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(54) Titre : ACIER INOXYDABLE AUSTENITIQUE ET SON PROCEDE DE PRODUCTION
(54) Title: AUSTENITIC STAINLESS STEEL AND PRODUCTION METHOD THEREOF

(57) Abrégé/Abstract:
Provided are: an austenitic stainless steel having a high strength and having good shape retention after heat treatment; and a method for producing the austenitic stainless steel. This austenitic stainless steel has a composition satisfying at most 0.12 mass% C, 0.1-1.0 mass% of Si, 0.1-3.0 mass% of Mn, at most 0.05 mass% of P, at most 0.01 mass% S, 13.0-22.0 mass% of Cr, 4.0-12.0 mass% of Ni, 0.01-0.50 mass% of Cu, at most 5.0 mass% of Mo, at most 0.03 mass% of Al, 0.05-0.30 mass% of Nb, and 0.10-0.50 mass% of N, with the remainder comprising Fe and inevitable impurities, and has a grain size number of at least 7.0.

ABSTRACT

Provided are an austenitic stainless steel that has high strength and favorable shape retention properties after a heat treatment, and a production method thereof. One aspect of the present invention is the austenitic stainless steel wherein a component composition satisfies C: less than or equal to 0.12% by mass; Si: greater than or equal to 0.1% by mass and less than or equal to 1.0% by mass; Mn: greater than or equal to 0.1% by mass and less than or equal to 3.0% by mass; P: less than or equal to 0.05% by mass; S: less than or equal to 0.01% by mass; Cr: greater than or equal to 13.0% by mass and less than or equal to 22.0% by mass; Ni: greater than or equal to 4.0% by mass and less than or equal to 12.0% by mass; Cu: greater than or equal to 0.01% by mass and less than or equal to 0.50% by mass; Mo: less than or equal to 5.0% by mass; Al: less than or equal to 0.03% by mass; Nb: greater than or equal to 0.05% by mass and less than or equal to 0.30% by mass; N: greater than or equal to 0.10% by mass and less than or equal to 0.50% by mass; and a balance consisting of Fe and inevitable impurities, and a crystal grain size number is greater than or equal to 7.0.

AUSTENITIC STAINLESS STEEL AND PRODUCTION METHOD THEREOF

[TECHNICAL FIELD]

[0001]

The present invention relates to an austenitic stainless steel and a production method thereof.

[BACKGROUND ART]

[0002]

Austenitic stainless steels are extensively used in various applications as steel materials superior in strength, workability, corrosion resistance, and the like. Further, various kinds of austenitic stainless steels having controlled component compositions, crystal structures, and the like have been developed in attempts to further improve performance in accordance with applications and the like (see Patent Documents 1 to 5).

[0003]

On the other hand, high-strength stainless steels such as duplex stainless steels are used for automobile fuel injection tubes in light of reduction in weight, prevention of fatigue fractures, corrosion resistance against salt water, and the like. For such materials used for automobile fuel injection tubes as well, development of materials having strength (proof stress, tensile strength) and the like higher than those of conventional materials has been desired to support an extension of useful life, higher performance, and the like. In addition, in production of automobile fuel injection tubes, a brazing heat treatment may be performed on steel tubes. When such a heat treatment is performed, strength of the steel tube may be reduced, and there is also a problem of the duplex stainless steel being unable to retain a straight tube shape.

[0004]

Patent Document 1: Japanese Patent No. 6137434

Patent Document 2: Japanese Patent No. 5131794

Patent Document 3: Japanese Unexamined Patent Application, Publication No. 2017-12244

Patent Document 4: Japanese Unexamined Patent Application, Publication No. 2016-44332

Patent Document 5: Japanese Patent No. 2787044

[SUMMARY OF THE INVENTION]

[0005]

The present invention was made on the basis of the foregoing circumstances and an object of the present invention is to provide: an austenitic stainless steel having high strength and favorable shape retention properties after a heat treatment; and a production method thereof.

[0006]

One aspect of the present invention made for solving the aforementioned problems is an austenitic stainless steel wherein a component composition satisfies C: less than or equal to 0.12% by mass; Si: greater than or equal to 0.1% by mass and less than or equal to 1.0% by mass; Mn: greater than or equal to 0.1% by mass and less than or equal to 3.0% by mass; P: less than or equal to 0.05% by mass; S: less than or equal to 0.01% by mass; Cr: greater than or equal to 13.0% by mass and less than or equal to 22.0% by mass; Ni: greater than or equal to 4.0% by mass and less than or equal to 12.0% by mass; Cu: greater than or equal to 0.01% by mass and less than or equal to 0.50% by mass; Mo: less than or equal to 5.0% by mass; Al: less than or equal to 0.03% by mass; Nb: greater than or equal to 0.05% by mass and less than or equal to 0.30% by mass; N: greater than or equal to 0.10% by mass and less than or equal to 0.50% by mass; and a balance consisting of Fe and inevitable impurities, and a crystal grain size number is greater than or equal to 7.0.

[0007]

The austenitic stainless steel, by virtue of having the above component composition and crystal grain size, has high strength (proof stress and tensile strength) due to solid-solution strengthening and/or crystal grain miniaturization. In addition, the austenitic stainless steel, being the austenitic stainless steel having the component composition and crystal grain size described above, has favorable shape retention properties after a heat treatment.

[0008]

It is preferable that the above component composition further satisfies the following inequality (1). In such a case, coarsening of crystal grains may be inhibited even when a heat treatment such as brazing or the like is performed. Thus, reduction in strength of the steel after the heat treatment may be suppressed.

$$200 \leq -2090\,[\%C] + 12.8\,[\%Cr] + 320\,[\%N] + 42.3\,[\%Nb] \leq 300 \quad (1)$$

In the inequality (1), [%C], [%Cr], [%N], and [%Nb] represent the content (% by mass) of each component.

