element, and does not have to be contained. In other words, the content of Ca may be 0%. When Ca is contained, that is, when the content of Ca is more than 0%, Ca immobilizes O (oxygen) and S (sulfur) as inclusions, and thereby increases the hot workability of the alloy. Ca also immobilizes S and thereby suppresses grain-boundary segregation of S. Consequently, during welding of the alloy, the weld hot cracking resistance in a heat affected zone (HAZ) of the alloy increases. If even a small amount of Ca is contained, the aforementioned advantageous effects will be obtained to a certain extent.

[0121] However, if the content of Ca is more than 0.0200%, even if the contents of other elements are within the range of the present embodiment, the cleanliness of the alloy will decrease, and the hot workability of the alloy will, on the contrary, decrease. Therefore, the content of Ca is 0 to 0.0200%.

[0122] A preferable lower limit of the content of Ca is 0.0001%, more preferably is 0.0002%, further preferably is 0.0005%, and further preferably is 0.0010%.

[0123] A preferable upper limit of the content of Ca is 0.0150%, more preferably is 0.0100%, further preferably is 0.0080%, further preferably is 0.0050%, and further preferably is 0.0040%.

Mg: 0 to 0.0200%

[0124] Magnesium (Mg) is an optional element, and does not have to be contained. In other words, the content of Mg may be 0%.

[0125] When Mg is contained, that is, when the content of Mg is more than 0%, Mg immobilizes O (oxygen) and S (sulfur) as inclusions, and thereby increases the hot workability of the alloy. Mg also immobilizes S and thereby suppresses grain-boundary segregation of S. Consequently, during welding of the alloy, the weld hot cracking resistance in a HAZ of the alloy

increases. If even a small amount of Mg is contained, the aforementioned advantageous effects will be obtained to a certain extent.

[0126] However, if the content of Mg is more than 0.0200%, even if the contents of other elements are within the range of the present embodiment, the cleanliness of the alloy will decrease, and the hot workability of the alloy will, on the contrary, decrease. Therefore, the content of Mg is 0 to 0.0200%.

[0127] A preferable lower limit of the content of Mg is 0.0001%, more preferably is 0.0002%, further preferably is 0.0005%, and further preferably is 0.0010%.

[0128] A preferable upper limit of the content of Mg is 0.0150%, more preferably is 0.0100%, further preferably is 0.0080%, further preferably is 0.0050%, and further preferably is 0.0040%.

Rare earth metal: 0 to 0.1000%

[0129] Rare earth metal (REM) is an optional element, and does not have to be contained. In other words, the content of REM may be 0%. When REM is contained, that is, when the content of REM is more than 0%, REM immobilizes O (oxygen) and S (sulfur) as inclusions, and thereby increases the hot workability of the alloy. REM also immobilizes S and thereby suppresses grain-boundary segregation of S. Consequently, during welding of the alloy, the weld hot cracking resistance in a HAZ of the alloy increases. If even a small amount of REM is contained, the aforementioned advantageous effects will be obtained to a certain extent.

[0130] However, if the content of REM is more than 0.1000%, even if the contents of other elements are within the range of the present embodiment, the cleanliness of the alloy will decrease, and the hot workability of the alloy will, on the contrary, decrease. Therefore, the content of REM is 0 to 0.1000%.

[0131] A preferable lower limit of the content of REM is 0.0001%, more preferably is 0.0005%, further preferably is 0.0010%, and further preferably is 0.0020%.

[0132] A preferable upper limit of the content of REM is 0.0800%, more preferably is 0.0600%, and further preferably is 0.0400%.

[0133] In the present description, the term "REM" includes at least one element or more among Sc, Y, and lanthanoids (elements from La with atomic number 57 through Lu with atomic number 71), and the term "content of REM" means the total content of these elements.

[(Feature 2) Regarding Formula (1)]

[0134] The chemical composition of the alloy of the present embodiment also satisfies Formula (1):

$$0.60 < \text{Al} + \text{Ti} < 1.20 \quad (1)$$

where, the content of the corresponding element in the chemical composition of the alloy is substituted in percent by mass for each symbol of an element in Formula (1).

[0135] Let F1 be defined as $F1 = \text{Al} + \text{Ti}$. F1 is an index of the formed amount of a y' phase. In the alloy of the present embodiment, a y' phase is formed during use in a high temperature environment. The creep strength of the alloy in a high temperature environment is increased by the y' phase.

[0136] Even when the content of each element in the chemical composition is within the range of the present embodiment, if F1 is 0.60 or less, a sufficient amount of the y' phase will not form in the alloy in a high temperature environment. In such case, the creep strength of the alloy in a high temperature environment will decrease.

[0137] On the other hand, even when the content of each element in the chemical composition is within the range of the present embodiment, if F1 is 1.20 or more, an excessively large amount of the y' phase will form in the alloy. In such case, the weld hot cracking resistance of the alloy will decrease. Therefore, F1 is to be more than 0.60 to less than 1.20.

[0138] A preferable lower limit of F1 is 0.62, more preferably is 0.64, further preferably is 0.66, further preferably is 0.68, and further preferably is 0.70.

[0139] A preferable upper limit of F1 is 1.15, more preferably is 1.10, further preferably is 1.05, further preferably is 1.00, and further preferably is 0.95.

[(Feature 3) Regarding Formula (2)]

[0140] The chemical composition of the alloy of the present embodiment also satisfies Formula (2):

$$1.12 \leq \text{Ti}/\text{Al} \quad (2)$$

where, the content of the corresponding element in the chemical composition of the alloy is substituted in percent by mass for each symbol of an element in Formula (2).

[0141] Let $F2$ be defined as $F2 = Ti/Al$. $F2$ is an index of the stress relaxation cracking resistance of the alloy in a high temperature environment.

[0142] In order to achieve both creep strength and stress relaxation cracking resistance in a high temperature environment, in the alloy of the present embodiment the content of Ti is made greater than the content of Al. In this case, the alloy contains a certain amount of TiC. Therefore, the grains in the alloy are refined by the TiC. As a result, the creep rupture elongation of the alloy in a high temperature environment increases. In addition, in the alloy of the present embodiment, by making the content of Ti greater than the content of Al, formation of TiC in the initial stage of a stress relaxation process is saturated. After the formation of TiC is saturated, the TiC coarsens with the passage of time. As a result, the amount of creep strain that is accumulated in Cr-depleted zones reaches a peak in the initial stage of the stress relaxation process. Thereafter, the amount of creep strain decreases with the passage of time. As a result, the stress relaxation cracking resistance in a high temperature environment increases. If $F2$ is less than 1.12, the aforementioned advantageous effect will not be sufficiently obtained. Therefore, $F2$ is 1.12 or more.

