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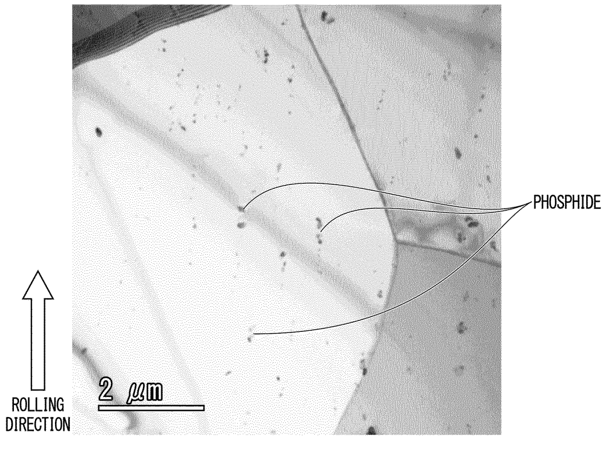
(54) FERRITIC STAINLESS STEEL SHEET AND METHOD FOR PRODUCING SAME

(57) This ferritic stainless steel sheet includes, by mass%: Cr: 11.0% to 30.0%; C: 0.001% to 0.030%; Si: 0.01% to 2.00%; Mn: 0.01% to 2.00%; P: 0.003% to 0.100%; S: 0.0100% or less; N: 0.030% or less; B: 0% to 0.0025%; Sn: 0% to 0.50%; Ni: 0% to 1.00%; Cu: 0% to 1.00%; Mo: 0% to 2.00%; W: 0% to 1.00%; Al: 0% to 1.00%; Co: 0% to 0.50%; V: 0% to 0.50%; Zr: 0% to 0.50%; Ca: 0% to 0.0050%; Mg: 0% to 0.0050%; Y: 0% to 0.10%; Hf: 0% to 0.10%; REM: 0% to 0.10%; Sb: 0% to 0.50%; and either one or both of Ti: 0.40% or less and Nb: 0.50% or less, with a balance being Fe and impurities, in which an amount of P present as a phosphide is 0.003 mass% or more, and a grain size number measured according to JIS G 0551 is 9.0 or more.

FIG. 1



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Description

TECHNICAL FIELD

[0001] The present invention relates to a ferritic stainless steel sheet and a method for producing the same, and particularly the present invention relates to a ferritic stainless steel sheet having excellent formability and resistance to roughening of a processed surface in a forming process, and a method for producing the same.

[0002] The present application claims priority on Japanese Patent Application No. 2018-069775 filed on March 30, 2018, the content of which is incorporated herein by reference.

BACKGROUND ART

[0003] SUS304 (18Cr-8Ni), which is a representative type of austenitic stainless steel, has excellent corrosion resistance, workability, fine appearance, and the like, and thus SUS304 is widely used in home electric appliances, kitchenware, building materials, and the like. However, because SUS304 contains a large amount of Ni, which is expensive and fluctuates greatly in price, a price of a steel sheet of SUS304 becomes high. On the other hand, a ferritic stainless steel does not contain Ni or the amount of Ni therein is very small; and therefore, demand is increasing as a material having an excellent cost performance. However, in the case where a ferritic stainless steel is used for forming, there is a problem of a limitation on forming, and a deterioration in resistance to roughening of a processed surface which occurs due to formation of surface irregularities after forming.

[0004] First, when limitations on forming are compared, the austenitic stainless steel has excellent stretch formability, whereas the ferritic stainless steel has inferior stretch formability and thus a shape thereof cannot be largely changed. However, because deep drawability can be controlled by adjusting crystal orientation (texture), a forming method mainly using deep drawing is used in many cases when the ferritic stainless steel is used for forming.

[0005] Next, surface characteristics after a forming process, particularly roughening of a processed surface (surface irregularities after forming) will be described. The term "surface irregularities" refers to fine irregularities (surface roughening) generated on a surface of a steel sheet after processing or forming. These fine irregularities correspond to crystal grains; and therefore, as grain size becomes larger, surface irregularities become more noticeable.

[0006] In the case of the austenitic stainless steel, it has excellent work-hardening properties, and a fine grain structure is relatively easily formed. Therefore, a steel sheet having a grain size number of about 10 is produced. For this reason, surface irregularities (surface roughening) after a forming process are small, and these surface irregularities cause almost no problems. On the other hand, in the case of the ferritic stainless steel, the grain size number is about 9 for SUS430 and the grain size number is about 7 for SUS430LX, which are smaller than that of the austenitic stainless steel. A small grain size number indicates a large grain size.

[0007] The reason why the ferritic stainless steel tends to include coarse grains is that a recrystallized grain size is easily increased in the ferritic stainless steel, and grains grow easily in a high-purity ferritic stainless steel, such as SUS430LX, in which amounts of C and N are reduced to improve workability and formability. Furthermore, in the ferritic stainless steel, surface roughening occurs in some cases even when the number of cold rolling is increased to produce a product sheet having a small grain size, and the reason is not necessarily clear.

[0008] In the case where relatively strict formability is required as is the case with a housing or an article of home electric appliances, a high-purity ferritic stainless steel such as SUS430LX is used as the ferritic stainless steel in many cases. In addition, a thickness of a stainless steel sheet is 0.6 mm or more in most cases in order to ensure strength after forming, but since the ferrite stainless steel has a large grain size as described above, surface roughening is severe after forming; and therefore, removal of surface irregularities by polishing is generally performed.

[0009] In view of the above-described background, a method of reducing surface roughening of a high-purity ferritic stainless steel is disclosed.

[0010] Patent Document 1 discloses a ferritic stainless steel having excellent formability and less roughening of a processed surface and a method for producing the same, and the ferritic stainless steel is obtained by controlling the size of precipitated particles and the grain size using a high-purity ferritic stainless steel. However, in Patent Document 1, although a steel sheet having a small grain size is obtained, there are problems that deep drawability is insufficient at the time of forming, and surface roughening easily occurs after forming regardless of a small grain size.

[0011] Patent Document 2 discloses a technique of producing a stainless steel having excellent resistance to surface roughening during forming by subjecting a ferritic stainless steel containing Ti and Nb to hot rolling at low temperature and adopting a high cold rolling reduction ratio to obtain fine grains. In the stainless steel of Patent Document 2, although the grain size number of 9.5 and a fine grain structure are obtained by such a technique, resistance to surface roughening after forming by cup drawing is not necessarily sufficient.

[0012] Patent Document 3 discloses a ferritic stainless steel having excellent deep drawability, ridging properties, and resistance to surface roughening, and the ferritic stainless steel is obtained by controlling the grain size before final cold rolling of a steel having a composition containing Nb and/or Ti. However, in Patent Document 3, the grain size of a final product is 15 μm (a grain size number of 9.1), and resistance to surface roughening is insufficient.

[0013] As described above, at present, it is very difficult to enable forming into a predetermined shape and to satisfy surface characteristics after forming when taking into consideration a forming process of a ferritic stainless steel. Accordingly, in the case where a ferritic stainless steel is used for forming, it is necessary to perform a polishing step to remove surface irregularities generated after forming. However, a polishing time is required in this polishing step, and a production cost is increased. Furthermore, there is a problem that a large amount of dust is generated by the polishing.

PRIOR ART DOCUMENTS

Patent Documents

[0014]

Patent Document 1: Japanese Patent No. 4749888
Patent Document 2: Japanese Unexamined Patent Application, First Publication No. H7-292417
Patent Document 3: Japanese Patent No. 3788311

DISCLOSURE OF INVENTION

Problems to be Solved by the Invention

[0015] The present invention has been made in view of the above-described problems, and the present invention provides a ferritic stainless steel sheet having excellent forming processability and resistance to roughening of a processed surface after a forming process, and a method for producing the same.

Solutions for Solving the Problems

[0016] It is known that the grain size and the strain amount are factors affecting roughening of a processed surface of a ferritic stainless steel. However, as described above, roughening of a processed surface occurs in some cases even when a grain size and a strain amount are increased by controlling cold rolling conditions and the like. Therefore, in recent years, a steel that enables to stably inhibit the occurrence of roughening of a processed surface has been desired.

[0017] Accordingly, the inventors of the present invention have investigated a relationship between roughening of a processed surface, and a metallographic structure in a ferritic stainless steel. They have found for the first time that not only a grain size and a strain amount, which are conventionally known factors, but also a precipitation amount of precipitates in a steel affects roughening of a processed surface. In addition, they have clarified that it is necessary to control the temperature of a heat treatment before and after cold rolling, and furthermore, it is necessary to conduct rapid heating in a heat treatment after cold rolling, in order to control a precipitation amount within an appropriate range.

[0018] The features of one aspect of the present invention are as follows.

