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(54) **FERRITIC STAINLESS STEEL SHEET**

(57) In order to provide a ferritic stainless-steel sheet having excellent formability, there is provided a forming method in which a ferritic stainless-steel sheet is subjected to rectangular drawing forming to a desired forming depth by press forming using a punch and a die, and a ferritic stainless-steel sheet that contains C, Si, Mn, P, S, Cr, N, Al, O, Ti, Nb, Sn, and Zr, has a component composition that satisfies the following Formula (1) and Formula (2), has a sheet thickness of 1.0 mm or less and a limiting drawing ratio in cylindrical cup drawing of 2.30

or more is used.

$$(0.4 \times \text{Al} + 0.5 \times \text{Zr} + 0.1 \times \text{Ti}) / \text{O} \geq 12.0 \dots (1)$$

$$0.6 \times \text{Cr} + 15 \times \text{Sn} + 8 \times \text{Al} \geq 10.0 \dots (2)$$

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Description

[Technical Field]

5 **[0001]** The present invention relates to a ferritic stainless-steel sheet.

[Background Art]

10 **[0002]** Ferritic stainless-steel sheets are used in a wide range of fields such as home appliances, kitchen devices, and electronic devices, but their applications are sometimes limited because they have poorer formability than austenitic stainless steel. However, in recent years, due to improvement in refining techniques, it has become possible to make ferritic stainless steel have an extremely low carbon content and an extremely low nitrogen content, and there have been attempts to improve the formability and corrosion resistance of ferritic stainless steel by additionally adding elements such as Ti and Nb. In addition, there have been attempts to improve the formability of ferritic stainless steel by controlling a component composition and a production method as in Patent Documents 1 to 3.

15 **[0003]** Ferritic stainless steel has been used in a wide range of applications due to improved formability achieved by these conventional improvement techniques, but in recent years, there has been an increasing demand for lighter final products, which leads to demands for further improvement. That is, in order to reduce the weight of final products, there is a need for ferritic stainless steel which has a thinner sheet thickness and can achieve higher formability than conventional ones.

20 **[0004]** For example, stretch forming is a processing method in which the material is formed by plastic deformation, mainly elongation deformation of a part in contact with a punch, without flowing into a mold. The deformation region is a region from the die shoulder area to the punch head area. In the case of rectangular forming processing using a mold, since the contact load between the material and the punch is generally largest around the punch shoulder area, and the movement of the material is restricted, deformation is concentrated between the punch shoulder area and the die shoulder area, and reduction in the sheet thickness is largest. Thus, when constriction occurs in this part, breakage occurs.

25 **[0005]** Applications for which members formed by this stretch forming are particularly required include exterior panels for home appliances and kitchen devices. In the related art, these exterior panels are formed using materials made of painted ordinary steel, but there is a problem of rust occurring from areas where the paint peels off or from the edges, and on the other hand, for the reasons such as improved formability of stainless steel and improved quality of design with clear coating that imparts a luxurious appearance, in recent years, stainless steel has been increasingly used as a material for exterior panels. In particular, since the exterior panel constitutes the appearance of the product, improvement in dimensional accuracy is required. Therefore, many types of processing are performed using stretch forming.

30 **[0006]** In addition, as described above, products such as home appliances and kitchen devices are required to be lightweight and exterior panels are also strongly required to be lightweight. It is thought that this weight reduction can be achieved by applying a stainless-steel sheet having a sheet thickness of 0.4 mm to less than 0.8 mm, which is thinner than conventional ones. However, there have been no ferritic stainless-steel sheets that can satisfy having the predetermined stretch formability with such a sheet thickness, in related art including the above Patent Documents 1 to 3.

35 **[0007]** Patent Document 4 describes a ferritic stainless-steel sheet for an exterior panel having predetermined chemical components, a sheet thickness of 0.4 to 0.8 mm, a forming speed of 3 to 10 mm/min, and a stretch height of 10 mm or more when an Erichsen test is performed. However, in Patent Document 4, the forming speed is limited to 10 mm/min or less, and there is a certain limit on the time required for forming the formed products. Therefore, there is a need to further improve the productivity of formed products.