[0143] A preferable lower limit of $F2$ is 1.13, more preferably is 1.15, further preferably is 1.30, further preferably is 1.40, and further preferably is 1.50.

[0144] The upper limit of $F2$ is not particularly limited. From the viewpoint of increasing the oxidation resistance of the alloy, a preferable upper limit of $F2$ is 4.00, more preferably is 3.90, further preferably is 3.70, further preferably is 3.50, and further preferably is 3.30.

[Preferred form of alloy of present embodiment]

[0145] Preferably the alloy of the present embodiment satisfies Feature 1 to Feature 3, and also satisfies the following Feature 4.

(Feature 4)

[0146] When the content of Ti in percent by mass in a residue obtained by an electrolytic extraction method is defined as $[Ti]_R$, the alloy of the present embodiment satisfies Formula (3):

$$0.050 < [Ti]_R < 0.72Ti - 0.01(Ti/Al) - 0.11 \quad (3)$$

where, the content of the corresponding element in the chemical composition of the alloy is substituted in percent by mass for each symbol of an element in Formula (3).

[0147] Hereunder, Feature 4 is described.

[(Feature 4) Regarding Formula (3)]

[0148] $[Ti]_R$ which represents the content of Ti in a residue is an index of the amount of TiC in the alloy. In order to achieve both excellent stress relaxation cracking resistance and excellent weld hot cracking resistance, it is preferable that the amount of TiC and the amount of dissolved Ti in the alloy are appropriate.

[0149] If $[Ti]_R$ is higher than 0.050, a certain amount of TiC will be present in the alloy before using the alloy in a high temperature environment. In such case, a pinning effect is obtained by the TiC. Therefore, the grains in the alloy are refined. As a result, the creep rupture elongation of the alloy in a high temperature environment increases. Further, before the alloy is used in a high temperature environment, a certain amount TiC is already present in the alloy. Therefore, as has been described above using FIG. 1, during use at a high temperature, formation of TiC is saturated in the initial stage of a stress relaxation process. Consequently, the amount of creep strain in Cr-depleted zones also reaches a peak in the initial stage of the stress relaxation process. Thereafter, the amount of creep strain decreases with the passage of time. As a result, stress relaxation cracking of the alloy in high temperature environments is further suppressed.

[0150] On the other hand, if $[Ti]_R$ is lower than $F3 (= 0.72Ti - 0.01(Ti/Al) - 0.11)$, the amount of TiC in the alloy will be appropriate and will not be too large. If, for instance, TiC is present in an excessively large amount in the alloy, during welding of the alloy, weld hot cracking that is attributable to TiC will occur. In other words, when $[Ti]_R$ is less than $F3$, the weld hot cracking resistance of the alloy increases further. Furthermore, for instance, if TiC is present in an excessively large amount in the alloy, a sufficient γ' phase will not form during use in a high temperature environment. In such case, the creep strength will not increase in a high temperature environment. That is, if $[Ti]_R$ is less than $F3$, the creep strength of the alloy will increase further. Therefore, preferably $[Ti]_R$ is higher than 0.050 and is less than $F3 (= 0.72Ti - 0.01(Ti/Al) - 0.11)$.

[0151] A more preferable lower limit of $[Ti]_R$ is 0.055, further preferably is 0.060, further preferably is 0.065, further

preferably is 0.070, and further preferably is 0.075.

[0152] A more preferable upper limit (F3) of $[Ti]_R$ is $0.72Ti-0.01(Ti/Al)-0.15$, further preferably is $0.72Ti-0.01(Ti/Al)-0.18$, and further preferably is $0.72Ti-0.01(Ti/Al)-0.20$.

5 [Method for measuring $[Ti]_R$]

[0153] $[Ti]_R$ can be measured by the following electrolytic extraction method.

[0154] A test specimen is taken from a position located at a depth of 1 mm or more from the surface of the alloy. The size of the test specimen is not particularly limited. The size of the test specimen is, for example, 10 mm in diameter $\times$ 70 mm in length.

[0155] The surface of the taken test specimen is polished to remove approximately 50 μm of the surface by preliminary electropolishing to obtain a newly formed surface. The electropolished test specimen is then subjected to a main electrolyzation with a current value of 270 mA using an electrolyte solution (10% acetylacetone + 1% tetraammonium + methanol). At such time, the electrolytic depth is to be approximately 31 μm . The electrolyte solution after the main electrolyzation is passed through a 0.2 μm filter to capture residue. The obtained residue is subjected to acid decomposition, and the Ti mass (g) in the residue is determined by ICP (inductively coupled plasma) emission spectrometry. In addition, the mass (g) of the test specimen before the main electrolyzation and the mass (g) of the test specimen after the main electrolyzation are measured. Then, a value obtained by subtracting the mass of the test specimen after the main electrolyzation from the mass of the test specimen before the main electrolyzation is defined as the base metal mass (g) electrolyzed by the main electrolyzation. The Ti mass in the residue is divided by the base metal mass electrolyzed by the main electrolyzation to thereby determine the content (mass%) of Ti in the residue. That is, $[Ti]_R$ (mass%) that represents the content of Ti in the residue is determined based on the following formula.

$$[Ti]_R = \text{Ti mass in residue} / \text{base metal mass} \times 100$$

[Advantageous effect of alloy]

[0156] The alloy of the present embodiment satisfies the aforementioned Feature 1 to Feature 3. As a result, the alloy of the present embodiment has sufficient creep strength in a high temperature environment, and can achieve both excellent stress relaxation cracking resistance and excellent weld crack resistance. When the alloy of the present embodiment also satisfies Feature 4, the creep strength and weld hot cracking resistance are further enhanced.

[Microstructure of alloy]

[0157] The microstructure of the alloy of the present embodiment consists of austenite.

[Shape of alloy]

[0158] The shape of the alloy of the present embodiment is not particularly limited. The alloy may be an alloy pipe, or may be an alloy plate. The alloy may also be an alloy bar. Preferably the alloy of the present embodiment is an alloy pipe.

[Method for producing alloy]

[0159] A method for producing the alloy of the present embodiment that satisfies Feature 1 to Feature 4 will now be described. The production method described hereunder is one example of a method for producing the alloy of the present embodiment. Therefore, an alloy that satisfies Feature 1 to Feature 4 may also be produced by a production method other than the production method described hereunder. However, the production method described hereunder is a preferable example of a method for producing the alloy of the present embodiment.

[0160] A method for producing the alloy of the present embodiment includes the following processes.

(Process 1) Preparation process

(Process 2) Hot working process

(Process 3) Cold working process

(Process 4) Heat treatment process

[0161] In the hot working process of process 2, the following condition 1 is satisfied.