[1] A ferritic stainless steel sheet including, by mass%:

Cr: 11.0% to 30.0%;
C: 0.001% to 0.030%;
Si: 0.01% to 2.00%;
Mn: 0.01% to 2.00%;
P: 0.003% to 0.100%;
S: 0.0100% or less;
N: 0.030% or less;
B: 0% to 0.0025%;
Sn: 0% to 0.50%;
Ni: 0% to 1.00%;
Cu: 0% to 1.00%;
Mo: 0% to 2.00%;
W: 0% to 1.00%;
Al: 0% to 1.00%;
Co: 0% to 0.50%;
V: 0% to 0.50%;

Zr: 0% to 0.50%;
Ca: 0% to 0.0050%;
Mg: 0% to 0.0050%;
Y: 0% to 0.10%;
Hf: 0% to 0.10%;
REM: 0% to 0.10%;
Sb: 0% to 0.50%; and

either one or both of Ti: 0.40% or less and Nb: 0.50% or less,
with a balance being Fe and impurities,
in which an amount of P present as a phosphide is 0.003 mass% or more, and a grain size number measured according to JIS G 0551 is 9.0 or more.
[2] The ferritic stainless steel sheet according to [1], including one or more of, by mass%:

B: 0.0001% to 0.0025%;
Sn: 0.005% to 0.50%;
Ni: 0.05% to 1.00%;
Cu: 0.05% to 1.00%;
Mo: 0.05% to 2.00%;
W: 0.05% to 1.00%;
Al: 0.05% to 1.00%;
Co: 0.05% to 0.50%;
V: 0.05% to 0.50%;
Zr: 0.05% to 0.50%;
Ca: 0.0001% to 0.0050%;
Mg: 0.0001% to 0.0050%;
Y: 0.001% to 0.10%;
Hf: 0.001% to 0.10%;
REM: 0.001% to 0.10%; and
Sb: 0.005% to 0.50%.

[3] A method for producing the ferritic stainless steel sheet according to [1] or [2], the method including: a hot rolling step of hot rolling a steel having the composition according to [1] or [2]; a hot-rolled sheet annealing step of performing a heat treatment at a temperature of 850°C to 900°C after the hot rolling step; a cold rolling step of rolling at a rolling reduction ratio of 75% to 90% after the hot-rolled sheet annealing step; and a cold-rolled sheet annealing step performed after the cold rolling step, in which, in the cold-rolled sheet annealing step, an average temperature rising rate in a temperature range of 400°C to 800°C is 80°C/s or more in a temperature rising process, a maximum reaching temperature of a sheet temperature is 880°C to 980°C, cooling is started within 5 seconds after reaching the maximum reaching temperature, and the cooling is performed at an average cooling rate of 50°C/s or more in a temperature range of the maximum reaching temperature to 700°C.
[4] A method for producing the ferritic stainless steel sheet according to [1] or [2], the method including: a hot rolling step of hot rolling a steel having the composition according to [1] or [2]; a hot-rolled sheet annealing step of performing a heat treatment at a temperature of 850°C to 900°C after the hot rolling step so as to set an amount of P present as a phosphide to be 0.003 mass% or more; a cold rolling step of rolling at a rolling reduction ratio of 75% to 90% after the hot-rolled sheet annealing step; and a cold-rolled sheet annealing step performed after the cold rolling step, in which, in the cold-rolled sheet annealing step, an average temperature rising rate in a temperature range of 400°C to 800°C is 80°C/s or more in a temperature rising process, a maximum reaching temperature of a sheet temperature is 880°C to 980°C, cooling is started within 5 seconds after reaching the maximum reaching temperature, and the cooling is performed at an average cooling rate of 50°C/s or more in a temperature range of the maximum reaching temperature to 700°C.

Effects of Invention

[0019] According to one aspect of the present invention, it is possible to provide a ferritic stainless steel sheet having excellent forming processability and resistance to roughening of a processed surface after a forming process.

BRIEF DESCRIPTION OF DRAWINGS

[0020]

FIG. 1 is a TEM observation result (a TEM photograph) of a recrystallized structure of a ferritic stainless steel sheet according to the present embodiment.

FIG. 2 is a graph showing a relationship between a grain size number and a precipitation amount (Pp) of P according to examples.

EMBODIMENTS FOR CARRYING OUT THE INVENTION

[0021] Hereinafter, each requirement of a ferritic stainless steel sheet according to one embodiment of the present invention will be described in detail. The symbol "%" of an amount of each element means "mass%."

[0022] (I) The reason for limiting components will be described below.

[0023] Cr is an element that improves corrosion resistance, which is a basic characteristic of stainless steel. In the case where the amount thereof is smaller than 11.0%, sufficient corrosion resistance cannot be obtained; and therefore, the lower limit is set to be 11.0% or more. On the other hand, in the case where an excessive amount of Cr is contained, generation of an intermetallic compound corresponding to a σ phase (an intermetallic compound of Fe-Cr) is promoted; and thereby, cracking is aggravated at the time of production. Therefore, the upper limit is set to be 30.0% or less. From the viewpoint of stable manufacturability (yield, roll marks, and the like), the amount thereof is preferably 14.0% to 25.0%. The amount thereof is more preferably 16.0% to 20.0%.

[0024] C is an element deteriorating formability which is an important factor in the present embodiment. Therefore, the amount of C is preferably small, and the upper limit thereof is set to be 0.030% or less. However, excessive reduction leads to an increase in refining cost; and therefore, the lower limit is set to be 0.001% or more. In consideration of both refining cost and formability, the amount thereof is preferably 0.002% to 0.020%.

[0025] Si is an element improving oxidation resistance, but formability deteriorates in the case where an excessive amount of Si is contained. Therefore, the upper limit is set to be 2.00% or less. From the viewpoint of formability, the amount of Si is preferably small. However, excessive reduction leads to an increase in raw material cost; and therefore, the lower limit is set to be 0.01% or more. From the viewpoint of manufacturability, the range of the amount thereof is preferably 0.05% to 1.00%, and is more preferably 0.05% to 0.30%.

[0026] As is the case with Si, formability deteriorates in the case where a large amount of Mn is contained. Therefore, the upper limit is set to be 2.00% or less. From the viewpoint of formability, the amount of Mn is preferably small. However, excessive reduction leads to an increase in raw material cost; and therefore, the lower limit is set to be 0.01 % or more. From the viewpoint of manufacturability, the range of the amount thereof is preferably 0.05% to 1.00%, and is more preferably 0.05% to 0.30%.

[0027] P is an important element in the steel sheet of the present embodiment, because P is precipitated as a phosphide; and thereby, P contributes to improvement in resistance to roughening of a processed surface. The amount of P is set to be 0.003% or more in order to secure a precipitation amount of a phosphide and improve resistance to roughening of a processed surface. However, P is an element that deteriorates formability; and therefore, the upper limit is set to be 0.100% or less. In the case of taking into consideration of both formability and resistance to roughening of a processed surface, in addition to the fact that excessive reduction of the amount of P leads to an increase in raw material cost, the range of the amount thereof is preferably 0.010% to 0.050%, and is more preferably 0.020% to 0.040%.

[0028] S is an impurity element and S aggravates cracking during production. Therefore, the amount thereof is preferably small, and the upper limit is set to be 0.0100% or less. An amount of S is preferably as low as possible, and is preferably 0.0030% or less. On the other hand, excessive reduction leads to an increase in refining costs; and therefore, the lower limit is preferably set to be 0.0003% or more. From the viewpoints of manufacturability and cost, a preferable range is 0.0004% to 0.0020%.

[0029] As is the case with C, N is an element that deteriorates formability; and therefore, the upper limit is set to be 0.030% or less. However, excessive reduction leads to an increase in refining cost; and therefore, the lower limit is preferably set to be 0.002% or more. From the viewpoint of formability and manufacturability, a preferable range is 0.005% to 0.015%.

[0030] Either one or both of Ti and Nb are contained as follows.

[0031] Ti is bonded to C and N to fix C and N as precipitates such as TiC and TiN, and through a high level of purification resulting therefrom, an r value and product elongation (elongation of a product) are improved. In order to obtain these effects, the lower limit is preferably set to be 0.03% or more in the case of including Ti. On the other hand, in the case where an excessive amount thereof is included, alloy cost is increased, and manufacturability deteriorates due to an increase in recrystallization temperature. Therefore, the upper limit is set to be 0.40% or less. From the viewpoint of formability and manufacturability, a preferable range is 0.05% to 0.30%. In addition, a suitable range in which the above-mentioned effects of Ti are positively utilized is 0.10% to 0.20%.

[0032] As is the case with Ti, Nb is a stabilizing element that fixes C and N, and through a high level of purification of steel resulting from this action, an r value and product elongation are improved. In order to obtain these effects, the lower limit is preferably set to be 0.03% or more in the case of including Nb. On the other hand, in the case where an excessive amount thereof is included, alloy cost is increased, and manufacturability deteriorates due to an increase in recrystallization temperature. Therefore, the upper limit is set to be 0.50% or less. From the viewpoint of alloy cost and manufacturability, a preferable range is 0.03% to 0.30%. In addition, a suitable range in which the above-mentioned effects of Nb are positively utilized is 0.04% to 0.15%. The range is more preferably 0.06% to 0.10%.

[0033] In the ferritic stainless steel sheet of the present embodiment, elements (the balance) other than the above-described elements are Fe and impurities, but in the present embodiment, the ferritic stainless steel sheet may selectively contain one or more selected from the following elements group in addition to the above-described basic composition. That is, the lower limit of the amount of each of B, Sn, Ni, Cu, Mo, W, Al, Co, V, Zr, Ca, Mg, Y, Hf, REM, and Sb is 0% or more.