[0009]

A maximum crystal grain diameter of the austenitic stainless steel is preferably less than or equal to 60 μm. In such a case, the coarsening of crystal grains may be inhibited even if a heat treatment such as brazing is performed. Thus, reduction in strength of the steel after the heat treatment may be suppressed.

[0010]

It is preferable that the component composition described above further satisfies the following inequality (2). Controlling the content of carbon and nitrogen in this way can, for example, further enhance the strength.

$$0.20 \leq [\%C] + [\%N] \leq 0.40 \quad (2)$$

In the inequality (2), [%C] and [%N] represent the content (% by mass) of each component.

[0011]

The austenitic stainless steel preferably has a maximum height Ry of less than or equal to 10 μm. Increasing a smoothness of a surface of the austenitic stainless steel in this way can improve corrosion resistance and the like.

[0012]

The austenitic stainless steel is preferably a seamless steel tube. In a case in which austenitic stainless steel is a seamless tube, breakage originating in a welding portion can be avoided. Thus, in a case in which the austenitic stainless steel is a seamless steel tube, it can be more suitably used for automobile fuel injection tubes and the like, to which repeated stress from internal pressure is applied.

[0013]

The austenitic stainless steel, due to its superior strength, can also sufficiently support an increase in direct-injection pressure in automobile engines, and therefore can be suitably used for automobile fuel injection tubes. In addition, the austenitic stainless steel, due also to its favorable shape retention properties after the heat treatment, can be suitably used for automobile fuel injection tubes to be subjected to a brazing heat treatment.

[0014]

Another aspect of the present invention made for solving the aforementioned problems is a production method A of the austenitic stainless steel, comprising: performing cold working on a steel material with a working rate per pass of greater than or equal to 20%; and performing a heat treatment on the steel material before and after performing the cold working, wherein a heat treatment temperature T (°C) in the heat treatment satisfies the following inequality (3):

$$1{,}000 \leq T \leq -2090\,[\%C] + 12.8\,[\%Cr] + 320\,[\%N] + 42.3\,[\%Nb] + 900 \quad (3)$$

wherein, in the inequality (3), [%C], [%Cr], [%N], and [%Nb] represent the content (% by mass) of each component in the steel material.

[0015]

According to the production method A, an austenitic stainless steel having high strength and favorable shape retention properties after a heat treatment can be obtained by performing solid-solution strengthening and/or crystal grain miniaturization strengthening.

[0016]

A still other aspect of the present invention made for solving the aforementioned problems is a production method B of the austenitic stainless steel comprising: performing cold working on a steel material with a working rate per pass of greater than or equal to 20%; and performing a heat treatment on the steel material before and after performing the cold working, wherein a heat treatment temperature T (°C) in the heat treatment is greater than or equal to 1,000°C and less than or equal to 1,200°C.

[0017]

According also to the production method B, an austenitic stainless steel having high strength and favorable shape retention properties after a heat treatment can be obtained by performing solid-solution strengthening and/or crystal grain miniaturization strengthening.

[0018]

In the production methods A and B, a final heat treatment after the cold working is preferably bright annealing. For example, in a case in which the final heat treatment is open air annealing, subsequent pickling is required, which causes surface roughening due to scale peeling and/or dissolution by acid. However, performing the bright annealing as the final heat treatment in this way makes pickling unnecessary; accordingly, the surface roughness does not occur. Thus, the austenitic stainless steel which is obtained has high smoothness, and as a result, is superior in corrosion resistance and the like.

[Effect of the Invention]

[0019]

The present invention can provide an austenitic stainless steel having high strength and favorable shape retention properties after a heat treatment, and a production method thereof.

[DESCRIPTION OF THE PREFERRED EMBODIMENTS]

[0020]

Hereinafter, an austenitic stainless steel and a production method thereof according to one embodiment of the present invention will be described in detail.

[0021]

Austenitic Stainless Steel

An austenitic stainless steel according to one embodiment of the present invention has a specific component composition and crystal grain size, thereby exhibiting high strength. It is to be noted that the austenitic stainless steel is substantially composed of an austenitic single phase, and its shape retention properties after a heat treatment are better than those of ferritic-austenitic duplex stainless steels. In the austenitic stainless steel of this embodiment, typically, greater than or equal to 99% of the structure is in the austenite phase.

[0022]

(Component composition)

The component composition of the austenitic stainless steel comprises a predetermined amount of C, Si, Mn, P, S, Cr, Ni, Cu, Mo, Al, Nb, and N, and the balance comprises Fe and inevitable impurities. A numerical range of the content of each component and a reason for the limitation will be described below.

[0023]

C: Less than or equal to 0.12% by mass

C (carbon) is an element effective for solid-solution strengthening and austenite phase stabilization. In addition, C is an element that forms non-intermetallic compounds by being added together with Cr, Nb, and N, thereby effectively serving to inhibit crystal grain coarsening due to a heat treatment. However, since excessive addition of carbon results in formation of carbides, a content of C is set to less than or equal to 0.12% by mass for forming the non-intermetallic compounds as aimed. In light of inhibiting formation of carbides and the like, the upper limit of the content of C is preferably 0.10% by mass, more preferably 0.08% by mass, and still more preferably 0.06% by mass. On the other hand, the lower limit of the content of C may be more than 0% by mass, and because of the solid-solution strengthening and the like due to adding C, is preferably 0.01% by mass, and more preferably 0.02% by mass.

[0024]

Si: Greater than or equal to 0.1% by mass and less than or equal to 1.0% by mass

Si (silicon) is an element effective for solid-solution strengthening of stainless

steels. On the other hand, in a case in which a stainless steel is used after being brazed, Si becomes a factor that may impair brazing properties. Thus, an amount of Si added must be less than or equal to 1.0% by mass. The upper limit of a content of Si is preferably 0.8% by mass. Further, Si is also an element used for preliminary deoxidation in melting and casting. Thus, a lower limit of the content is preferably 0.2% by mass, more preferably 0.3% by mass, still more preferably 0.35% by mass, sometimes even more preferably 0.4% by mass, and sometimes even more preferably 0.5% by mass.