(Condition 1)

[0162] A heating temperature T1 (°C) during heating before hot working, and a holding time t1 (mins) at the heating temperature T1 are within the following ranges.

T1: 1100 to 1280°C
t1: 3 to 120 mins

[0163] In addition, in the heat treatment process of process 4, the following condition 2 is satisfied.

(Condition 2)

[0164] A heat treatment temperature T2 (°C) in the heat treatment process, and a holding time t2 (mins) at the heat treatment temperature T2 are within the following ranges.

T2: 1050 to 1300°C
t2: 1 to 60 mins

[0165] Hereunder, each process is described.

[(Process 1) Preparation process]

[0166] In the preparation process, a starting material having a chemical composition according to the above Feature 1 is prepared. The starting material may be supplied by a third party or may be produced. The starting material may be an ingot, or may be a slab, a bloom, or a billet.

[0167] In the case of producing the starting material, the starting material is produced by the following method. A molten steel that has the chemical composition described above is produced. The produced molten steel is used to produce an ingot by an ingot-making process. The produced molten steel may also be used to produce a slab, a bloom, or a billet by a continuous casting process. Hot working may be performed on the produced ingot, slab, or bloom to produce a billet. For example, hot forging may be performed on the ingot to produce a cylindrical billet, and the billet may be used as the starting material. In such case, although not particularly limited, the temperature of the starting material immediately before the start of the hot forging is, for example, 1000 to 1300°C. The method for cooling the starting material after hot forging is not particularly limited.

[(Process 2) Hot working process]

[0168] In the hot working process, hot working is performed on the starting material prepared in the preparation process, to thereby produce an intermediate alloy. The intermediate alloy, for example, may be an alloy pipe, may be an alloy plate, or may be an alloy bar.

[0169] If the intermediate alloy is an alloy pipe, the following working is performed in the hot working process. First, a cylindrical starting material is prepared. A through-hole is formed along the central axis in the cylindrical starting material by machining. The cylindrical starting material in which the through-hole has been formed is heated. The heated cylindrical starting material is then subjected to a hot-extrusion process, which is typified by the Ugine-Sejournet process, to produce an intermediate alloy (alloy pipe). A hollow forging process may be performed instead of the hot extrusion process.

[0170] Further, instead of hot extrusion, an alloy pipe may be produced by performing piercing-rolling according to the Mannesmann process. In such case, the cylindrical starting material is heated. The heated cylindrical starting material is then subjected to piercing-rolling using a piercing machine. In the case of performing piercing-rolling, although not particularly limited, the piercing ratio is, for example, 1.0 to 4.0. The cylindrical starting material subjected to piercing-rolling is further subjected to hot rolling with a mandrel mill, a stretch reducing mill, a sizing mill or the like to produce a hollow blank (alloy pipe). Although not particularly limited, the cumulative reduction of area in the hot working process is, for example, 20 to 80%. In the case of producing an alloy pipe by hot working, preferably the temperature (finishing temperature) of the hollow blank immediately after completing the hot working is 800°C or more.

[0171] If the intermediate alloy is an alloy plate, one or a plurality of rolling mills equipped with a pair of work rolls is used in the hot working process. The starting material such as a slab is heated. The heated starting material is subjected to hot working using the rolling mill to produce an alloy plate.

[0172] In the hot working process, the aforementioned condition 1 is satisfied. That is, the heating temperature T1 (°C) during heating before hot working, and the holding time t1 (mins) at the heating temperature T1 are within the following ranges.

T1: 1100 to 1280°C

t1: 3 to 120 mins

[0173] Preferably, in the hot working process, the following condition 3 is satisfied.

(Condition 3)

[0174] The heating temperature T1 (°C) and the holding time t1 (mins) at the heating temperature T1 are set so as to satisfy the following Formula (A).

$$800 \leq T1 \times \log(t1) \leq 2100 \quad (A)$$

[0175] Let FA be defined as $FA = T1 \times \log(t1)$. FA influences the amount of TiC in the alloy after production.

[0176] If FA is 800 or more, a sufficient amount of TiC will form during heating before hot working. Therefore, in the alloy after production, $[Ti]_R$ will be higher than 0.050.

[0177] On the other hand, if FA is 2100 or less, an appropriate amount of TiC will form during heating before hot working. Therefore, in the alloy after production, $[Ti]_R$ will be less than $F3 (= 0.72Ti - 0.01(Ti/Al) - 0.11)$. Therefore, preferably FA is 800 to 2100.

[0178] A more preferable lower limit of FA is 820, further preferably is 840, further preferably is 860, further preferably is 1000, and further preferably is 1200.

[0179] A more preferable upper limit of FA is 2050, further preferably is 2000, further preferably is 1950, and further preferably is 1850.

[(Process 3) Cold working process]

[0180] A cold working process is performed as necessary. In other words, a cold working process does not have to be performed. In the case of performing a cold working process, cold working is performed on the intermediate alloy after the intermediate alloy has been subjected to a pickling treatment. If the intermediate alloy is an alloy pipe or an alloy bar, the cold working is, for example, cold drawing. If the intermediate alloy is an alloy plate, the cold working is, for example, cold rolling. Performing the cold working process allows the development of recrystallization and the uniformed grain size to occur. Although not particularly limited, the reduction of area in the cold working process is, for example, 10 to 90%.

[(Process 4) Heat treatment process]

[0181] In the heat treatment process, the intermediate alloy after the hot working process or after the cold working process is subjected to a heat treatment to adjust the amount of TiC and the size of the grains in the alloy.

[0182] In the heat treatment process, the aforementioned condition 2 is satisfied. That is, the heat treatment temperature T2 (°C), and the holding time t2 (mins) at the heat treatment temperature T2 are within the following ranges.

T2: 1050 to 1300°C

t2: 1 to 60 mins

[0183] Preferably, in the heat treatment process, the following condition 4 is satisfied.

(Condition 4)

[0184] The heat treatment temperature T2 (°C), and the holding time t2 (mins) at the heat treatment temperature T2 are set so as to satisfy the following Formula (B).

$$2600 \leq T2 \times (\log(t2) + 2) \leq 4400 \quad (B)$$

[0185] Let FB be defined as $FB = T2 \times (\log(t2) + 2)$. FB influences the amount of TiC in the alloy after production, similarly to FA.

[0186] If FB is 2600 or more, a sufficient amount of TiC will form in the alloy after production. Therefore, $[Ti]_R$ will be higher than 0.050.

[0187] On the other hand, if FB is 4400 or less, an appropriate amount of TiC will form in the alloy after production. Therefore, $[Ti]_R$ will be less than $0.72Ti - 0.01(Ti/Al) - 0.11$. Therefore, preferably FB is 2600 to 4400.