[0034] The term "impurities" in the present embodiment refer to components, which are mixed due to various factors in a production process, including raw materials such as ores and scraps in industrial production of steel, and include inevitably mixed components.

[0035] B is an element that improves secondary workability. The lower limit is set to be 0.0001% or more to enable the effect to be exhibited. On the other hand, in the case where an excessive amount thereof is included, manufacturability, particularly castability deteriorates; and therefore, the upper limit is set to be 0.0025% or less. A preferable range is 0.0003% to 0.0012%.

[0036] Sn is an element having an effect of improving corrosion resistance; and therefore, it may be included according to a corrosive environment at room temperature. The lower limit is set to be 0.005% or more to enable the effect to be exhibited. On the other hand, in the case where a large amount thereof is included, manufacturability deteriorates; and therefore, the upper limit is set to be 0.50% or less. In consideration of manufacturability, a preferable range is 0.02% to 0.10%.

[0037] Ni, Cu, Mo, Al, W, Co, V, and Zr are effective elements for improving corrosion resistance or oxidation resistance, and may be included as necessary. The effect is exhibited by setting the amount of each of Ni, Cu, Mo, Al, W, Co, V, and Zr to be 0.05% or more. However, in the case where excessive amounts thereof are included, this leads to not only a deterioration in formability, but also to an increase in alloy cost and a deterioration in manufacturability. Accordingly, the upper limit of the amount of each of Ni, Cu, Al, and W is set to be 1.00% or less. The upper limit of the amount of each of Ni, Cu, Al, and W is preferably 0.50% or less. Mo causes a deterioration in manufacturability; and therefore, the upper limit is set to 2.00% or less. The upper limit of the amount of Mo is preferably 1.00% or less. The upper limit of the amount of each of Co, V, and Zr is set to be 0.50% or less in consideration of the effect of improving corrosion resistance or oxidation resistance. The more preferable lower limit of the amount of each of Ni, Cu, Mo, Al, W, Co, V, and Zr is 0.10% or more.

[0038] Ca and Mg are elements that improve hot workability and secondary workability, and may be included as necessary. However, in the case where excessive amounts thereof are included, manufacturability deteriorates; and therefore, the upper limit of the amount of each of Ca and Mg is set to be 0.0050% or less. The lower limit of the amount of each thereof is preferably 0.0001% or more. In consideration of manufacturability and hot workability, a preferable range of the amount of each of Ca and Mg is 0.0002% to 0.0010%.

[0039] Y, Hf, and REM are effective elements for improving hot workability and cleanliness of steel, and improving oxidation resistance, and Y, Hf, and REM may be included as necessary. In the case where they are included, the upper limit of the amount of each of the elements is 0.10% or less. The lower limit of the amount of each of Y, Hf, and REM is preferably 0.001% or more. The "REM" in the present embodiment refers to one or more element selected from the group of elements (lanthanoids) belonging to atomic numbers 57 to 71, and includes, for example, La, Ce, Pr, Nd, and the like. In addition, the amount of "REM" in the present embodiment is the total amount of lanthanoids.

[0040] As is the case with Sn, Sb is an element having an effect of improving corrosion resistance, and Sb may be included as necessary. However, in the case where a large amount thereof is included, manufacturability deteriorates; and therefore, the upper limit is set to be 0.50% or less. The lower limit is set to be 0.005% or more to enable the effect of improving corrosion resistance to be exhibited.

[0041] In the ferritic stainless steel sheet of the present embodiment, elements other than the above-described elements are Fe and impurities (including unavoidable impurities), but other elements can be included in addition to the above-described elements as long as the effects of the present embodiment are not impaired. In the present embodiment, for example, Bi, Pb, Se, H, Ta, or the like may be included, but in that case, the amount thereof is preferably as small as possible. Amount ratios of these elements are controlled to be within ranges that enable to solve the problem of the present embodiment, and one or more of Bi $\leq$ 100 ppm, Pb $\leq$ 100 ppm, Se $\leq$ 100 ppm, H $\leq$ 100 ppm, and Ta $\leq$ 500 ppm may be included as necessary.

[0042] (II) Next, a metallographic structure will be described.

[0043] The ferritic stainless steel sheet of the present embodiment consists of a ferrite single-phase structure in which a grain size number is 9.0 or more.

[0044] The grain size number is 9.0 or more. Roughening of a processed surface after forming is less likely to occur as a grain size number increases, that is, as a grain size of ferrite grains decreases. Therefore, the lower limit is set to the above-described value. In order to further inhibit surface roughening, the grain size number is preferably more than 9.5, and more preferably more than 10.0. However, in the case where the grain size of crystal grains is too small, there is a concern that strength increases and thus press formability decreases. For this reason, the grain size number is preferably 12 or less.

[0045] A grain size number can be obtained by a line segment method of JIS G 0551 (2013). A "grain number: 9" corresponds to the fact that an average line segment length per crystal grain traversing the inside of a crystal grain is 14.1 μm, and a "grain number: 10" corresponds to the fact that an average line segment length per crystal grain traversing the inside of a crystal grain is 10.0 μm. In the measurement of a grain size, the number of crystal grains traversing in one sample is set to be 500 or more in an optical microscope structure photograph of a cross section of a test piece. An etching liquid is preferably aqua regia or inverse aqua regia, but other solutions may be used as long as crystal grain boundaries can be determined. In addition, grain boundaries may not be clearly visible depending on orientation relationships between adjacent crystal grains; and therefore, it is preferable to perform deep etching. Furthermore, in measurement of crystal grain boundaries, twin crystal boundaries are not measured.

[0046] Furthermore, a metallographic structure of the ferritic stainless steel sheet of the present embodiment consists of a ferrite single-phase structure, and precipitates (phosphide) of P to be described later is generated. This means that the steel sheet does not include an austenite phase or a martensite structure. This is because it is relatively easy to reduce a crystal grain size in the case where the steel sheet includes an austenite phase or a martensite structure. Furthermore, an austenite phase shows high formability due to a TRIP effect. However, a raw material cost becomes high, and a decrease in yield due to edge cracking easily occurs during production; and therefore, a metallographic structure is set to be a ferrite single-phase structure. There may be a case in which precipitates such as carbonitrides other than phosphides are present in the steel, but these other precipitates are not taken into account because they do not greatly affect the effects of the present embodiment, and the above description is regarding a structure of a primary phase.

[0047] (III) Next, a precipitation amount of P will be described.

[0048] It is generally considered that the amount of P in a ferritic stainless steel sheet needs to be reduced because P deteriorates formability (an r value and product elongation). However, as a result of the examination by the inventors of the present invention, it has been found for the first time that a precipitation amount of phosphide in steel affects roughening of a processed surface. Based on this result, the present embodiment has clarified that it is possible to further stably inhibit roughening of a processed surface by controlling a crystal grain size and in addition by controlling the amount of P present as a phosphide, that is, a precipitation amount Pp of P. The present embodiment is characterized in that a precipitation amount Pp of P is defined.

[0049] As described above, a phosphide in the steel greatly contributes to inhibition of roughening of a processed surface; and therefore, it is necessary to secure a precipitation amount of P. Accordingly, in the present embodiment, the amount of P present as a phosphide (a precipitation amount Pp of P) is set to be 0.003 mass% or more. An amount thereof is preferably 0.004 mass% or more, and more preferably 0.005 mass% or more. The upper limit of a precipitation amount Pp of P is not particularly limited, but the upper limit of a precipitation amount Pp of P may be set to be 0.100% or less, since the upper limit of the amount of P in the steel sheet is 0.100% or less. Examples of phosphides in the present embodiment include a Fe phosphide, a Mn phosphide, a Ti phosphide, a Nb phosphide, an Al phosphide, and the like, but the type and composition thereof are not particularly limited. That is, in the present embodiment, it is important that the amount of P present as a phosphide (a precipitation amount Pp of P) is within the above-mentioned range, regardless of a specific composition and existence form of phosphides.

[0050] The details of a method of controlling a precipitation amount Pp of P to be within the above-mentioned range will be described later, but the controlling can be performed by controlling a treatment temperature in heat treatment (hot-rolled sheet annealing (annealing of a hot-rolled sheet) and final annealing) to be performed before and after a cold rolling step, and rapidly performing a heating process in heat treatment after the cold rolling.

[0051] The reason why a precipitated phosphide contributes to inhibition of roughening of a processed surface is under intensive investigation, but the following is considered at present.

[0052] It is considered that, because precipitates are generally likely to precipitate on grain boundaries, most of phosphides precipitated due to hot-rolled sheet annealing also precipitate on grain boundaries. It is considered that, thereafter, a metallographic structure is crushed due to cold rolling and a steel is elongated in a rolling direction; and thereby, the phosphides precipitated on the grain boundaries are arranged substantially parallel to the rolling direction. From this state, when the steel is subjected to final annealing which includes rapid heating, retention for a short time, and rapid cooling and thus the steel is recrystallized, a recrystallized structure of the metallographic structure can be obtained without substantially changing the above-mentioned precipitated state of phosphides. That is, the final annealing is conducted to include rapid heating, retention for a short time, and rapid cooling; and thereby, a recrystallized structure is obtained in which phosphides are maintained in a state of being arranged in parallel to the rolling direction.