[0025]

Mn: Greater than or equal to 0.1% by mass and less than or equal to 3.0% by mass

Mn (manganese) is an austenite-forming element. An addition of Mn can reduce an added amount of Ni, which is an expensive element. However, the addition of Mn promotes formation of non-intermetallic compounds such as MnS, which harm corrosion resistance; thus, excessive addition of Mn must be avoided. Accordingly, a content of Mn is set to greater than or equal to 0.1% by mass and less than or equal to 3.0% by mass. The lower limit of the content of Mn is preferably 0.3% by mass, more preferably 0.5% by mass, and still more preferably 0.7% by mass. On the other hand, the upper limit of the content is preferably 2.7% by mass, and more preferably 2.4% by mass.

[0026]

P: Less than or equal to 0.05% by mass

P (phosphorus) is an element which may be contained as an impurity. Since P may reduce hot workability, weldability, strength, and the like, a content of P is set to less than or equal to 0.05% by mass. The upper limit of the content of P is preferably 0.04% by mass, more preferably 0.03% by mass, and still more preferably 0.02% by mass. The lower limit of the content of P may be more than 0% by mass, and may be 0.001% by mass or 0.005% by mass.

[0027]

S: Less than or equal to 0.01% by mass

S (sulfur) is an element which may be contained as an impurity, and is an element that bonds with Mn and/or Ca to form non-intermetallic compounds that may harm corrosion resistance and/or mechanical properties. S forms sulfides and reduces corrosion resistance, and thus, an amount of S added should be limited to be as low as possible. Accordingly, the upper limit of a content of S must be 0.01% by mass, and is preferably 0.005% by mass, and more preferably 0.003% by mass. On the other hand, the lower limit of the content of S may be more than 0% by mass, and

may be 0.0001% by mass or 0.0003% by mass.

[0028]

Cr: Greater than or equal to 13.0% by mass and less than or equal to 22.0% by mass

Cr (chromium) is an element effective for corrosion resistance improvement and solid-solution strengthening. In addition, Cr forms non-intermetallic compounds when added in combination with C, Nb and N, thereby inhibiting the coarsening of crystal grains due to the heat treatment. Increasing the amount of added Cr elevates the temperatures at which the non-intermetallic compounds are stable, and therefore, a microstructure can be maintained even when the heat treatment is performed at a higher temperature. However, since Cr acts as a ferrite-forming element, excessive addition must be avoided in such cases as when added amounts of C, Mn, Ni, and N are small, and the like. Thus, a content of Cr is set to greater than or equal to 13.0% by mass and less than or equal to 22.0% by mass. Excessive addition of Cr leads to increased costs and/or decreased stability of the austenite phase, and therefore the upper limit of the content of Cr is preferably 21.0% by mass, and more preferably 20.0% by mass. On the other hand, in light of enhancing the aforementioned effects and the like, the lower limit of the content of Cr is preferably 15.0% by mass, more preferably 16.0% by mass, and even more preferably 18.0% by mass.

[0029]

Ni: Greater than or equal to 4.0% by mass and less than or equal to 12.0% by mass

Ni (nickel) is an element effective for forming austenite. However, excessive addition of Ni leads to increased material costs, and thus a content of Ni is set to greater than or equal to 4.0% by mass and less than or equal to 12.0% by mass. The lower limit of the content of Ni is preferably 5.0% by mass, more preferably 7.0% by mass, and still more preferably 7.8% by mass. Further, by comparatively increasing the content of Ni, a single-phase austenitic stainless steel can be obtained. On the other hand, the upper limit of the content of Ni is preferably 11.0% by mass, and more preferably 10.0% by mass.

[0030]

Cu: Greater than or equal to 0.01% by mass and less than or equal to 0.50% by mass

Cu (copper) is an austenite-forming element. Since Cu is an element that becomes mixed in from stainless steel scraps and the like, excessive reduction leads to an increase in raw material costs. Thus, a content of Cu is set to greater than or equal to 0.01% by mass and less than or equal to 0.50% by mass. The lower limit of

the content of Cu is sometimes preferably 0.05% by mass, and sometimes preferably 0.1% by mass. On the other hand, the upper limit of the content of Cu is preferably 0.40% by mass.

[0031]

Mo: Less than or equal to 5.0% by mass

Mo (molybdenum) is an element effective for corrosion resistance improvement and solid-solution strengthening. However, Mo is an expensive element and leads to an increase in raw material costs. Thus, a content of Mo is set to less than or equal to 5.0% by mass. The upper limit of the content of Mo is sometimes preferably 1.0% by mass, sometimes more preferably 0.50% by mass, sometimes even more preferably 0.45% by mass, and sometimes yet even more preferably 0.40% by mass. On the other hand, the lower limit of the content of Mo may be greater than 0% by mass, and is preferably 0.01% by mass, more preferably 0.05% by mass, and still more preferably 0.1% by mass.

[0032]

Al: Less than or equal to 0.03% by mass

Al (aluminum) is an element that has a deoxidation action, but stabilizes ferrite, and therefore, excessive addition of Al may lower the stability of austenite, thereby lowering its hot workability and/or ductility. Further, Al-based inclusions may be a cause of decreased workability and/or scratches on mirror surfaces. Thus, the upper limit of a content of Al is 0.03% by mass, and is preferably 0.02% by mass. On the other hand, the lower limit of the content of Al content may be greater than 0% by mass, and is sometimes preferably 0.001% by mass, and sometimes more preferably 0.005% by mass.