[0188] A more preferable lower limit of FB is 2650, further preferably is 2700, and further preferably is 2750.

[0189] A more preferable upper limit of FB is 4350, further preferably is 4300, further preferably is 4250, further preferably is 4000, and further preferably is 3800.

[0190] After being held at the heat treatment temperature T2 (°C) for the holding time t2 (mins), the intermediate alloy is cooled. Rapid cooling (water cooling) is preferable as the cooling method.

[0191] Preferably, in the hot working process and the heat treatment process, the following condition 5 is also satisfied.

(Condition 5)

[0192]

$$0.30 \leq FA/FB \quad (C)$$

[0193] Let FC be defined as $FC = FA/FB$. FC influences the amount of TiC in the alloy after production, similarly to FA and FB. If FC is 0.30 or more, it will be easy to obtain a sufficient amount of TiC in the alloy after production. Therefore, $[Ti]_R$ will be higher than 0.050.

[0194] Therefore, preferably FC is 0.30 or more.

[0195] A more preferable lower limit of FC is 0.33, further preferably is 0.35, and further preferably is 0.38.

[0196] The upper limit of FC is not particularly limited. The upper limit of FC is, for example, 0.60.

[0197] The alloy of the present embodiment can be produced by the processes described above. The production method described above is one example of a method for producing the alloy of the present embodiment. Therefore, a method for producing the alloy of the present embodiment is not limited to the above production method. As long as Feature 1 to Feature 3 are satisfied, or Feature 1 to Feature 4 are satisfied, a method for producing the alloy is not limited to the production method described above.

[Method for producing welded joint of alloy]

[0198] A welded joint of the alloy of the present embodiment can be produced by the following method.

[0199] The alloy of the present embodiment is prepared as a base metal. A bevel is then formed in the prepared base metal. Specifically, a bevel is formed in an end of the base metal by a well-known processing method. The bevel shape may be a V shape, may be a U shape, may be an X shape, or may be a shape other than a V shape, a U shape or an X shape.

[0200] Welding is performed on the prepared base metal to produce a welded joint. Specifically, two base metals in which a bevel has been formed are prepared. The bevels of the prepared base metals are butted together. The portion where the pair of bevels are butted together is then subjected to welding using a well-known welding consumable to thereby form a weld metal having the aforementioned chemical composition. The welding consumable is, for example, a welding consumable with the AWS classification: ER NiCr-3. However, the welding consumable is not limited to this example.

[0201] The welding method may be one in which the weld metal is produced by single-pass welding or by multi-pass welding. The welding methods include, for example, gas tungsten arc welding (GTAW), shielded metal arc welding (SMAW), flux-cored arc welding (FCAW), gas metal arc welding (GMAW), and submerged arc welding (SAW). A welded joint of the alloy of the present embodiment can be produced by the above production process.

EXAMPLES

[0202] The advantageous effects of the alloy of the present embodiment will now be described more specifically by way of examples. The conditions adopted in the following examples are one example of conditions adopted for confirming the feasibility and advantageous effects of the alloy of the present embodiment. Accordingly, the alloy of the present embodiment is not limited to this one example of conditions.

[Production of alloys]

[0203] Ingots having the chemical compositions shown in Table 1-1 and Table 1-2 were produced. Each ingot was formed in a cylindrical shape with an outer diameter of 120 mm, and the mass of each ingot was 30 kg.

[Table 1-1]

[0204]

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Table 1-1

	Test Number	Chemical Composition (unit is mass%; balance is Fe and impurities)										
		C	Si	Mn	P	S	Cr	Ni	N	Al	Ti	B
5	1	0.059	0.10	1.08	0.011	0.0005	19.79	30.38	0.002	0.26	0.57	0.0018
	2	0.062	0.18	0.92	0.012	0.0005	19.82	30.45	0.002	0.22	0.55	0.0016
	3	0.058	0.14	1.11	0.011	0.0005	19.74	30.26	0.002	0.18	0.59	0.0015
10	4	0.091	0.13	0.85	0.011	0.0006	19.88	30.54	0.002	0.21	0.55	0.0018
	5	0.053	0.72	1.04	0.013	0.0005	19.80	31.12	0.002	0.29	0.49	0.0011
	6	0.062	0.17	1.44	0.010	0.0003	19.84	30.99	0.002	0.23	0.51	0.0016
15	7	0.060	0.14	0.49	0.011	0.0006	19.96	30.84	0.003	0.24	0.53	0.0018
	8	0.061	0.23	1.07	0.028	0.0007	19.53	30.77	0.001	0.27	0.57	0.0015
	9	0.057	0.16	0.93	0.012	0.0012	19.47	30.85	0.002	0.22	0.57	0.0022
20	10	0.059	0.15	0.85	0.011	0.0008	22.14	31.08	0.004	0.28	0.54	0.0017
	11	0.062	0.22	1.16	0.013	0.0005	20.86	34.25	0.003	0.22	0.49	0.0013
	12	0.058	0.19	0.88	0.012	0.0004	20.44	30.46	0.028	0.25	0.52	0.0016
25	13	0.060	0.12	1.16	0.014	0.0005	20.43	32.01	0.002	0.24	0.54	0.0028
	14	0.064	0.22	1.03	0.012	0.0004	19.96	30.83	0.002	0.22	0.51	0.0014
	15	0.063	0.15	0.68	0.011	0.0003	19.28	30.46	0.002	0.27	0.47	0.0011
30	16	0.067	0.28	0.99	0.011	0.0004	21.49	31.66	0.003	0.25	0.50	0.0022
	17	0.061	0.18	0.89	0.013	0.0005	19.88	32.22	0.001	0.22	0.55	0.0019
	18	0.055	0.13	0.94	0.012	0.0006	21.53	31.28	0.002	0.26	0.53	0.0019
35	19	0.062	0.28	1.08	0.016	0.0004	19.67	31.18	0.004	0.25	0.55	0.0018
	20	0.064	0.16	0.82	0.010	0.0004	19.71	31.47	0.002	0.28	0.56	0.0015
	21	0.059	0.21	0.79	0.013	0.0007	20.81	32.55	0.002	0.26	0.49	0.0017
40	22	0.055	0.17	1.02	0.011	0.0005	19.69	30.89	0.002	0.32	0.58	0.0012
	23	0.057	0.19	1.25	0.012	0.0006	20.63	31.37	0.003	0.24	0.56	0.0016
	24	0.062	0.23	0.96	0.010	0.0005	19.77	30.76	0.002	0.23	0.54	0.0017
45	25	0.063	0.16	0.72	0.012	0.0003	19.84	31.15	0.001	0.25	0.55	0.0021
	26	0.061	0.22	1.13	0.015	0.0007	20.45	31.09	0.002	0.22	0.52	0.0019
	27	0.060	0.18	0.84	0.011	0.0004	19.62	31.98	0.002	0.34	0.56	0.0014
50	28	0.061	0.09	0.90	0.011	0.0005	19.76	31.54	0.003	0.31	0.57	0.0010
	29	0.052	0.07	1.35	0.024	0.0005	19.89	30.38	0.002	0.51	0.58	0.0011
	30	0.051	0.17	0.84	0.023	0.0004	19.73	30.55	0.002	0.17	0.49	0.0012
55	31	0.055	0.15	1.16	0.026	0.0012	21.74	30.44	0.008	0.50	0.57	0.0021
	32	0.057	0.11	0.93	0.025	0.0011	20.82	30.39	0.005	0.51	0.58	0.0022
	33	0.056	0.14	1.26	0.022	0.0013	20.77	30.58	0.006	0.50	0.57	0.0010
	34	0.097	0.10	1.09	0.023	0.0010	21.11	30.51	0.004	0.51	0.57	0.0021
	35	0.073	0.68	1.18	0.021	0.0006	19.79	30.38	0.003	0.28	0.33	0.0018
	36	0.073	0.68	1.20	0.011	0.0006	19.70	30.28	0.003	0.79	0.18	0.0012
	37	0.052	0.15	0.89	0.022	0.0005	19.28	30.47	0.002	0.16	0.21	0.0011
	38	0.061	0.54	1.08	0.024	0.0009	19.55	30.64	0.003	0.55	0.68	0.0019