40 **[0008]** [Prior Art Document]

[Patent Document]

[0008]

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[Patent Document 1]

Japanese Unexamined Patent Application, First Publication No. S57-198248

[Patent Document 2]

Japanese Unexamined Patent Application, First Publication No. S58-61258

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[Patent Document 3]

Japanese Unexamined Patent Application, First Publication No. 2004-217996

[Patent Document 4]

Japanese Patent No. 6050701

[Summary of Invention]

[Problem to be Solved by the Invention]

5 **[0009]** The present invention has been made in view of the above circumstances, and an object of the present invention is to provide a ferritic stainless-steel sheet having excellent formability.

[Means for Solving the Problem]

10 **[0010]** In order to achieve the above object, the present invention has the following configurations.

[1] A ferritic stainless-steel sheet which contains, in mass%,

15 C: 0.0200% or less,
Si 0.70% or less,
Mn: 1.00% or less,
P: 0.030% or less,
S: 0.005% or less,
Cr: 11.0 to 19.5%,
20 N: 0.020% or less,
Al: 0.005 to 0.100%,
O: 0.0050% or less,
Ti: 0.03 to 0.20%,
Nb: 0.010 to 0.300%,
25 Sn: 0.001 to 0.300%, and
Zr: 0.001 to 0.080%, with
a remainder of Fe and impurities,
and has a component composition that satisfies the following Formula (1) and Formula (2), has a sheet thickness
of 1.0 mm or less, and a limiting drawing ratio in cylindrical cup drawing of 2.30 or more:

$$(0.4 \times Al + 0.5 \times Zr + 0.1 \times Ti) / O \geq 12.0 \dots (1)$$

$$0.6 \times Cr + 15 \times Sn + 8 \times Al \geq 10.0 \dots (2)$$

where, element symbols in Formula (1) and Formula (2) represent the amount (mass%) of the elements in the ferritic stainless-steel sheet.

40 [2] The ferritic stainless-steel sheet according to claim 1, which contains, in mass%, one or more of Mo: 0.05 to 0.50%, Ni: 0.05 to 0.50%, and Cu: 0.01 to 1.00%, in place of some Fe.

[3] The ferritic stainless-steel sheet according to claim 1 or 2, which contains, in mass%, one or more of B: 0.0003 to 0.0050%, Ga: 0.0001 to 0.2%, and W: 0.001 to 0.300%, in place of some Fe.

45 [4] The ferritic stainless-steel sheet according to any one of claims 1 to 3, wherein the average Lankford value is 1.8 or more, and the planar anisotropy (Δr) of the Lankford value is 0.5 or more.

[Effects of Invention]

50 **[0011]** According to the present invention, it is possible to provide a ferritic stainless-steel sheet having excellent formability. In particular, according to the present invention, when a formed product having a thin wall thickness required for parts for reducing the weight of home appliances and kitchen devices is produced, since the ferritic stainless-steel sheet according to the present invention can be used as a blank, and favorable formability can be exhibited, it is possible to obtain a formed product that satisfies having dimensional accuracy and quality of design.

55 [Embodiments of the Invention]

[0012] The present inventors conducted extensive studies in order to obtain a formed product having improved formability and excellent quality of design without cracks or forming defects from ferritic stainless-steel sheets, which are

generally said to have lower formability than austenitic stainless-steel sheets.