[0033]

Nb: Greater than or equal to 0.05% by mass and less than or equal to 0.30% by mass

Nb (niobium) forms non-intermetallic compounds when added in combination with C, Cr, and N, thereby inhibiting the coarsening of crystal grains due to the heat treatment. Increasing an amount of added Nb elevates the temperatures at which the non-intermetallic compounds are stable, and therefore, the microstructure can be maintained even when the heat treatment is performed at a higher temperature. However, Nb is an expensive element. Thus, excessive addition of Nb needs to be avoided in light of cost. Accordingly, a range of a content of Nb is set to greater than or equal to 0.05% by mass to less than or equal to 0.30% by mass. The lower limit of the content of Nb is preferably 0.07% by mass, and more preferably 0.09% by mass. On the other hand, the upper limit of the content of Nb is preferably 0.20% by

mass, and more preferably 0.15% by mass.

[0034]

N: Greater than or equal to 0.10% by mass and less than or equal to 0.50% by mass

N (nitrogen) is an element effective for austenite stabilization, corrosion resistance improvement, and solid-solution strengthening. In addition, N forms non-intermetallic compounds when added in combination with C, Cr, and Nb, thereby inhibiting the coarsening of crystal grains due to the heat treatment. Increasing an amount of added N elevates the temperatures at which the non-intermetallic compounds are stable, which thereby inhibits the coarsening of crystal grains even when the heat treatment is performed at a higher temperature. However, increasing the amount of added N decreases workability and the like. Thus, a range of a content of N is set to greater than or equal to 0.10% by mass to less than or equal to 0.50% by mass. Further, considering an effect on the austenite stabilization and an influence on the workability due to adding N, the lower limit of the content of N is preferably 0.15% by mass, and more preferably 0.20% by mass. The upper limit of the content of N is preferably 0.35% by mass, and more preferably 0.30% by mass.

[0035]

Fe and inevitable impurities

Basic components of the component composition constituting the austenitic stainless steel are as described above, and remaining components comprise Fe and inevitable impurities. The inevitable impurities are impurities inevitably mixed in during melt forming, and are contained within a range not impairing various properties of the steel tubes. In addition, the component composition of the austenitic stainless steel may further comprise other elements in addition to the aforementioned components to an extent not adversely affecting effects of the present invention.

[0036]

Inequality (1)

The component composition of the austenitic stainless steel preferably further satisfies the following inequality (1):

$$200 \leq -2090\,[\%C] + 12.8\,[\%Cr] + 320\,[\%N] + 42.3\,[\%Nb] \leq 300 \quad (1)$$

In the inequality (1), [%C], [%Cr], [%N], and [%Nb] represent the content (% by mass) of each component.

[0037]

The present inventors have found that, by controlling the content of C, Cr, N, and Nb, the compounds (z-phase) of C, Cr, N, and Nb are stably present before and

after the heat treatment, and crystal grain diameters and/or precipitate amounts are maintained before and after the heat treatment; therefore, crystal grain miniaturization strengthening and/or precipitation strengthening can be utilized even after the heat treatment. More specifically, it was found that, by having a component composition in which a value of −2,090 [%C] + 12.8 [%Cr] + 320 [%N] + 42.3 [%Nb] is greater than or equal to 200 and less than or equal to 300, a temperature of a z-phase solid solution becomes greater than or equal to 1,100°C. On the other hand, for example, steel tubes used for automobile fuel injection tubes are typically processed into parts through a brazing heat treatment using a Cu-based brazing filler or the like. Since the Cu-based brazing filler has a melting point of 1,082°C, the heat treatment is often performed at approximately 1,080°C to 1,150°C. Thus, in a case in which the component composition of the austenitic stainless steel satisfies the above inequality (1), a grain boundary pinning effect or the like by the precipitates can be obtained even when the brazing heat treatment is performed in the above temperature range. In this manner, when the above inequality (1) is satisfied, the coarsening of crystal grains after the heat treatment can be inhibited, and enhancing the strength through crystal grain miniaturization and/or precipitation strengthening can be utilized. In addition, when the above inequality (1) is satisfied, mixed grain sizes can be suppressed, thereby contributing to inhibition of the formation of a weak portion leading to a fatigue fracture.

[0038]

Inequality (2)

The component composition of the austenitic stainless steel preferably further satisfies the following inequality (2):

$$0.20 \leq [\%C] + [\%N] \leq 0.40 \quad (2)$$

In the inequality (2), [%C] and [%N] represent the content (% by mass) of each component.

[0039]

C and N effectively act as solid-solution strengthening elements. Setting the value of [%C] + [%N] to greater than or equal to 0.20 provides sufficient solid-solution strengthening, which enables enhancement of the proof stress, the tensile strength, and the like. The lower limit of [%C] + [%N] is preferably 0.25. On the other hand, by setting the value of [%C] + [%N] to less than or equal to 0.40, sufficient workability can be attained, thereby reducing the frequency of crack occurrences when cold working is performed. The upper limit of [%C] + [%N] is preferably 0.35.

[0040]

Crystal grain size

In the austenitic stainless steel, the lower limit of a crystal grain size number of the austenite crystals is 7.0, and is preferably 8.0, more preferably 9.0, and still more preferably 9.5. In the austenitic stainless steel, setting the crystal grain size number to greater than or equal to the lower limit in addition to having the specific component composition can facilitate crystal grain miniaturization strengthening, enabling expression of great strength. It is to be noted that generally, adding nitrogen and/or carbon as a solid-solution element is effective to strengthen a stainless steel, but excessive addition of these elements decreases workability due to strain aging. For this reason, in the austenitic stainless steel, the strengthening by crystal grain miniaturization is utilized to enhance the strength of the stainless steel while limiting the content of nitrogen and/or carbon.

[0041]

On the other hand, the upper limit of the crystal grain size number of the austenite crystals is not particularly limited, but it may, for example, be 16.0, and may be 14.0, 13.0, 12.0, 11.5, or 11.0. In addition, the crystal grain size number is a value measured in accordance with JIS G0551 (2013), and is specifically a value determined by a method described in the Examples.

[0042]

It is to be noted that the crystal grain size of the austenitic stainless steel can be adjusted by, for example, a heat treatment temperature before and after cold working, or the like, as will be described later.