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(continued)

Test Number	Chemical Composition (unit is mass%; balance is Fe and impurities)										
	C	Si	Mn	P	S	Cr	Ni	N	Al	Ti	B
39	0.079	0.11	1.39	0.010	0.0005	19.19	30.43	0.002	0.59	0.29	0.0011

[Table 1-2]

[0205]

Table 1-2

Test Number	Chemical Composition (unit is mass%; balance is Fe and impurities)												F1	F2
	Nb	Ta	V	Zr	Hf	Cu	Mo	W	Co	Ca	Mg	REM		
1	-	-	-	-	-	-	-	-	-	-	-	-	0.83	2.19
2	-	-	-	-	-	-	-	-	-	-	-	-	0.77	2.50
3	-	-	-	-	-	-	-	-	-	-	-	-	0.77	3.28
4	-	-	-	-	-	-	-	-	-	-	-	-	0.76	2.62
5	-	-	-	-	-	-	0.40	-	-	-	-	-	0.78	1.69
6	-	-	-	-	-	-	-	-	-	-	-	-	0.74	2.22
7	-	-	-	-	-	-	-	-	-	-	-	-	0.77	2.21
8	-	-	-	-	-	-	-	-	-	-	-	-	0.84	2.11
9	-	-	-	-	-	-	-	-	-	-	-	-	0.79	2.59
10	-	-	-	-	-	-	-	-	-	-	-	-	0.82	1.93
11	-	-	-	-	-	-	-	-	-	-	-	-	0.71	2.23
12	-	-	-	-	-	-	-	-	-	-	-	-	0.77	2.08
13	-	-	-	-	-	-	0.38	-	-	-	-	-	0.78	2.25
14	-	-	-	-	-	-	-	-	-	-	-	-	0.73	2.32
15	0.05	-	-	-	-	-	-	-	-	-	-	-	0.74	1.74
16	-	0.27	-	-	-	-	-	-	-	-	-	-	0.75	2.00
17	-	-	0.15	-	-	-	-	-	-	-	-	-	0.77	2.50
18	-	-	-	0.04	-	-	-	-	-	-	-	-	0.79	2.04
19	-	-	-	-	0.07	-	-	-	-	-	-	-	0.80	2.20
20	-	-	-	-	-	0.46	-	-	-	-	-	-	0.84	2.00
21	-	-	-	-	-	-	0.92	-	-	-	-	-	0.75	1.88
22	-	-	-	-	-	-	-	0.18		-	-	-	0.90	1.81
23	-	-	-	-	-	-	-	-	0.95	-	-	-	0.80	2.33
24	-	-	-	-	-	-	-	-	-	0.0028	-	-	0.77	2.35
25	-	-	-	-	-	-	-	-	-	-	0.0015	-	0.80	2.20
26	-	-	-	-	-	-	-	-	-	-	-	0.0048	0.74	2.36
27	-	-	-	-	-	-	0.42	-	-	0.0022	-	-	0.90	1.65
28	-	-	0.08	-	-	-	0.35	-	-	0.0026	-	-	0.88	1.84
29	-	-	-	-	-	-	0.37	-	-	-	-	-	1.09	1.14
30	-	-	-	-	-	-	-	-	-	-	-	-	0.66	2.88
31	-	-	-	-	-	-	-	-	-	-	-	-	1.07	1.14

(continued)

Test Number	Chemical Composition (unit is mass%; balance is Fe and impurities)												F1	F2
	Nb	Ta	V	Zr	Hf	Cu	Mo	W	Co	Ca	Mg	REM		
32	-	-	-	-	-	-	-	-	-	-	-	-	1.09	1.14
33	-	-	-	-	-	-	-	-	-	-	-	-	1.07	1.14
34	-	-	-	-	-	-	-	-	-	-	-	-	1.08	1.12
35	-	-	-	-	-	-	-	-	-	-	-	-	0.61	1.18
36	-	-	-	-	-	-	-	-	-	-	-	-	0.97	0.23
37	-	-	-	-	-	-	-	-	-	-	-	-	0.37	1.31
38	-	-	-	-	-	-	-	-	-	-	-	-	1.23	1.24
39	-	-	-	-	-	-	-	-	-	-	-	-	0.88	0.49

[0206] The symbol "-" in Table 1-2 means that the content of the corresponding element was at the level of an impurity or less.

[0207] Each of the produced ingots was subjected to hot forging to produce a starting material (alloy plate) having a thickness of 30 mm. The heating temperature of the ingots in the hot forging was 1000 to 1300°C.

[0208] The produced starting material was subjected to a hot working process. Specifically, the starting material was heated in a heating furnace. The heating temperature T1 in the hot working process was 1100 to 1280°C, and the holding time t1 at the heating temperature T1 was 3 to 120 minutes. The FA value is shown in Table 2. After being heated, the starting material was subjected to hot rolling to produce an intermediate alloy (alloy plate) having a thickness of 15 mm.