[0053] The inventors of the present invention have actually confirmed a state in which phosphides within crystal grains of a recrystallized structure are arranged in parallel to the rolling direction in a thin film TEM observation of a product sheet produced by such a production method (within a range of the production method of the present embodiment to be described later). FIG. 1 shows a TEM observation result of a recrystallized structure of a steel sheet produced under conditions satisfying the present embodiment to be described later. As is clear from FIG. 1, it can be confirmed that a phosphide precipitates along the rolling direction within crystal grains of a recrystallized structure. Whether or not precipitates precipitated in crystal grains were phosphides was identified by EDS analysis and electron diffraction pattern analysis.

[0054] When a stainless steel sheet including phosphides in such a precipitated state is processed and strains are applied, dislocation movement is avoided due to the phosphides arranged in parallel to each other. As a result, it is considered that these phosphides exhibited the same action and effect as those of crystal grain boundaries; and thereby, these phosphides contributed to inhibition of roughening of a processed surface.

[0055] A precipitation amount Pp of P is measured by the following electrolytic extraction residue method.

[0056] A test piece having a size of about 30 mm square is cut out from the center in a width direction of a stainless steel sheet, and the entire surface of the test piece corresponding to a surface of the steel sheet is subjected to wet polishing with a No. #600 waterproof abrasive paper. After polishing, a base material (a stainless base material) of the test piece is dissolved by electrolysis at a constant potential of -100 mV in a methanol solution containing 10% of maleic acid anhydride and 2% of tetramethylammonium chloride. After the electrolysis, residues (precipitates) which are not dissolved and remain in the solution are captured using a 200-nm mesh filter. The captured precipitates are washed with pure water and dried. Next, the precipitates are dissolved with aqua regia and perchloric acid, and elemental analysis is performed using ICP emission spectrochemical analysis in accordance with JIS G 1258 to measure a mass of P in the precipitates. The obtained amount of P is divided by a change in mass of the test piece due to the electrolysis ("a mass of the test piece before the electrolysis" - "a mass of the test piece after the electrolysis"), and a value expressed as a percentage is defined as a "precipitation amount Pp of p" (%mass).

[0057] (IV) Next, a method for producing a ferritic stainless steel sheet of the present embodiment will be described.

[0058] The method for producing a ferritic stainless steel sheet according to the present embodiment combines hot rolling, hot-rolled sheet annealing (annealing of a hot-rolled sheet), cold rolling, and cold-rolled sheet annealing (annealing of a cold-rolled sheet, final annealing), and pickling is appropriately performed if necessary. That is, as an example of the production method, it is possible to employ a production method including each of steps of steelmaking, hot rolling, hot-rolled sheet annealing, cold rolling, and cold-rolled sheet annealing (final annealing).

[0059] Conditions to be controlled in order to satisfy both of the crystal grain size and the precipitated state of phosphides, which are regarded important in the present embodiment, as described above are conditions of heat treatment (hot-rolled sheet annealing) after hot rolling, a cold rolling reduction ratio, and conditions of heat treatment (cold-rolled sheet annealing) after cold rolling, and steps other than these steps and conditions thereof are not particularly limited.

[0060] After hot rolling, heat treatment (hot-rolled sheet annealing) is performed at a temperature of 850°C to 900°C to secure a precipitation amount Pp of phosphides after the heat treatment. In the case where a heat treatment temperature is lower than 850°C, poor recrystallization may occur at the center of a sheet thickness, there is a concern that this causes a deterioration in formability due to a decrease in r-value, and a deterioration in polishing characteristics after processing due to generation of ridging. For this reason, the lower limit of a heat treatment temperature in the hot-rolled sheet annealing is set to be 850°C or higher. The temperature thereof is preferably 860°C or higher. In addition, in the case where a heat treatment temperature is higher than 900°C, a precipitation amount of phosphides is insufficient, and the precipitation amount Pp mentioned above cannot be secured. For this reason, the upper limit of a heat treatment temperature in the hot-rolled sheet annealing is set to be 900°C or lower. The temperature thereof is preferably 880°C or lower, and more preferably lower than 870°C. Because a precipitated state is hardly changed in annealing after cold rolling (final annealing), it is important to control a precipitation amount Pp of P at this stage. By the hot-rolled sheet annealing, the amount of P present as a phosphide (a precipitation amount Pp of P) is preferably controlled to be 0.003 mass% or more at the stage after the hot-rolled sheet annealing.

[0061] A rolling reduction ratio in the subsequent cold rolling is set to be in a range of 75% to 90%.

[0062] It is necessary to increase an introduced strain amount in order to reduce a recrystallized grain size by heat treatment performed after the cold rolling. Recrystallization starts from a portion to which a plurality of strains are introduced. That is, a material which is processed at a larger amount of processing (at a higher rolling reduction ratio) includes a larger number of portions (nuclei) that serve as starting points of recrystallization; and thereby, a recrystallized grain size becomes smaller. Based on these matters, a higher rolling reduction ratio is preferably in order to increase a grain size number (to decrease a grain size). In the case where the rolling reduction ratio is less than 75%, there is a concern that these effects cannot be obtained, and an r-value may be reduced; and thereby, formability may deteriorate. Accordingly, the rolling reduction ratio is set to be 75% or more in the present embodiment. In addition, as the rolling reduction ratio becomes higher, the r-value is increased. Therefore, a rolling reduction ratio is preferably 80% or more. On the other hand, in the case where a rolling reduction ratio exceeds 90%, there is a concern that an r-value may be decreased; and thereby, formability may deteriorate. Accordingly, the rolling reduction ratio is set to be 90% or less.

[0063] After the cold rolling, heat treatment (cold-rolled sheet annealing) is subsequently performed, and the present embodiment is characterized in that the heat treatment is rapidly performed. Specifically, in the cold-rolled sheet annealing, an average temperature rising rate in a temperature range of 400°C to 800°C is set to be 80°C/s or more in a temperature rising process. The maximum reaching temperature is 880°C to 980°C. Cooling is started within 5 seconds after reaching the maximum reaching temperature, and the cooling is performed at an average cooling rate of 50°C/s or more in a temperature range from the maximum reaching temperature to 700°C.

[0064] The "average temperature rising rate in a temperature range of 400°C to 800°C" in the present embodiment refers to a value obtained by dividing an increased amount of temperature (400°C) of a steel sheet in the temperature range by a time required for raising a temperature in the temperature range. The "average cooling rate in a temperature range from the maximum reaching temperature to 700°C" refers to a value obtained by dividing a decreased amount of temperature of a steel sheet from the maximum reaching temperature to 700°C by a required time from a time point when the maximum reaching temperature is attained to a time point when the temperature reaches 700°C. In addition, all the temperatures (°C) in the following description refer to a steel sheet temperature.

[0065] As described above, in the present embodiment, phosphides precipitated by hot-rolled sheet annealing are crushed by cold rolling to obtain the precipitated state where the phosphides are arranged in parallel to a cold rolling direction, recrystallization is performed while maintaining this precipitation state; and thereby, a product sheet is obtained. In addition, even in the case where a product sheet including the phosphides in the precipitated state described above is processed and strains are applied thereto, dislocation movement can be avoided due to the phosphides; and therefore, it becomes possible to inhibit roughening of a processed surface.

[0066] For this reason, it is important to carry out cold-rolled sheet annealing under conditions that enable recrystallization while maintaining the precipitated state after cold rolling.

[0067] In order to maintain the precipitated state after cold rolling and obtain the effect of inhibiting roughening of a processed surface, an average temperature rising rate in the temperature range of 400°C to 800°C is set to be 80°C/s or more in a temperature rising process, and cooling is started within 5 seconds after reaching the maximum reaching temperature. That is, a temperature is rapidly raised at an average temperature rising rate of 80°C/s or more in the temperature range of 400°C to 800°C, heating is performed up to the maximum reaching temperature (880°C to 980°C), a retention time at the maximum reaching temperature is set to be 5 seconds or shorter, and then cooling is started. In the present embodiment, a temperature may be retained constant when the temperature is retained at the maximum reaching temperature, but a retention temperature is allowed to fluctuate as long as the fluctuation is within a range of the maximum reaching temperature ± 10°C (a range of the maximum reaching temperature - 10°C to the maximum reaching temperature + 10°C). However, in the case where a retention temperature fluctuates within the above-mentioned range, it is necessary to control the temperature so as not to be out of an appropriate range (880°C to 980°C) of the maximum reaching temperature.

[0068] In the case where an average temperature rising rate in a temperature range of 400°C to 800°C is less than 80°C/s or a retention time is longer than 5 seconds, there may be a case in which phosphides are solid-solubilized and a precipitation amount as a product cannot be secured. In addition, a rapid temperature rise in a temperature range of 400°C to 800°C also has an effect of reducing the recrystallized grain size, and thus the rapid temperature rise is effective in inhibiting roughening of a processed surface. Furthermore, in the case where a temperature is rapidly raised in the presence of precipitates, a grain growth is inhibited by a pinning effect of the precipitates; and therefore, there is an effect of further reducing the grain size of a product and further inhibiting roughening of a processed surface. From such a viewpoint, the average temperature rising rate in a temperature range of 400°C to 800°C is preferably 150°C/s or more.