[0043]

Maximum crystal grain diameter

In the austenitic stainless steel, the upper limit of a maximum crystal grain diameter of the austenitic crystals may, for example, be 200 μm, 150 μm, or 100 μm, but is preferably 60 μm, more preferably 50 μm, still more preferably 40 μm, and even more preferably 30 μm. In the austenitic stainless steel, reducing the maximum crystal grain diameter in addition to having a greater crystal grain size number, or in other words, having a smaller average crystal grain diameter, as described above, inhibits the mixed grain sizes and/or crystal grain coarsening after the heat treatment. As a result, reduction in strength of the steel after the heat treatment is suppressed.

[0044]

On the other hand, the lower limit of the maximum crystal grain diameter is, for example, 1 μm, may be 5 μm, and may also be 10 μm. In addition, the maximum crystal grain diameter is a value measured by a method described in the Examples

described later.

[0045]

It is to be noted that, for example, by controlling the temperature in the heat treatment, having the component composition that satisfies the above inequality (1), and the like, the maximum crystal grain diameter of the austenitic stainless steel can be set to less than or equal to 60 μm.

[0046]

Surface roughness

For the austenitic stainless steel, the upper limit of a maximum height Ry is preferably 10 μm, more preferably 8 μm, and still more preferably 6 μm. Setting the maximum height of the austenitic stainless steel to less than or equal to the upper limit so as to increase the smoothness of a surface can enhance the corrosion resistance, fatigue strength, and the like of the austenitic stainless steel. That is, setting the maximum height of the austenitic stainless steel to less than or equal to the upper limit can, for example, extend the useful life of the austenitic stainless steel when it is used for automobile fuel injection tubes and the like.

[0047]

On the other hand, the lower limit of the maximum height Ry is not particularly limited, but it, for example, is 0.5 μm, or may be 1 μm or 2 μm. In addition, the maximum height Ry as referred to herein means a value measured in accordance with JIS B0601 (1994). It is to be noted that in a case in which the austenitic stainless steel is a steel tube, the maximum height Ry may be a measurement value on an external surface.

[0048]

It is to be noted that a surface roughness (maximum height Ry) of the austenitic stainless steel can be reduced by performing bright annealing as a final step as will be described later, subjecting the austenitic stainless steel to mirror finishing aside from the bright annealing, or the like.

[0049]

Shape, application, etc.

The shape of the austenitic stainless steel is not particularly limited, and may be a plate shape, a rod shape, a tubular shape, or the like, but a tubular shape is preferred. That is, the austenitic stainless steel is suitably used as a steel tube. Examples of the steel tube include a seamless steel tube, an electric resistance welded steel tube, an arc-welded steel tube such as a UOE steel tube or a spiral steel tube, a forged steel tube, and the like. The seamless steel tube is preferred.

[0050]

The austenitic stainless steel has high strength and can be applied to various applications. As a particularly notable example, the austenitic stainless steel can be suitably used for automobile fuel injection tubes. In particular, as described above, the austenitic stainless steel can inhibit deformation after the brazing heat treatment, and can be made to maintain a crystal structure having high strength even after the heat treatment by adjusting the composition and the like. Thus, the austenitic stainless steel is suitable as a material for automobile fuel injection tubes to be subjected to a brazing heat treatment.

[0051]

(Production Method of Austenitic Stainless Steel)

The austenitic stainless steel can be suitably obtained by the following method. In other words, a production method of an austenitic stainless steel according to one embodiment of the present invention comprises: performing cold working (1) on a steel material with a working rate per pass of greater than or equal to 20%; and performing a heat treatment (2) on the steel material before and after performing the cold working (1).

[0052]

Cold working (1)

In the cold working (1), the steel material having the aforementioned component composition is cold-worked with a working rate per pass of greater than or equal to 20%. Examples of the cold working include cold rolling, cold drawing, and the like, and a procedure is selected from these, depending on the shape and the like of the final product. For example, to obtain steel tubes, the cold drawing is suitably employed.

[0053]

In cold working, strain is more likely to be generated in proximity to a surface layer than to a central portion. When the working rate is less than 20%, sufficient strain cannot be introduced into the central portion, and it is difficult to miniaturize the crystal grains in the central portion. Thus, the working rate of cold working is greater than or equal to 20%, and is preferably greater than or equal to 25%. On the other hand, giving consideration to uniform elongation of the austenitic stainless steel, the upper limit of the working rate per pass is preferably 50%, and more preferably 40%.

[0054]

Heat treatment (2)

Before and after the cold working (1), a heat treatment (2) is performed on the

steel material. The heat treatment temperature T (°C) in the heat treatment (2) preferably satisfies the following inequality (3) in both the heat treatment before and the heat treatment after the cold working (1). This can inhibit the coarsening of crystal grains due to the heat treatment and enhance the strength of the austenitic stainless steel to be obtained.

$$1{,}000 \leq T \leq -2090\,[\%C] + 12.8\,[\%Cr] + 320\,[\%N] + 42.3\,[\%Nb] + 900 \quad (3)$$

In the inequality (3), [%C], [%Cr], [%N], and [%Nb] represent the content (% by mass) of each component.

[0055]

It is to be noted that when adopting the production method, the value of −2090 [%C] + 12.8 [%Cr] + 320 [%N] + 42.3 [%Nb] in the component composition of the austenitic stainless steel is greater than or equal to 100.

[0056]

In addition, the heat treatment temperature T (°C) in the heat treatment (2) is preferably greater than or equal to 1,000°C and less than or equal to 1,200°C for both the heat treatment before and the heat treatment after the cold working (1). This can inhibit the coarsening of crystal grains due to the heat treatment and enhance the strength of the austenitic stainless steel to be obtained. It is to be noted that the upper limit of the heat treatment temperature T is preferably 1,150°C, and more preferably 1,130°C.