[Table 2]

[0209]

Table 2

Test Number	Hot Working Process	Heat Treatment Process		FC	[Ti] _R (mass%)	F3	[Ti] _R <F3	Creep Strength	Stress Relaxation Cracking Resistance	Weld Hot Cracking Resistance	Remarks
	FA	FB									
1	1435		3212	0.45	0.110	0.278	T	E	E	E	Inventive Example of Present Invention
2	1411		3347	0.42	0.080	0.261	T	E	E	E	Inventive Example of Present Invention
3	1574		2996	0.53	0.170	0.282	T	E	E	E	Inventive Example of Present Invention
4	1435		3212	0.45	0.170	0.260	T	E	E	E	Inventive Example of Present Invention
5	1587		3212	0.49	0.090	0.226	T	E	E	E	Inventive Example of Present Invention
6	1200		3212	0.37	0.093	0.235	T	E	E	E	Inventive Example of Present Invention
7	1220		3660	0.33	0.080	0.250	T	E	E	E	Inventive Example of Present Invention
8	1423		3158	0.45	0.130	0.279	T	E	E	E	Inventive Example of Present Invention
9	1220		3212	0.38	0.100	0.274	T	E	E	E	Inventive Example of Present Invention
10	1210		3266	0.37	0.090	0.260	T	E	E	E	Inventive Example of Present Invention
11	1411		2915	0.48	0.150	0.221	T	E	E	E	Inventive Example of Present Invention
12	1435		3540	0.41	0.100	0.244	T	E	E	E	Inventive Example of Present Invention
13	1561		2942	0.53	0.160	0.256	T	E	E	E	Inventive Example of Present Invention
14	1548		3212	0.48	0.090	0.234	T	E	E	E	Inventive Example of Present Invention
15	1423		2738	0.52	0.120	0.211	T	E	E	E	Inventive Example of Present Invention
16	1574		3570	0.44	0.100	0.230	T	E	E	E	Inventive Example of Present Invention
17	1678		3022	0.56	0.090	0.261	T	E	E	E	Inventive Example of Present Invention
18	1802		3212	0.56	0.090	0.251	T	E	E	E	Inventive Example of Present Invention
19	1561		3450	0.45	0.130	0.264	T	E	E	E	Inventive Example of Present Invention
20	1411		3780	0.37	0.120	0.273	T	E	E	E	Inventive Example of Present Invention
21	1435		3570	0.40	0.080	0.224	T	E	E	E	Inventive Example of Present Invention
22	1220		3212	0.38	0.110	0.289	T	E	E	E	Inventive Example of Present Invention
23	1561		3144	0.50	0.120	0.270	T	E	E	E	Inventive Example of Present Invention

(continued)

Test Number	Hot Working Process	Heat Treatment Process	FC	[Ti] _R (mass%)	F3	[Ti] _R ≤F3	Creep Strength	Stress Relaxation Cracking Resistance	Weld Hot Cracking Resistance	Remarks
	FA	FB								
24	1210	2948	0.41	0.100	0.255	T	E	E	E	Inventive Example of Present Invention
25	1423	3541	0.40	0.160	0.264	T	E	E	E	Inventive Example of Present Invention
26	1574	3375	0.47	0.130	0.241	T	E	E	E	Inventive Example of Present Invention
27	1692	2973	0.57	0.100	0.277	T	E	E	E	Inventive Example of Present Invention
28	1773	3405	0.52	0.150	0.282	T	E	E	E	Inventive Example of Present Invention
29	611	2416	0.25	0.036	0.296	T	E	G	E	Inventive Example of Present Invention
30	2287	4520	0.51	0.230	0.214	F	G	E	G	Inventive Example of Present Invention
31	608	3900	0.16	0.045	0.289	T	E	G	E	Inventive Example of Present Invention
32	2218	3790	0.59	0.301	0.296	F	E	E	G	Inventive Example of Present Invention
33	1561	2520	0.62	0.040	0.289	T	E	G	E	Inventive Example of Present Invention
34	1901	4496	0.42	0.305	0.289	F	G	E	G	Inventive Example of Present Invention
35	1011	3610	0.28	0.048	0.116	T	E	G	E	Inventive Example of Present Invention
36	1435	3374	0.43	0.010	0.017	T	B	B	B	Comparative Example
37	1200	2738	0.44	0.020	0.028	T	B	G	E	Comparative Example
38	1574	4138	0.38	0.170	0.367	T	E	G	B	Comparative Example
39	1411	2738	0.52	0.030	0.094	T	G	B	E	Comparative Example

[0210] Each intermediate alloy was subjected to a heat treatment process. In the heat treatment process, the heat treatment temperature T2 was 1050 to 1300°C, and the holding time t2 at the heat treatment temperature T2 was 1 to 60 mins. The FB value and FC value are shown in Table 2. After the holding time t2 elapsed, the intermediate alloy was water-cooled to normal temperature. An alloy (alloy plate) of each test number was produced by the above process.

[Evaluation tests]

[0211] The following evaluation tests were performed using the produced alloys.

- (Test 1) [Ti]_R measurement test
- (Test 2) Creep strength evaluation test
- (Test 3) Stress relaxation cracking resistance evaluation test
- (Test 4) Weld hot cracking resistance evaluation test

[0212] Hereunder, each evaluation test is described.

[(Test 1) [Ti]_R measurement test]

[0213] A test specimen was taken from a position at a depth of 1 mm or more from the surface of the alloy of each test number. The size of the test specimen was 10 mm in diameter × 70 mm in length. The content of Ti in a residue [Ti]_R (mass%) was determined based on the method described above in the section [Method for measuring [Ti]_R]. The obtained [Ti]_R value is shown in the column "[Ti]_R (mass%)" in Table 2.

[(Test 2) Creep strength evaluation test]

[0214] The following creep strength evaluation test was performed on the alloy (alloy plate) of each test number.

[0215] A creep rupture test specimen in accordance with JIS Z2271: 2010 was taken from a position located at the center position of the plate width and the center position of the plate thickness of the alloy (alloy plate) of each test number. The cross section perpendicular to the axial direction of the parallel portion of the creep rupture test specimen was circular. The parallel portion had an outer diameter of 6 mm, and had a length of 30 mm. The longitudinal direction of the creep rupture test specimen was parallel to the rolling direction of the alloy plate.

[0216] A creep rupture test conforming to JIS Z2271: 2010 was carried out using the prepared creep rupture test specimen. Specifically, the creep rupture test specimen was heated to 700°C. Thereafter, the creep rupture test was carried out. The test stress was set to 80 MPa. In the test, the creep rupture time (hours) was determined.

[0217] The creep strength was evaluated as follows according to the obtained creep rupture time.