[0013] Generally, the processability is improved when the yield ratio of the steel sheet to be formed is lower. The yield ratio is a ratio of the yield stress to the tensile strength, and when the yield ratio is lower, a load range in which a uniform elongation region is obtained is wider, and plastic processing is easily performed. On the other hand, for example, in the case of cylindrical cup drawing, the sheet thickness distribution of the steel sheet during forming increases, reduction in sheet thickness is accelerated, and cracks are more likely to occur starting from inherent inclusions. Therefore, the present inventors examined the relationship between the type and amount of each element contained in ferritic stainless steel and formability in order to impart formability sufficient to enable cylindrical cup drawing. Cylindrical cup drawing is a highly difficult forming method, and minimizing a reduction in sheet thickness at a stress concentration part is effective in improving formability. If the sheet thickness decreases, processing hardening occurs and processability decreases. When the fracture surface of a formed product in which cracks have occurred during forming processing is observed in detail, many Al oxides and TiN are confirmed. Considering that these Al oxides and TiN accelerate cracking, steel components that can inhibit uneven distribution of Al oxides and growth of TiN were examined. As a result, it was found that, when a steel sheet having a specific steel component is applied to a blank for deep drawing, forming that satisfies having dimensional accuracy becomes possible.

[0014] Hereinafter, a ferritic stainless-steel sheet according to an embodiment of the present invention will be described.

[0015] The ferritic stainless-steel sheet of the present embodiment is a steel sheet which contains, in mass%, C: 0.0200% or less, Si: 0.70% or less, Mn: 1.00% or less, P: 0.030% or less, S: 0.005% or less, Cr: 11.0 to 19.5%, N: 0.020% or less, Al: 0.005 to 0.100%, O: 0.0050% or less, Ti: 0.03 to 0.20%, Nb: 0.010 to 0.300%, Sn: 0.001 to 0.300%, and Zr: 0.001 to 0.080%, with a remainder of Fe and impurities, and has a component composition that satisfies the following Formula (1) and Formula (2), has a sheet thickness of 1.0 mm or less, and a limiting drawing ratio in cylindrical cup drawing of 2.30 or more:

$$(0.4 \times \text{Al} + 0.5 \times \text{Zr} + 0.1 \times \text{Ti}) / \text{O} \geq 12.0 \dots (1)$$

$$0.6 \times \text{Cr} + 15 \times \text{Sn} + 8 \times \text{Al} \geq 10.0 \dots (2)$$

where, element symbols in Formula (1) and Formula (2) represent the amount (mass%) of the elements in the ferritic stainless-steel sheet.

[0016] In addition, the ferritic stainless-steel sheet may contain, in mass%, one or more of Mo: 0.05 to 0.50%, Ni: 0.05 to 0.50%, and Cu: 0.01 to 1.00%, in place of some Fe.

[0017] In addition, the ferritic stainless-steel sheet may contain, in mass%, one or more of B: 0.0003 to 0.0050%, Ga: 0.0001 to 0.2%, and W: 0.001 to 0.300%, in place of some Fe.

[0018] The reasons for limiting chemical components of the ferritic stainless-steel sheet will be explained. Here, unless otherwise noted, the unit of component contents is mass%.

C: 0.0200% or less

[0019] Since C deteriorates formability and corrosion resistance, a lower content is better, and the upper limit is 0.0200% or less. However, since an excessive reduction in the amount of C leads to an increase in refining cost, the lower limit of the amount of C is desirably 0.0010% or more. A preferable amount of C is 0.0030 to 0.0070%.

Si: 0.70% or less

[0020] Si may be contained as a deoxidizing element, but it is a solid solution strengthening element, and in order to reduce the yield stress, a lower content is better, and the upper limit is 0.70% or less. However, since an excessive reduction in the amount of Si leads to an increase in refining cost, the lower limit is desirably 0.01% or more. A preferable amount of Si is 0.05 to 0.50%.

Mn: 1.00% or less

[0021] Like Si, Mn is a solid solution strengthening element, and in order to reduce the yield stress, a lower content is better, and the upper limit is 1.00% or less. However, since an excessive reduction in the amount of Mn leads to an increase in refining cost, the lower limit is desirably 0.01% or more. A preferable amount of Mn is 0.05 to 0.50%.

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P: 0.030% or less

[0022] P is an element that is unavoidably mixed in from a raw material, and it is a solid solution strengthening element like Si and Mn, and thus a lower content is better, and in consideration of elongation, the upper limit is 0.030% or less. A preferable amount is less than 0.030%, and a more preferable amount is 0.025% or less. However, since an excessive reduction in the amount of P leads to an increase in refining cost, the lower limit may be 0.010% or more.