[0057]

The heat treatment procedure in the heat treatment (2) is not particularly limited, and a known procedure may be used for the heat treatment. However, the heat treatment performed after the cold working (1) is preferably bright annealing. It is to be noted that the heat treatment performed after the cold working (1) is preferably a final heat treatment. The bright annealing is a heat treatment performed in a reducing atmosphere, and can heat-treat the stainless steel without oxidizing the surface thereof. This enables omission of pickling after the heat treatment, and a stainless steel having great smoothness, which is to say superior corrosion resistance and the like, can be obtained.

[0058]

In the production method, known procedures may be adopted for steps other than the cold working (1) and the heat treatment (2).

[0059]

Other Embodiments

The present invention is not limited to the embodiments described above. Various modifications and improvements can be made in addition to the aspects of the

invention described above. For example, in the production method of the austenitic stainless steel, the final heat treatment may be performed with open-air annealing, followed by pickling, and then mirror-finishing the surface to increase the smoothness.

EXAMPLES

[0060]

Hereinafter, the present invention will be described in more detail with reference to Examples, but the present invention is not limited to the following Examples.

[0061]

(Examples 1 to 7 and Comparative Examples 1 to 3: Preparation of Steel Plate (Plate Material))

Using a vacuum induction melting furnace (VIF), an ingot weighing 20 kg and being cylindrical, and having the component composition described in Table 1 (the balance being Fe and inevitable impurities) was prepared. The ingot was heat-treated at greater than or equal to 1,250°C for 24 hours, and hot-forged at a temperature in a range of greater than or equal to 1,200°C to less than or equal to 1,000°C to prepare a plate material of W60 mm x L250 mm x t17 mm. The plate material was heat-treated at a pre-cold working heat treatment temperature (Tc) as described in Table 1. Then, the plate material was cold-rolled at a working rate of 30%. Thereafter, as the final heat treatment, the plate material was heat-treated in a bright annealing furnace at a post-cold working heat treatment temperature (Tf) described in Table 1 to give test samples for Examples 1 to 7 and Comparative Examples 1 to 3. It is to be noted that Examples 1 to 7 and Comparative Examples 1 to 2 are austenitic stainless steels, and Comparative Example 3 is a duplex stainless steel.

[0062]

(Example 8: Preparation of Steel Tube)

Using a vacuum induction melting furnace (VIF), an ingot weighing 150 kg and being cylindrical, and having the component composition (the balance being Fe and inevitable impurities) described in Table 1 was prepared. The ingot was heat-treated for 24 hours at greater than or equal to 1,250°C, and hot-forged at a temperature in a range of greater than or equal to 1,200°C to less than or equal to 1,000°C to prepare a bloom of φ150 mm. A billet of φ146 mm x 330 mm was prepared from the bloom, and a steel tube was obtained by the Ugine-Sejournet hot extrusion method. After being subjected to the heat treatment and the cold working multiple times, the steel tube was heat-treated at the pre-cold working heat treatment temperature (Tc) described

in Table 1. Then, the steel tube was shaped by cold working with a working rate of 35%. Subsequently, as the final heat treatment, the steel was heat-treated in a bright annealing furnace at the post-cold working heat treatment temperature (Tf) described in Table 1 to give the test sample (austenitic stainless steel) of Example 8.

[0063]

Crystal grain size number

A sample of 1 cm x 1 cm x 1.2 cm was cut out from each test sample (plate material) obtained in Examples 1 to 7 and Comparative Examples 1 to 3. Each sample was filled with a resin so that a width-thickness cross-section was visible, and a surface thereof was polished to a mirror finish; subsequently, each sample was subjected to a 65% nitric acid electrolytic etch to reveal a structure. Further, a sample was cut out from a test sample (steel tube) obtained in Example 8 so that a vertical surface in a lengthwise direction was visible. The sample was filled with a resin so that a width-thickness cross-section was visible, and a surface thereof was polished to a mirror finish; subsequently, the sample was subjected to a 65% nitric acid electrolytic etch to reveal a structure. For each sample, the structure was observed with an optical microscope at a magnification of 400x to measure crystal grain size numbers in five fields of view, and a median value was determined to be the crystal grain size number. The measurement results are shown in Table 1. It is to be noted that "-" in the table indicates that a measurement was not performed.

[0064]

Maximum crystal grain diameter

An average value of minor and major diameters of the largest crystal grain observed in the five fields of view in which the crystal grain size numbers were measured was determined to be the maximum crystal grain diameter. The measurement results are shown in Table 1. It is to be noted that "-" in the table indicates that a measurement was not performed.

[0065]

Maximum height Ry

The maximum height Ry was obtained in accordance with JIS B0601 (1994). A roughness meter was used to perform the measurement for 3 mm in an axial direction. It is to be noted that for the test sample (steel tube) in Example 8, the external surface was measured for 3 mm in a length direction. The measurement results are shown in Table 1.

[0066]

Evaluations

Tensile test: 0.2% Proof stress and tensile strength

A tensile test specimen having a parallel section of φ4 x L15 was prepared from each test sample (plate material) of Examples 1 to 7 and Comparative Examples 1 to 3, to be used for a tensile test. Further, for Example 8 (steel tube), a No. 11 test specimen in compliance with JIS Z 2241 was prepared for use in the tensile test. In the tensile test, the test specimen was pulled at a constant speed at an initial strain rate of $2.0 \times 10^{-3}s^{-1}$. The 0.2% proof stress and the tensile strength were measured. For the 0.2% proof stress, greater than or equal to 400 MPa was evaluated as A, greater than or equal to 370 MPa and less than 400 MPa was evaluated as B, and less than 370 MPa was evaluated as C. For the tensile strength, greater than or equal to 800 MPa was evaluated as A, greater than or equal to 710 MPa and less than 800 MPa was evaluated as B, and less than 710 MPa was evaluated as C. The results are shown in Table 2.