[0069] Furthermore, from the viewpoint of maintaining the precipitated state of phosphides, a retention time at the maximum reaching temperature is preferably 2 seconds or shorter. The retention time may be 0 seconds, that is, cooling may be started immediately after the temperature reaches the maximum reaching temperature.

[0070] In the present embodiment, since the temperature rising process is performed by rapid heating, a time required for raising a temperature is short. The maximum reaching temperature is set to be 880°C or higher in order to complete recrystallization in this short time. In the case where the maximum reaching temperature is lower than 880°C, there is a concern that recrystallization becomes insufficient, and workability deteriorates due to a deterioration in elongation. Accordingly, in the present embodiment, the maximum reaching temperature is set to be 880°C or higher, and is preferably set to be 900°C or higher. In the case where growth of crystal grains progresses after the completion of recrystallization, crystal grains coarsen, and phosphides are solid-solubilized and thus a precipitation amount becomes short. As a result, there is a concern that resistance to roughening of a processed surface may deteriorate. Therefore, the maximum reaching temperature is set to be 980°C or lower. The maximum reaching temperature is preferably 950°C or lower.

[0071] In the case where growth of crystal grains or solid-solubilization of phosphides progresses in a cooling process, resistance to roughening of a processed surface deteriorates. Therefore, the lower limit of an average cooling rate in the temperature range from the maximum reaching temperature to 700°C is set to be 50°C/s or more. The average cooling rate is preferably 100°C/s or more. The upper limit of the average cooling rate in the temperature range from the maximum reaching temperature to 700°C is preferably 500°C/s or less.

[0072] In the cold-rolled sheet annealing, it is possible to secure phosphides and to obtain a recrystallized structure by performing heat treatment for a long time in a temperature range lower than that in the above-described conditions, but a crystal grain size increases, and resistance to roughening of a surface deteriorates. In addition, the effect of inhibiting roughening of a processed surface is exhibited only after a precipitated state of phosphides in grains becomes a state of being arranged in parallel to a rolling direction. Accordingly, the effect is not exhibited even in the case where phosphides are precipitated in the process of cold-rolled sheet annealing. That is, it is important to control a precipitated state of phosphides by cold rolling and to perform cold-rolled sheet annealing under the above-described conditions that enable to maintain the precipitated state.

[0073] It is possible to produce the ferritic stainless steel sheet according to the present embodiment by the production method described above.

[0074] In the present embodiment, the hot-rolled sheet annealing and the cold-rolled sheet annealing may be batch annealing or continuous annealing. In addition, if necessary, each annealing may be bright annealing performed in a non-oxidizing atmosphere such as hydrogen gas or nitrogen gas, or may be annealing performed in the air.

[0075] In addition, a sheet thickness applied to the ferritic stainless steel sheet of the present embodiment is not particularly limited, but it is preferably 0.5 mm or more, and more preferably 0.6 mm or more from the viewpoint of securing strength. This is because, in the case where a thickness is thin, strength of a part after forming may be insufficient in some cases. It is required to design a steel sheet in consideration of the size, the shape, the load capacity, and the like of a production target.

[0076] As described above, according to the present embodiment, it is possible to provide a ferritic stainless steel sheet having excellent forming processability and resistance to roughening of a processed surface after forming. In addition, the ferritic stainless steel sheet of the present embodiment has excellent resistance to roughening of a processed surface; and therefore, the ferritic stainless steel sheet of the present embodiment is particularly suitable for use applications that require polishing for removing surface irregularities (roughening of a surface) after a forming process.

EXAMPLES

[0077] Next, examples of the present invention will be described. The conditions in the examples are examples of one condition adopted to confirm the practicability and effects of the present invention, and the present invention is not limited to the conditions used in the following examples. The present invention can adopt various conditions as long as the present invention does not deviate from the requirements of the present invention, and the object of the present invention is achieved.

[0078] Underlines shown in the following tables show that the corresponding values are out of the ranges of the present embodiment.

[0079] A stainless steel having a composition shown in Table 1 was melted and cast into a slab, and the slab was subjected to hot rolling to obtain a predetermined thickness. Thereafter, the slab was subjected to hot-rolled sheet annealing, cold rolling, and cold-rolled sheet annealing; and thereby, stainless steel sheets (product sheets) No. 1 to No. 44 having a thickness of 0.6 mm were produced. A heat treatment temperature (annealing temperature) in the hot-rolled sheet annealing, a cold rolling reduction ratio, an average temperature rising rate between 400°C and 800°C in the cold-rolled sheet annealing, a maximum reaching temperature, a required time (a retention time) until the start of cooling, and an average cooling rate in a temperature range from the maximum reaching temperature to 700°C were changed as shown in Tables 2 to 4. An annealing time (a retention time) in the hot-rolled sheet annealing was within a range of 40 to 60 seconds.

[0080] Next, a test piece was cut out from the center of width of each of the obtained stainless steel sheets No. 1 to No. 44, and a grain size number (GSN) was measured by a line segment method according to JIS G 0551 (2013). In the measurement of a grain size, the number of grains traversing in one sample was set to be 500 or more in an optical microscope structure photograph of a cross section of a test piece.

[0081] In addition, a sample having a diameter of 110 mm was cut out from each of the stainless steel sheets No. 1 to No. 44, and a cup forming test with a drawing ratio of 2.2 was performed using a hydraulic forming tester. It was found that a drawing ratio greatly affected roughening of a surface after the cup forming, but other forming conditions did not affect the roughening of a surface after the cup forming. Conditions for the cup forming test performed in the examples were as follows: a punch diameter was 50 mm; a punch shoulder R was 5 mm; a die diameter was 52 mm, a die shoulder R was 5 mm, a wrinkle bar pressure was 1 ton, a clearance was 1.67 t on one side (t was a sheet thickness). Furthermore, as a lubricant between the sample and the punch, a rust preventive oil "Daphne Oil Coat Z3 (registered trademark)" manufactured by Idemitsu Kosan Co., Ltd. was applied. Thereafter, a lubricating sheet "NAFLON tape TOMBO9001 manufactured by NICHIAS Corporation" was attached to protect a surface of the formed steel sheet.

[0082] With regard to the sample that could be formed at a drawing ratio of 2.2, surface roughness after the cup forming was measured to evaluate roughening of a processed surface.

[0083] When a degree of surface roughness and variations of each part of the sample (a formed article) after the cup forming were examined, it was found that there was a variation between the inside and the outside of a standing (vertical) wall portion. The examination results will be described in detail.

[0084] The inventors of the present invention have examined surface roughness of each part of the sample after the cup forming. It was generally known that roughening of a processed surface after the cup forming was proportional to the grain size and the amount of strain, but it was found that the roughening of a processed surface after the cup forming was not simply proportional to a grain size and the amount of strain, and generation of irregularities on the surface of the formed article was inhibited by contact with a die during the forming; and therefore, surface roughness was reduced. It was found that in particular, with regard to an outer wall of the standing wall portion of the formed article, a force pressed against the die during the forming was strong, and generation of irregularities during the forming and inhibition of irregularities due to contact with the die were competing; and therefore, roughness of the formed article varied greatly at each measurement position. Accordingly, it was considered inappropriate to evaluate roughening of a processed surface after the cup forming based on the outer wall of the standing wall portion.

[0085] Therefore, surface roughness of an inner wall of the standing wall portion in which a force pressed against the die was relatively small was measured. As a result, it was found that surface roughness after the cup forming can be measured with high accuracy. In addition, because the inner wall had a surface roughness larger than that of the outer wall, the longest polishing time was taken for the inner wall having the larger roughness in a polishing step after the forming. For this reason, it is considered appropriate to perform measurement of surface roughness (evaluation of roughening of a processed surface) assuming polishing after forming on the inner wall of the standing wall portion of the formed article. If evaluation result of roughening of a processed surface was favorable on the inner wall of the standing wall portion of the formed article, it can be determined that evaluation result of roughening of a processed surface would also be favorable on the outer wall.

[0086] With respect to a length of 5 mm parallel to a height direction at the center portion of a height inside the standing wall portion of the sample after the cup forming, surface roughness was measured as described in JIS B 0601 using a two-dimensional contact-type surface roughness measuring device, and an arithmetic average roughness Ra was calculated. Criterion was set to the arithmetic average roughness Ra of 1.00 μm, and it was determined that evaluation result of roughening of a processed surface was favorable ("○") when the Ra was less than 1.00 μm, and it was determined that evaluation result of roughening of a processed surface was poor ("x") when the Ra was 1.00 μm or more.

[0087] In addition, in the same manner as described above, a precipitation amount Pp of P in the product sheet was measured by the electrolytic extraction residue method.