Evaluation E (Excellent): Creep rupture time was longer than 4000 hours

Evaluation G (Good): Creep rupture time was 2000 to 4000 hours

Evaluation B (Bad): Creep rupture time was shorter than 2000 hours

[0218] In the case of evaluation G or evaluation E, it was determined that excellent creep strength had been obtained. The evaluation results are shown in the column "Creep Strength" in Table 2.

[(Test 3) Stress relaxation cracking resistance evaluation test]

[0219] The alloy (alloy plate) of each test number was subjected to the following stress relaxation cracking resistance evaluation test.

[0220] A square-shaped test specimen was taken from a position located at the center position of the plate width and the center position of the plate thickness of the alloy (alloy plate) of each test number. A cross section perpendicular to the longitudinal direction of the square-shaped test specimen was a rectangle with dimensions of 10 mm × 10 mm. The length of the square-shaped test specimen was made 100 mm. The longitudinal direction of the square-shaped test specimen was parallel with the rolling direction of the alloy (alloy plate).

[0221] A high frequency heat cycle apparatus was used to apply the following heat history to the prepared square-shaped test specimen. Specifically, the temperature of the square-shaped test specimen was raised from normal temperature to 1300°C at a rate of 70°C/sec. Thereafter, the temperature was held at 1300°C for 180 seconds. Next, the square-shaped test specimen was cooled to normal temperature at a cooling rate of 50°C/sec. A simulated HAZ test specimen was prepared by applying the heat history described above to the square-shaped test specimen.

[0222] A stress relaxation test in accordance with ASTM E328-02 was conducted using the simulated HAZ test

specimen. Specifically, a test specimen for a stress relaxation test was prepared from the simulated HAZ test specimen. The test specimen was formed into a flanged creep test specimen having a length of 80 mm and a gauge length GL of 30 mm. An initial cold strain of 20% was applied to the test specimen using a test jig for deflection displacement loading. The test jig to which the test specimen to which the cold strain had been applied was provided was placed into a heating furnace and held at 650°C for 300 hours.

[0223] The results of the stress relaxation test in accordance with ASTM E328-02 were evaluated as follows.

Evaluation E (Excellent): Test specimen was not ruptured after 300 hours had passed

Evaluation G (Good): Test specimen ruptured after 200 to 300 hours had passed

Evaluation B (Bad): Test specimen ruptured in less than 200 hours

[0224] In the case of evaluation G or evaluation E, it was determined that excellent stress relaxation cracking resistance was obtained. The evaluation results are shown in the column "Stress Relaxation Cracking Resistance" in Table 2.

[(Test 4) Weld hot cracking resistance evaluation test]

[0225] From the alloy (alloy plate) of each test number, a test specimen having a thickness of 12 mm, a width of 40 mm, and a length of 300 mm was taken, which was centered on the central position of the plate width and the central position of the plate thickness of the alloy (alloy plate). The prepared test specimen was subjected to a longitudinal Varestraint test described below.

[0226] Specifically, melt run TIG welding was performed in the longitudinal direction at the central position of the plate width of the test specimen under welding conditions of a welding current of 200 A, a voltage of 12 V, and a speed of 15 cm/min. In the course of performing the melt run TIG welding, bending stress was momentarily applied in parallel to the welding direction so that strain of 2% was applied to the outer layer.

[0227] A portion including a place where a weld crack occurred due to application of the bending stress was cut out in a size that could be observed with an optical microscope. The size of the cut sample was 40 mm × 40 mm × 12 mm.

[0228] Scale on the surface of the weld zone of the cut sample was removed by buffing. Thereafter, using an optical microscope at a magnification of × 100, whether or not a crack was present in the HAZ was determined, and in a case where a crack had occurred, the length of the crack was measured. Specifically, taking the boundary between the weld metal and the HAZ as the starting point, the length of a crack that propagated in a direction perpendicular to the welding direction (the length in the direction perpendicular to the welding direction) was measured. The lengths in the direction perpendicular to the welding direction of all cracks that had occurred in the test specimen were determined. The total of the lengths of those cracks was defined as the total crack length (mm). The total crack length was determined for two test specimens, respectively. The arithmetic average value of the determined total crack lengths was defined as the averaged total crack length.

[0229] The weld hot cracking resistance was evaluated as follows based on the obtained averaged total crack length.

Evaluation E (Excellent): Averaged total crack length is 2.0 mm or less

Evaluation G (Good): Averaged total crack length is more than 2.0 to less than 3.0 mm

Evaluation B (Bad): Averaged total crack length is 3.0 mm or more

[0230] In the case of evaluation G or evaluation E, it was determined that excellent weld hot cracking resistance was obtained. The evaluation results are shown in the column "Weld Hot Cracking Resistance" in Table 2.

[Test results]

[0231] The test results are shown in Table 2.

[0232] Referring to Table 1-1, Table 1-2, and Table 2, in Test Nos. 1 to 35, the alloy satisfied Feature 1 to Feature 3. Therefore, in a high temperature environment, sufficient creep strength was obtained. In addition, excellent stress relaxation cracking resistance and excellent weld hot cracking resistance were obtained.

[0233] In addition, in Test Nos. 1 to 28, with respect to the production conditions, FA satisfied Formula (A), FB satisfied Formula (B), and FC satisfied Formula (C). As a result, in Test Nos. 1 to 28, the alloy also satisfied Feature 4, and not just Feature 1 to Feature 3. Therefore, in Test Nos. 1 to 28, the evaluation E was obtained in the creep strength evaluation test, the stress relaxation cracking resistance evaluation test, and the weld hot cracking resistance evaluation test, and thus further excellent creep strength, stress relaxation cracking resistance, and weld hot cracking resistance were obtained.

[0234] On the other hand, in Test No. 36, the content of Al was too high. Therefore, sufficient stress relaxation cracking resistance and weld hot cracking resistance were not obtained. In addition, sufficient creep strength was not obtained.

[0235] In Test No. 37, although the content of each element in the chemical composition was appropriate, F1 was less

than the lower limit of Formula (1). Therefore, sufficient creep strength was not obtained.

[0236] In Test No. 38, although the content of each element in the chemical composition was appropriate, F1 was more than the upper limit of Formula (1). Therefore, sufficient weld hot cracking resistance was not obtained.

[0237] In Test No. 39, although the content of each element in the chemical composition was appropriate, F2 was less than the lower limit of Formula (2). As a result, sufficient stress relaxation cracking resistance was not obtained.

[0238] An embodiment of the present invention has been described above. However, the embodiment described above is merely an example for carrying out the present invention. Therefore, the present invention is not limited to the above embodiment, and can be implemented by appropriately modifying the above embodiment within a range that does not depart from the gist of the present invention.