[0067]

Amount of warp after heat treatment

The test samples were wire-cut into plate materials having a length of 200 mm and a thickness of 2.0 mm. Each of the plate materials was heat-treated at 1,100°C for 5 minutes under an air-cooling condition while being supported at two points being 50 mm away from both ends of the plate material. To measure the amount of warp of the plate material after the heat treatment, image data was used to draw a perpendicular line from a line connecting both ends of the plate material, and a length at a time at which the perpendicular line was the longest was determined to be the amount of warp caused by the heat treatment. The amount of warp being less than or equal to 0.1 mm was evaluated as A, greater than 0.1 mm and less than or equal to 1 mm was evaluated as B, and greater than 1 mm was evaluated as C. The measurement results are shown in Table 2.

[0068]

Crystal structure after heat treatment at 1,100°C for 5 minutes

Each test sample was heat-treated at 1,100°C for 5 minutes under a water-cooling condition. Subsequently, each test sample (plate material) of Examples 1 to 7 and Comparative Examples 1 to 3 was cut so that a width-thickness cross-section was visible and filled with a resin, and a surface thereof was polished to a mirror finish; subsequently, each test sample was subjected to a 65% nitric acid electrolytic etch to reveal a structure. The test sample (steel tube) of Example 8 was cut so that a surface perpendicular to a length direction was visible, then filled with a resin, and a surface thereof was polished to a mirror finish; subsequently, the test sample was subjected to a 65% nitric acid electrolytic etch to reveal a structure. Each structure was observed with an optical microscope at a magnification of 400x to measure crystal grain size

numbers in 5 fields of view. Each median value was determined to be the crystal grain size number. The crystal grain size number being greater than or equal to 9.0 was evaluated as A, as the coarsening of crystal grains had been inhibited even after the heat treatment, and the crystal grain size number being less than 9.0 was evaluated as B. The results are shown in Table 2. It is to be noted that "-" in the table indicates that a measurement was not performed.

[0069]

As an evaluation of the presence/absence of the mixed grain sizes: a case in which less than or equal to 5% of crystal grains in one field of view had crystal grain size numbers that differed from each other by greater than or equal to 2 was evaluated as A; a case in which greater than 5% and less than or equal to 20% of crystal grains in one field of view had crystal grain size numbers that differed from each other by greater than or equal to 2 was evaluated as B; and a case in which greater than 20% of crystal grains in one field of view had crystal grain size numbers that differed from each other by greater than or equal to 2 was evaluated as C. The results are shown in Table 2. It is to be noted that "-" in the table indicates that a measurement was not performed.

[0070]

Table 1

	Component Composition (% by mass)														Heat Treatment Temperature		Final Heat Treatment	Crystal Structure			Steel Type (*3)
	C	Si	Mn	P	S	Cr	Ni	Cu	Mo	Al	Nb	N	X (*1)	Y (*2)	Pre-Cold Working Tc (°C)	Post-Cold Working Tf (°C)		Crystal Grain Size Number	Maximum Crystal Grain Diameter (μm)	Ry (μm)	
Example 1	0.050	0.66	1.75	0.027	0.002	18.12	8.05	0.21	0.28	0.013	0.08	0.23	204.4	0.280	1070	1050	Bright annealing	9.5	38.6	5.2	I
Example 2	0.040	0.57	0.75	0.026	0.001	18.54	8.25	0.22	0.19	0.017	0.07	0.25	236.7	0.290	1080	1080	Bright annealing	10.0	34.2	3.9	I
Example 3	0.049	0.51	2.21	0.018	0.001	19.19	9.55	0.30	0.32	0.015	0.10	0.22	217.9	0.269	1080	1080	Bright annealing	10.5	23.0	3.2	I
Example 4	0.020	0.71	1.25	0.013	0.002	19.20	8.16	0.21	0.26	0.016	0.11	0.28	298.2	0.300	1100	1100	Bright annealing	11.5	15.3	5.9	I
Example 5	0.036	0.51	2.14	0.021	0.001	18.62	8.13	0.13	0.12	0.013	0.12	0.15	216.2	0.186	1080	1080	Bright annealing	10.5	38.4	4.8	I
Example 6	0.057	0.52	2.20	0.019	0.001	18.09	9.15	0.30	0.25	0.012	0.08	0.21	183.0	0.267	1080	1080	Bright annealing	10.0	115.2	4.4	I
Example 7	0.120	0.54	2.21	0.024	0.001	18.54	8.25	0.23	0.43	0.013	0.12	0.22	62.0	0.340	1080	1080	Bright annealing	9.0	122.2	5.2	I
Example 8	0.040	0.49	0.75	0.009	0.001	19.61	7.91	0.20	0.21	0.010	0.12	0.22	242.9	0.260	1080	1080	Bright annealing	12.0	20.0	6.0	I
Comparative Example 1	0.031	0.52	1.33	0.020	0.002	18.54	8.06	0.29	0.17	0.014	0.13	0.21	245.2	0.241	1220	1080	Bright annealing	5.5	120.9	3.1	I
Comparative Example 2	0.040	0.62	2.15	0.022	0.002	18.55	8.29	0.23	0.32	0.014	0.01	0.23	227.9	0.270	1080	1080	Bright annealing	7.0	145.0	4.8	I
Comparative Example 3	0.029	0.51	1.65	0.023	0.001	20.42	4.36	0.15	0.21	0.011	0.12	0.18	263.4	0.209	1100	1100	Bright annealing	-	-	13.0	II

*1 $X = -2090\ [\%C] + 12.8\ [\%Cr] + 320\ [\%N] + 42.3[\%Nb]$

*2 $Y = [\%C] + [\%N]$

*3 I: Austenitic Stainless Steel, II: Duplex Stainless Steel

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[0071]