[0088] First, a test piece having a size of about 30 mm square was cut out from the center in a width direction of a stainless steel sheet, and the entire surface of the test piece corresponding to a surface of the steel sheet was subjected to wet polishing with a No. #600 waterproof abrasive paper. After polishing, a base material (a stainless base material) of the test piece was dissolved by electrolysis at a constant potential of -100 mV in a methanol solution containing 10% of maleic acid anhydride and 2% of tetramethylammonium chloride. After the electrolysis, residues (precipitates) which were not dissolved and remained in the solution were captured using a 200-nm mesh filter. The captured precipitates were washed with pure water and dried. Next, the precipitates were dissolved with aqua regia and perchloric acid, and elemental analysis was performed using ICP emission spectrochemical analysis in accordance with JIS G 1258 to measure a mass of P in the precipitates. The obtained amount of P was divided by a change in mass of the test piece due to the electrolysis ("a mass of the test piece before the electrolysis" - "a mass of the test piece after the electrolysis"), and a value expressed as a percentage was defined as a "precipitation amount Pp of p" (%mass).

[0089] A precipitation amount Pp of P in the hot-rolled and annealed sheet before being subjected to cold rolling was also measured by the same method.

[0090] The measurement results and evaluation results are shown in Tables 5 to 7.

[0091] As shown in Tables 2 to 7, it was found that, according to the present embodiment, it was possible to obtain a ferritic stainless steel sheet having excellent resistance to roughening of a surface after a forming process and formability by controlling a precipitation amount of phosphides through optimization of annealing conditions and rolling conditions.

[0092] In the invention examples, Ra < 1.00 μm, and roughening of a processed surface was inhibited.

[0093] On the other hand, Nos. 25 and 26 in Tables 2 to 7 are examples in which the composition was out of the range. In both cases, a precipitation amount Pp of P and a grain size number were within the ranges of the embodiment, but formability deteriorated and drawing was not possible. In addition, both No. 27 and No. 28 were examples using a steel L in which Ti and Nb were not included, but immobilization of P was insufficient; and therefore, a precipitation amount Pp of P became less than 0.001%, and furthermore, formability deteriorated and drawing was not possible.

[0094] In Nos. 3 and 22, an average temperature rising rate during the cold-rolled sheet annealing was too low; and therefore, solid-solubilization of phosphides proceeded, and a precipitation amount Pp of P became insufficient. Furthermore, a grain size number was reduced, and resistance to roughening of a processed surface deteriorated.

[0095] In Nos. 5, 10, 12, and 24, a retention time was too long; and therefore, solid-solubilization of phosphides proceeded, and a precipitation amount Pp of P became insufficient. Furthermore, a grain size number was reduced, and resistance to roughening of a processed surface deteriorated.

[0096] In Nos. 6 and 15, an annealing temperature during the hot-rolled sheet annealing was low, and an average temperature rising rate was too low; and therefore, a grain size number was reduced, and resistance to roughening of a processed surface deteriorated.

[0097] In No. 7, a cold rolling reduction ratio was small, and the maximum reaching temperature was too high; and therefore, grain growth proceeded, a grain size number was reduced, and resistance to roughening of a processed surface deteriorated.

[0098] In No. 9, an annealing temperature during the hot-rolled sheet annealing was too high; and therefore, a precipitation amount Pp of P could not be secured, and resistance to roughening of a processed surface deteriorated.

[0099] In No. 16, the maximum reaching temperature was too high; and therefore, a grain size number was reduced, and resistance to roughening of a processed surface deteriorated.

[0100] In No. 19, an average temperature rising rate during the cold-rolled sheet annealing was low, and a retention time was too long; and therefore, solid-solubilization of phosphides proceeded, and a precipitation amount Pp of P became insufficient. Furthermore, a grain size number was reduced, and resistance to roughening of a processed surface deteriorated.

[0101] In No. 20, a cold rolling reduction ratio was too small; and therefore, a grain size number was reduced. As a result, resistance to roughening of a processed surface deteriorated.

[0102] In No. 21, an annealing temperature during the hot-rolled sheet annealing was too high; and therefore, a precipitation amount Pp of P could not be secured, and resistance to roughening of a processed surface deteriorated.

[0103] In No. 14, the maximum reaching temperature was too high, and grain growth progressed; and therefore, a grain size number was reduced, and resistance to roughening of a processed surface deteriorated.

[0104] In No. 31, an average cooling rate during the cold-rolled sheet annealing was low; and therefore, solid-solubilization of phosphides proceeded and a precipitation amount Pp of P became insufficient, and furthermore, grain size number was reduced and resistance to roughening of a processed surface deteriorated.

[0105] In No. 32, an average cooling rate during the cold-rolled sheet annealing was low; and therefore, solid-solubilization of phosphides proceeded and a precipitation amount Pp of P became insufficient, and resistance to roughening of a processed surface deteriorated.

[0106] In No. 36, an annealing temperature during the hot-rolled sheet annealing was too high; and therefore, a precipitation amount Pp of P could not be secured, and resistance to roughening of a processed surface deteriorated.

[0107] In No. 38, an average temperature rising rate during the cold-rolled sheet annealing was low, and furthermore the maximum reaching temperature was too high; and therefore, grain growth proceeded, a grain size number was reduced, and resistance to roughening of a processed surface deteriorated.

[0108] Furthermore, in FIG. 2, in a region in which a grain size number was 9.0 or more and a precipitation amount of P was less than 0.003%, a slight amelioration of roughening of a processed surface could be expected due to a relatively fine grain, but there was no effect of inhibiting roughening of a processed surface by phosphides. Therefore, the region was inferior in resistance to roughening of a processed surface as compared with invention examples in which a grain size number was the same as that of the region, and the amount of P precipitated was larger.

[0109] Regarding a steel component in which the amount of P was less than 0.003%, when production was performed in the same manner as in No. 4 in Tables 2 to 7, a precipitation amount of P was 0.003% or less, and Ra after the forming test was 1.00 μm or more. Regarding a steel composition in which the amount of P was more than 0.1%, when production was performed in the same manner as in No. 4 in Tables 2 to 7, formability was poor, and forming was not possible.

Table 1

Steel	Component (mass%): the remainder is iron and impurities									
	C	Si	Mn	P	S	Cr	Ti	Nb	N	Others
A	0.003	0.06	0.07	0.022	0.0001	16.3	0.15	0.07	0.007	0.0007B, 0.04Sn
B	0.005	0.07	0.24	0.015	0.0012	14.5	0.14		0.015	
C	0.008	0.38	0.38	0.028	0.0025	17.3		0.26	0.009	0.08Ni, 0.04Cu, 0.0015Mg, 0.0014Ca
D	0.009	0.81	0.91	0.035	0.0007	18.9	0.22		0.006	0.25Mo, 0.01Sn, 0.07Sb
E	0.002	0.16	0.24	0.039	0.0035	24.1	0.12	0.12	0.014	0.01REM, 0.03Hf, 0.44V, 0.0030Ca, 0.12Co

(continued)

Steel	Component (mass%): the remainder is iron and impurities									
	C	Si	Mn	P	S	Cr	Ti	Nb	N	Others
F	0.004	0.25	0.35	0.091	0.0015	18.3	0.02	0.34	0.011	0.0021B, 0.62Ni, 0.54A1, 0.35W
G	0.001	0.39	0.02	0.055	0.0038	13.5		0.27	0.017	0.0002B, 0.0005Ca, 0.07V, 0.06Ni
H	0.001	0.72	0.09	0.025	0.0061	11.7	0.34		0.005	0.28Sb, 0.03V, 0.04Co, 1.10Mo
I	0.004	0.02	0.19	0.030	0.0011	16.4	0.33	0.42	0.011	0.004Al, 0.09Sn, 0.0003Mg
J	0.008	0.25	0.35	0.027	0.0024	16.2	0.18		0.014	
K	0.034	0.34	0.08	0.015	0.0009	17.2	0.15	0.15	0.009	0.06Co, 0.22Al, 0.15Cu
L	0.005	0.60	0.25	0.069	0.0018	17.9	_	_	0.010	0.022Zr, 0.33W, 0.08Hf, 0.013Y
M	0.006	1.83	0.12	0.035	0.0002	16.8		0.30	0.015	0.04W, 0.05Mo
N	0.004	0.09	1.90	0.025	0.0010	18.6	0.08	0.14	0.009	0.31Ni, 0.02V, 0.01REM
O	0.008	0.08	0.03	0.089	0.0004	12.2	0.35	0.12	0.008	
P	0.0016	0.28	0.16	0.052	0.0008	26.7		0.44	0.015	

Table 2

No.	Steel	Hot-rolled sheet annea ling	Cold rolling	Cold-rolled sheet annealing				Remark
		Annealing temperature (°C)	Cold rolling reduction ratio (%)	Average temperature rising rate (°C/s)	Maximum reaching temperature (°C)	Retention time (s)	Average cooling rate (°C/s)	
1	A	875	85	200	920	1	70	Invention Example
2	A	850	92	120	820	5	100	Comparative Example
3	A	890	88	10	880	2	150	Comparative Example
4	B	900	86	80	920	5	70	Invention Example
5	B	860	82	250	940	6	150	Comparative Example
6	C	825	90	50	900	2	100	Comparative Example
7	C	860	72	200	1050	1	200	Comparative Example
8	C	890	80	80	960	4	150	Invention Example
9	D	910	84	120	940	2	70	Comparative Example
10	D	860	86	90	900	8	100	Comparative Example
11	E	875	78	200	950	1	70	Invention Example
12	E	875	82	100	880	6	200	Comparative Example
13	E	890	92	150	860	2	70	Comparative Example