Claims

1. An alloy having a chemical composition consisting of, in mass%,

C: 0.050 to 0.100%,
 Si: 1.00% or less,
 Mn: 1.50% or less,
 P: 0.035% or less,
 S: 0.0015% or less,
 Cr: 19.00 to 23.00%,
 Ni: 30.00 to 35.00%,
 N: 0.100% or less,
 Al: 0.15 to 0.70%,
 Ti: 0.15 to 0.70%,
 B: 0.0010 to 0.0050%,
 Nb: 0 to 0.30%,
 Ta: 0 to 0.50%,
 V: 0 to 1.00%,
 Zr: 0 to 0.10%,
 Hf: 0 to 0.10%,
 Cu: 0 to 1.00%,
 Mo: 0 to 1.00%,
 W: 0 to 1.00%,
 Co: 0 to 1.00%,
 Ca: 0 to 0.0200%,
 Mg: 0 to 0.0200%, and
 rare earth metal: 0 to 0.1000%,
 with the balance being Fe and impurities, and
 satisfying Formula (1) and Formula (2):

$$0.60 < \text{Al} + \text{Ti} < 1.20 \quad (1)$$

$$1.12 \leq \text{Ti}/\text{Al} \quad (2)$$

where, a content of a corresponding element in the chemical composition of the alloy is substituted in percent by mass for each symbol of an element in Formula (1) and Formula (2).

2. The alloy according to claim 1, wherein:

when a content of Ti in percent by mass in a residue obtained by an electrolytic extraction method is defined as $[\text{Ti}]_R$, the alloy further satisfies Formula (3):

$$0.050 < [\text{Ti}]_R < 0.72\text{Ti} - 0.01(\text{Ti}/\text{Al}) - 0.11 \quad (3)$$

where, a content of a corresponding element in the chemical composition of the alloy is substituted in percent by

mass for each symbol of an element in Formula (3).

3. The alloy according to claim 1 or claim 2, comprising one or more elements selected from a group consisting of:

5 Nb: 0.01 to 0.30%,
Ta: 0.01 to 0.50%,
V: 0.01 to 1.00%,
Zr: 0.01 to 0.10%,
Hf: 0.01 to 0.10%,
10 Cu: 0.01 to 1.00%,
Mo: 0.01 to 1.00%,
W: 0.01 to 1.00%,
Co: 0.01 to 1.00%,
Ca: 0.0001 to 0.0200%,
15 Mg: 0.0001 to 0.0200%, and
rare earth metal: 0.001 to 0.1000%.

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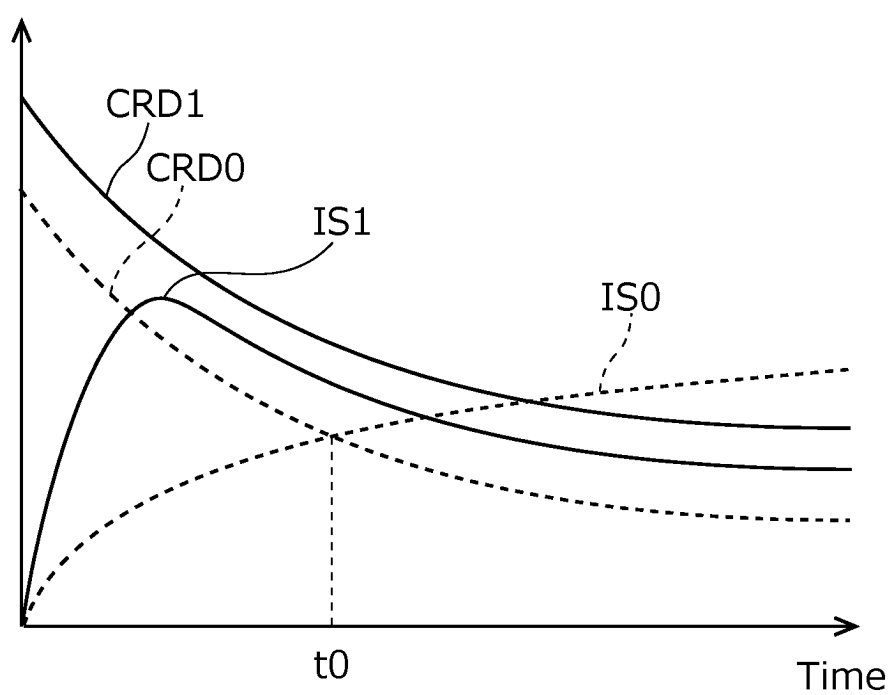
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FIG.1



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/014635

A. CLASSIFICATION OF SUBJECT MATTER

C21D 6/00(2006.01)i; **C21D 8/10**(2006.01)i; **C22C 30/00**(2006.01)i; **C22C 38/00**(2006.01)i; **C22C 38/54**(2006.01)i
 FI: C22C38/00 302Z; C21D6/00 101L; C21D8/10 D; C22C30/00; C22C38/54

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)

C21D6/00; C21D8/10; C22C30/00; C22C38/00; C22C38/54

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 1971-2023
 Registered utility model specifications of Japan 1996-2023
 Published registered utility model applications of Japan 1994-2023

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	WO 2018/066579 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 12 April 2018 (2018-04-12)	1-3
A	JP 2004-315973 A (GENERAL ELECTRIC CO <GE>) 11 November 2004 (2004-11-11)	1-3
A	EP 0264357 A2 (VEREINIGTE EDELSTAHLWERKE AKTIENGESELLSCHAFT (VEW)) 20 April 1988 (1988-04-20)	1-3
P, X	JP 2022-163585 A (NIPPON STEEL STAINLESS STEEL CORP) 26 October 2022 (2022-10-26) paragraphs [0014]-[0031], [0039]-[0042], [0047]-[0049], [0051], tables 1-1, 1-2, 2	1-3

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

* Special categories of cited documents:

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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

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Date of the actual completion of the international search

20 June 2023

Date of mailing of the international search report

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Name and mailing address of the ISA/JP

Japan Patent Office (ISA/JP)
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 Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/JP2023/014635

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		paragraphs [0020]-[0037], [0062]-[0069], [0073]-[0075], [0077], tables 1-3	
		KR 10-2023-0070052 A	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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- **HANS VAN WORTEL.** Control of Relaxation Cracking in Austenitic High Temperature Components. *CORROSION 2007 (2007), NACE, Paper No. 07423* [0008]
- **RICHARD COLWELL ; CATHLEEN SHARGAY.** Alloy 800H: Material and fabrication challenges associated with the mitigation of stress relaxation cracking. *ASME Pressure Vessels & Piping Conference 2020* [0008]