Table 2

	Shape	0.2% Proof Stress		Tensile Strength		Amount of Warp after Heat Treatment		Crystal Structure after Heat Treatment at 1,100°C for 5 minutes		
								Crystal Grain Size		Mixed Grain Sizes
		(MPa)	-	(MPa)	-	mm	-	(Number)	-	
Example 1	Steel plate	462	A	806	A	0.02	A	9.0	A	B
Example 2	Steel plate	445	A	809	A	0.04	A	9.5	A	B
Example 3	Steel plate	499	A	840	A	0.04	A	10.5	A	A
Example 4	Steel plate	550	A	845	A	0.06	A	11.5	A	A
Example 5	Steel plate	370	B	735	B	0.04	A	9.5	A	A
Example 6	Steel plate	377	B	720	B	0.03	A	8.5	B	C
Example 7	Steel plate	466	A	839	A	0.06	A	8.0	B	C
Example 8	Steel tube	530	A	846	A	0.09	A	11.0	A	A
Comparative Example 1	Steel plate	359	C	703	C	0.03	A	5.5	B	C
Comparative Example 2	Steel plate	354	C	709	C	0.02	A	6.5	B	B
Comparative Example 3	Steel plate	480	A	711	B	2.3	C	-	-	-

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[0072]

As shown in Table 2, all of Examples 1 to 8 received an evaluation of A or B for the 0.2% proof stress and the tensile strength, revealing high strength, and an evaluation of A for the amount of warp after the heat treatment, revealing favorable shape retention properties after the heat treatment. Further, among the Examples, in the evaluations pertaining to crystal structure after the heat treatment at 1,100°C for 5 minutes, Examples 1 to 5 and 8, in which X (= −2090 [%C] + 12.8 [%Cr] + 320 [%N] + 42.3 [%Nb]) was greater than or equal to 200 and less than or equal to 300; and the maximum crystal grain diameter was less than or equal to 60 μm, received an evaluation of A for the crystal grain size number, and an evaluation of A or B for the mixed grain sizes. These evaluations indicate that the coarsening of crystal grains after the heat treatment was inhibited in Examples 1 to 5 and Example 8. In other words, it is concluded that, in Examples 1 to 5 and Example 8, the steel had high strength, and the high strength was maintained even after the heat treatment. Further, among Examples 1 to 5 and 8, Examples 1 to 4 and 8, in which Y (= [%C] + [%N]) was greater than or equal to 0.20 and less than or equal to 0.40, received an evaluation of A for the 0.2% proof stress and the tensile strength, indicating particularly high strength.

[0073]

It is to be noted that in Comparative Example 3, Ry was greater than 10 μm even though the final heat treatment was performed through bright annealing. The Ry is considered to have increased because, in Comparative Example 8, the stainless steel had a structure of an α/γ duplex stainless steel rather than that of a single-phase austenitic stainless steel, and the α -phase and the γ-phase each had different strengths and/or deformation behaviors.

[INDUSTRIAL APPLICABILITY]

[0074]

The austenitic stainless steel according to the present invention can be suitably used for automobile fuel injection tubes and the like.

WHAT IS CLAIMED IS:

1. An austenitic stainless steel, wherein

a component composition satisfies

C: less than or equal to 0.12% by mass;

Si: greater than or equal to 0.1% by mass and less than or equal to 1.0% by mass;

Mn: greater than or equal to 0.1% by mass and less than or equal to 3.0% by mass;

P: less than or equal to 0.05% by mass;

S: less than or equal to 0.01% by mass;

Cr: greater than or equal to 13.0% by mass and less than or equal to 22.0% by mass;

Ni: greater than or equal to 4.0% by mass and less than or equal to 12.0% by mass;

Cu: greater than or equal to 0.01% by mass and less than or equal to 0.50% by mass;

Mo: less than or equal to 5.0% by mass;

Al: less than or equal to 0.03% by mass;

Nb: greater than or equal to 0.05% by mass and less than or equal to 0.30% by mass;

N: greater than or equal to 0.10% by mass and less than or equal to 0.50% by mass; and

a balance consisting of Fe and inevitable impurities, and

a crystal grain size number is greater than or equal to 7.0.

2. The austenitic stainless steel according to claim 1,

wherein the component composition satisfies inequality (1):

$200 \leq -2090\,[\%C] + 12.8\,[\%Cr] + 320\,[\%N] + 42.3\,[\%Nb] \leq 300$ (1)

wherein, in the inequality (1), [%C], [%Cr], [%N], and [%Nb] represent a content (% by mass) of each component.

3. The austenitic stainless steel according to claim 1 or 2, wherein a maximum crystal grain diameter is less than or equal to 60 μm.

4. The austenitic stainless steel according to any one of claims 1 to 3,

wherein the component composition satisfies inequality (2):

$0.20 \leq [\%C] + [\%N] \leq 0.40$(2)

wherein, in the inequality (2), [%C] and [%N] represent a content (% by mass) of each component.

5. The austenitic stainless steel according to any one of claims 1 to 4, wherein a maximum height Ry is less than or equal to 10 μm.

6. The austenitic stainless steel according to any one of claims 1 to 5, wherein the austenitic stainless steel is a seamless steel tube.

7. The austenitic stainless steel according to any one of claims 1 to 6 for use in an automobile fuel injection tube.

8. A production method of the austenitic stainless steel according to any one of claims 1 to 7, comprising:

performing cold working on a steel material with a working rate per pass of greater than or equal to 20%; and

performing a heat treatment on the steel material before and after performing the cold working,

wherein a heat treatment temperature T (°C) in the heat treatment satisfies inequality (3):

$1{,}000 \leq T \leq -2090\,[\%C] + 12.8\,[\%Cr] + 320\,[\%N] + 42.3\,[\%Nb] + 900$ (3)

wherein, in the inequality (3), [%C], [%Cr], [%N], and [%Nb] represent a content (% by mass) of each component in the steel material.

9. A production method of the austenitic stainless steel according to any one of claims 1 to 7, comprising:

performing cold working on a steel material with a working rate per pass of greater than or equal to 20%; and

performing a heat treatment on the steel material before and after performing the cold working;

wherein a heat treatment temperature T (°C) in the heat treatment is greater than or equal to 1,000°C and less than or equal to 1,200°C.

10. The production method of the austenitic stainless steel according to claim 8 or 9, wherein a final heat treatment after performing the cold working comprises bright annealing.