(continued)

No.	Steel	Hot-rolled sheet annea ling	Cold rolling	Cold-rolled sheet annealing				Remark
		Annealing temperature (°C)	Cold rolling reduction ratio (%)	Average temperature rising rate (°C/s)	Maximum reaching temperature (°C)	Retention time (s)	Average cooling rate (°C/s)	
14	F	860	80	120	1020	1	150	Comparative Example
15	F	840	75	30	980	2	150	Comparative Example

Table 3

No.	Steel	Hot-rolled sheet annealing	Cold rolling	Cold-rolled sheet annealing				Remark
		Annealing temperature (°C)	Cold rolling reduction ratio (%)	Average temperature rising rate (°C/s)	Maximum reaching temperature (°C)	Retention time (s)	Average cooling rate (°C/s)	
16	G	850	76	300	1000	1	70	Comparative Example
17	G	890	80	200	980	5	100	Invention Example
18	H	875	84	90	880	2	200	Invention Example
19	H	860	88	50	900	8	100	Comparative Example
20	H	900	74	200	950	4	150	Comparative Example
21	I	925	78	100	960	1	70	Comparative Example
22	I	890	85	30	940	5	150	Comparative Example
23	J	860	88	80	900	4	200	Invention Example
24	J	875	80	250	960	10	200	Comparative Example
25	K	890	84	120	940	1	100	Comparative Example
26	K	900	90	200	880	3	70	Comparative Example
27	L	875	86	90	920	4	150	Comparative Example
28	L	900	82	150	950	1	100	Comparative Example

(continued)

No.	Steel	Hot-rolled sheet annealing	Cold rolling	Cold-rolled sheet annealing				Remark
		Annealing temperature (°C)	Cold rolling reduction ratio (%)	Average temperature rising rate (°C/s)	Maximum reaching temperature (°C)	Retention time (s)	Average cooling rate (°C/s)	
29	F	900	85	80	920	5	200	Invention Example
30	G	890	90	100	900	1	100	Invention Example

Table 4

No.	Steel	Hot-rolled sheet annealing	Cold rolling	Cold-rolled sheet annealing				Remark
		Annealing temperature (°C)	Cold rolling reduction ratio (%)	Average temperature rising rate (°C/s)	Maximum reaching temperature (°C)	Retention time (s)	Average cooling rate (°C/s)	
31	B	880	78	100	980	5	10	Comparative Example
32	D	900	90	150	880	3	40	Comparative Example
33	I	860	90	150	900	2	70	Invention Example
34	J	880	90	200	880	2	200	Invention Example
35	M	880	82	100	940	3	150	Invention Example
36	M	920	85	150	920	2	200	Comparative Example
37	N	875	88	90	920	3	200	Invention Example
38	N	890	80	10	1000	2	100	Comparative Example
39	O	875	84	100	920	4	70	Invention Example
40	O	880	82	200	900	1	150	Invention Example
41	O	860	80	150	1050	4	150	Comparative Example
42	P	900	86	150	880	2	200	Invention Example
43	P	870	86	120	960	4	100	Invention Example

(continued)

No.	Steel	Hot-rolled sheet annealing	Cold rolling	Cold-rolled sheet annealing				Remark
		Annealing temperature (°C)	Cold rolling reduction ratio (%)	Average temperature rising rate (°C/s)	Maximum reaching temperature (°C)	Retention time (s)	Average cooling rate (°C/s)	
44	P	950	78	120	900	3	70	Comparative Example

Table 5

No..	Steel	Precipitation amount Pp of P after hot-rolled sheet annealing (%mass)	Precipitation amount Pp of P after cold-rolled sheet annealing (%mass)	Grain size number (-)	Forming test			Remark
					Whether forming is possible or not	Ra after forming (μm)	Roughening of processed surface	
1	A	0.007	0.005	9.9	○	0.70	○	Invention Example
2	A	0.008	0.005	9.3	×	-	-	Comparative Example
3	A	0.006	0.002	8.5	○	1.20	×	Comparative Example
4	B	0.004	0.003	9.2	○	0.96	○	Invention Example
5	B	0.006	0.002	8.9	○	1.09	×	Comparative Example
6	C	0.010	0.003	8.8	○	1.02	×	Comparative Example
7	C	0.007	0.004	8.4	×	-	-	Comparative Example
8	C	0.006	0.003	9.1	○	0.99	○	Invention Example
9	D	0.002	0.001	9.25	○	1.01	×	Comparative Example
10	D	0.008	0.002	8.5	○	1.23	×	1 Comparative Example
11	E	0.007	0.004	9.4	○	0.87	○	Invention Example
12	E	0.007	0.002	8.7	○	1.16	×	Comparati ve Example
13	E	0.004	0.005	10.2	×	-	-	Comparative Example
14	F	0.009	0.006	8.6	○	1.12	×	Comparative Example
15	F	0.012	0.008	8.3	○	1.10	×	Comparati ve Example

Table 6

No.;	Steel	Precipitation amount Pp of P after hot-rolled sheet annealing (%mass)	Precipitation amount Pp of P after cold-rolled sheet annealing (%mass)	Grain size number (-)	Forming test			Remark
					Whether forming is possible or not	Ra after forming (μm)	Roughening of processed surface	
16	G	0.009	0.002	8.6	○	1.20	×	Comparative Example
17	G	0.007	0.004	9.1	○	0.96	○	Invention Example
18	H	0.005	0.004	9.3	○	0.89	○	Invention Example
19	H	0.005	0.002	8.5	○	1.20	×	Comparative Example
20	H	0.004	0.003	8.6	×	-	-	Comparative Example
21	1	0.002	0.001	9.25	○	1.02	×	Comparative Example
22	I	0.004	0.001	8.2	○	1.32	×	Comparative Example
23	J	0.007	0.003	9.3	○	0.92	○	Invention Example
24	J	0.007	0.001	8.1	○	1.44	×	Comparative Example
25	K	0.004	0.003	10.3	×	-	-	Comparative Example
26	K	0.003	0.003	9.8	×	-	-	Comparative Example
27	L	<0.001	<0.001	9.9	×	-	-	Comparative Example
28	L	<0.001	<0.001	10.3	×	-	-	Comparative Example
29	F	0.007	0.006	9.2	○	0.85	○	Invention Example
30	G	0.007	0.003	9.6	○	0.88	○	Invention Example

Table 7

No.,	Steel	Precipitation amount Pp of P after hot-rolled sheet annealing (%mass)	Precipitation amount Pp of P after cold-rolled sheet annealing (%mass)	Grain size number (-)	Forming test			Remark
					Whether forming is possible or not	Ra after forming (μm)	Roughening of processed surface	
31	B	0.005	0.001	8.7	○	1.25	×	Comparative Example

(continued)

No.,	Steel	Precipitation amount Pp of P after hot-rolled sheet annealing (%mass)	Precipitation amount Pp of P after cold-rolled sheet annealing (%mass)	Grain size number (-)	Forming test			Remark
					Whether forming is possible or not	Ra after forming (μm)	Roughening of processed surface	
32	D	0.003	0.002	9.1	○	1.05	×	Comparative Example
33	I	0.006	0.005	9.5	○	0.84	○	Invention Example
34	J	0.006	0.003	9.8	○	0.81	○	Invention Example
35	M	0.006	0.004	9.6	○	0.80	○	Invention Example
36	M	0.002	0.001	9.2	○	1.11	×	Comparative Example
37	N	0.005	0.004	9.1	○	0.89	○	Invention Example
38	N	0.004	0.003	8.3	○	1.42	×	Comparative Example
39	O	0.025	0.012	10.8	○	0.62	○	Invention Example
40	O	0.019	0.014	11.2	○	0.51	○	Invention Example
41	O	0.021	0.002	8.7	○	1.25	×	Comparative Example
42	P	0.016	0.012	10.6	○	0.65	○	Invention Example
43	P	0.018	0.008	9.8	○	0.73	○	Invention Example
44	P	0.002	0.001	8.6	○	1.15	×	Comparative Example

Industrial Applicability

[0110] According to the present embodiment, it is possible to provide a ferritic stainless steel sheet having excellent forming processability and resistance to roughening of a processed surface after a forming process, and a method for producing the same. Accordingly, the ferritic stainless steel sheet of the present embodiment is suitably applied to forming applications.

Claims

1. A ferritic stainless steel sheet comprising, by mass%:

Cr: 11.0% to 30.0%;
C: 0.001% to 0.030%;
Si: 0.01% to 2.00%;
Mn: 0.01 % to 2.00%;

P: 0.003% to 0.100%;
S: 0.0100% or less;
N: 0.030% or less;
B: 0% to 0.0025%;
Sn: 0% to 0.50%;
Ni: 0% to 1.00%;
Cu: 0% to 1.00%;
Mo: 0% to 2.00%;
W: 0% to 1.00%;
Al: 0% to 1.00%;
Co: 0% to 0.50%;
V: 0% to 0.50%;
Zr: 0% to 0.50%;
Ca: 0% to 0.0050%;
Mg: 0% to 0.0050%;
Y: 0% to 0.10%;
Hf: 0% to 0.10%;
REM: 0% to 0.10%;
Sb: 0% to 0.50%; and
either one or both of Ti: 0.40% or less and Nb: 0.50% or less,
with a balance being Fe and impurities,
wherein an amount of P present as a phosphide is 0.003 mass% or more, and
a grain size number measured according to JIS G 0551 is 9.0 or more.

2. The ferritic stainless steel sheet according to claim 1, comprising one or more of, by mass%:

B: 0.0001% to 0.0025%;
Sn: 0.005% to 0.50%;
Ni: 0.05% to 1.00%;
Cu: 0.05% to 1.00%;
Mo: 0.05% to 2.00%;
W: 0.05% to 1.00%;
Al: 0.05% to 1.00%;
Co: 0.05% to 0.50%;
V: 0.05% to 0.50%;
Zr: 0.05% to 0.50%;
Ca: 0.0001% to 0.0050%;
Mg: 0.0001% to 0.0050%;
Y: 0.001% to 0.10%;
Hf: 0.001% to 0.10%;
REM: 0.001% to 0.10%; and
Sb: 0.005% to 0.50%.

3. A method for producing the ferritic stainless steel sheet according to claim 1 or 2, the method comprising:

a hot rolling step of hot rolling a steel having the composition according to claim 1 or 2;
a hot-rolled sheet annealing step of performing a heat treatment at a temperature of 850°C to 900°C after the hot rolling step;
a cold rolling step of rolling at a rolling reduction ratio of 75% to 90% after the hot-rolled sheet annealing step; and
a cold-rolled sheet annealing step performed after the cold rolling step,
wherein, in the cold-rolled sheet annealing step, an average temperature rising rate in a temperature range of 400°C to 800°C is 80°C/s or more in a temperature rising process, a maximum reaching temperature of a sheet temperature is 880°C to 980°C, cooling is started within 5 seconds after reaching the maximum reaching temperature, and the cooling is performed at an average cooling rate of 50°C/s or more in a temperature range of the maximum reaching temperature to 700°C.

4. A method for producing the ferritic stainless steel sheet according to claim 1 or 2, the method comprising:

a hot rolling step of hot rolling a steel having the composition according to claim 1 or 2;
a hot-rolled sheet annealing step of performing a heat treatment at a temperature of 850°C to 900°C after the hot rolling step so as to set an amount of P present as a phosphide to be 0.003 mass% or more;
a cold rolling step of rolling at a rolling reduction ratio of 75% to 90% after the hot-rolled sheet annealing step; and
a cold-rolled sheet annealing step performed after the cold rolling step,
wherein, in the cold-rolled sheet annealing step, an average temperature rising rate in a temperature range of 400°C to 800°C is 80°C/s or more in a temperature rising process, a maximum reaching temperature of a sheet temperature is 880°C to 980°C, cooling is started within 5 seconds after reaching the maximum reaching temperature, and the cooling is performed at an average cooling rate of 50°C/s or more in a temperature range of the maximum reaching temperature to 700°C.

FIG. 1

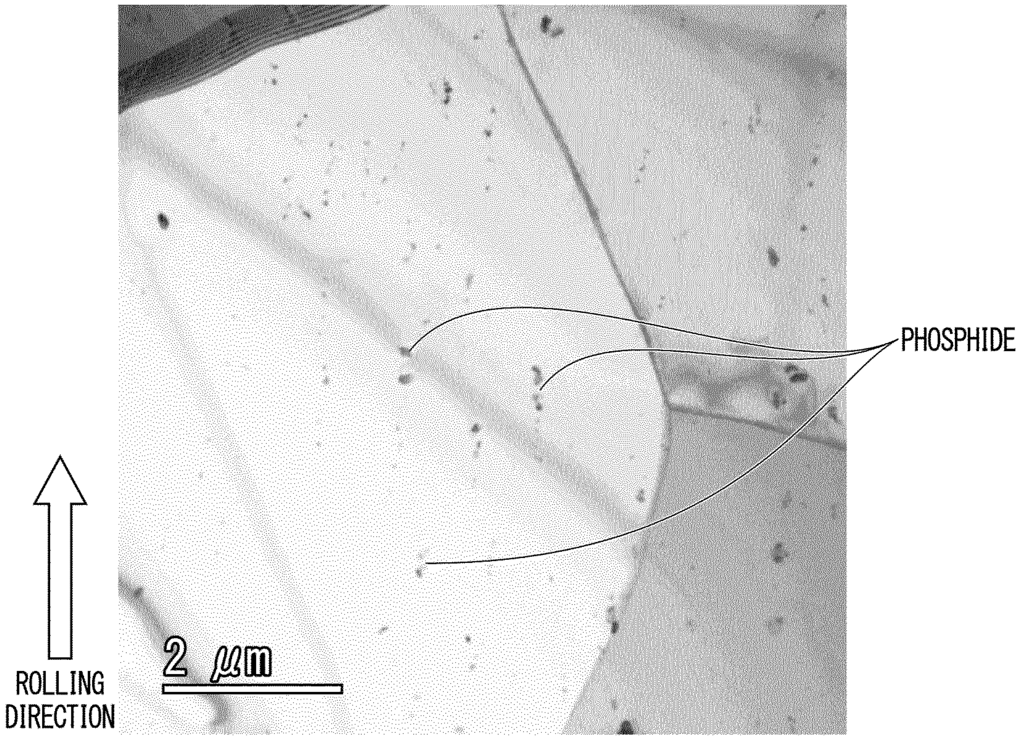
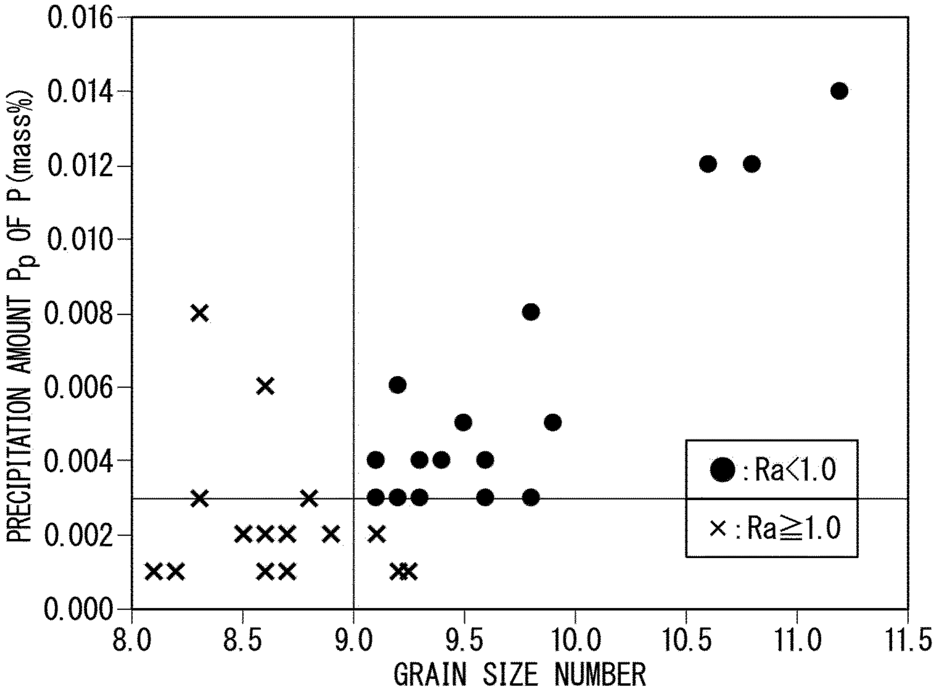

PHOSPHIDE
ROLLING DIRECTION
2 μm

FIG. 2


PRECIPITATION AMOUNT Pp OF P (mass%)
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
GRAIN SIZE NUMBER
●: Ra<1.0
×: Ra≧1.0

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2019/009147

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. C22C38/00(2006.01)i, C21D9/46(2006.01)i, C22C38/60(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl. C22C38/00-38/60, C21D9/46

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	1971-2019
Registered utility model specifications of Japan	1996-2019
Published registered utility model applications of Japan	1994-2019

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2017-048417 A (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORP.) 09 March 2017 (Family: none)	1-4
A	WO 2003/106725 A1 (JFE STEEL CORPORATION) 24 December 2003 & US 2005/0173033 A1 & EP 1514949 A1 & CN 1662667 A & KR 10-2005-0008826 A	1-4
A	JP 2007-314837 A (NISSHIN STEEL CO., LTD.) 06 December 2007 (Family: none)	1-4

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

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"&" document member of the same patent family

Date of the actual completion of the international search
24.05.2019

Date of mailing of the international search report
04.06.2019

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Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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- JP 2018069775 A **[0002]**
- JP 4749888 B **[0014]**
- JP H7292417 B **[0014]**
- JP 3788311 B **[0014]**