S: 0.005% or less

[0023] In the case of Ti-added steel, S forms $Ti_4C_2S_2$ together with Ti and C and has a function of fixing C. Since $Ti_4C_2S_2$ is a coarse precipitate that precipitates at a high temperature, it has little effect on recrystallization and grain growth behavior, but if a large amount of this precipitate precipitates, it becomes a starting point for rusting, and corrosion resistance deteriorates. Therefore, the upper limit of S is 0.005% or less. However, since an excessive reduction in the amount of S leads to an increase in refining cost, the lower limit of the amount of S may be 0.0001% or more.

Cr: 11.0 to 19.5%

[0024] In order to improve corrosion resistance, it is necessary to contain 11.0% or more of Cr, but an excessive content deteriorates toughness and deteriorates productivity, and also increases the yield stress. Therefore, the upper limit of Cr is 19.5% or less. A preferable amount of Cr is 13.0 to 17.5%.

N: 0.020% or less

[0025] Like C, N deteriorates formability and corrosion resistance, and thus a lower content is better, and the upper limit is 0.020% or less. However, in consideration of production cost reduction, the lower limit may be 0.003% or more. A preferable amount of N is 0.005 to 0.015%.

Al: 0.005 to 0.100%

[0026] Al may be contained in an amount of 0.005% or more as a deoxidizing element. On the other hand, since an excessive amount of Al reduces formability and weldability, and also causes deterioration of surface quality, the upper limit is 0.100% or less. A preferable amount of Al is 0.010 to 0.080%.

O: 0.0050% or less

[0027] O deteriorates corrosion resistance and processability. Therefore, the amount of O needs to be kept low, and the upper limit is 0.0050% or less. However, since an excessive reduction in the amount of O increases the refining cost, the lower limit of the amount of O may be 0.0001% or more. A preferable range of the amount of O is 0.0005 to 0.0030%.

Ti: 0.03 to 0.20%

[0028] Ti combines with C, N, and S to form an inclusion, and has an effect of improving corrosion resistance, intergranular corrosion resistance and deep drawability, and thus it is contained in an amount of 0.03% or more. On the other hand, since Ti is a solid solution strengthening element, an excessive amount of Ti leads to an increase in solid solution Ti, and leads to a decrease in elongation, which is an index of stretch formability. Therefore, the upper limit of Ti is 0.20% or less. A preferable amount of Ti is 0.08 to 0.12%.

Nb: 0.010 to 0.300%

[0029] Nb is an element that improves formability and corrosion resistance, and its effects are exhibited when it is contained in an amount of 0.010% or more. However, an excessive content causes a decrease in ductility due to solid solution strengthening, and thus the content is 0.300% or less. A preferable amount of Nb is 0.100 to 0.200%.

Sn: 0.001 to 0.300%

[0030] When Sn is contained, it has an effect of lowering the yield ratio and improving stretch formability. In order to obtain this effect, Sn is contained in an amount of 0.001% or more. On the other hand, since an excessive content

deteriorates productivity, the upper limit is 0.300% or less. A preferable amount of Sn is 0.020 to 0.200%.

Zr: 0.001 to 0.080%

- 5 **[0031]** Zr is contained in an amount of 0.001% or more as a deoxidizing element. On the other hand, since an excessive amount of Zr causes deterioration of formability, weldability and surface quality, the upper limit is 0.080% or less. A preferable amount of Zr is 0.002 to 0.020%.

$(0.4 \times \text{Al} + 0.5 \times \text{Zr} + 0.1 \times \text{Ti})/\text{O} \geq 12.0$

- 10 **[0032]** When the fracture surface of a formed product in which cracks have occurred is observed in detail, Al oxides present at the bottom of many dimples and massive TiN that exists regardless of the dimples can be observed, and these serve as starting points for cracks or promote crack propagation. In order to inhibit uneven distribution of Al oxides and growth of TiN, modification of the inclusion composition is effective, and use of Zr, which is a strong deoxidizing agent, is effective. As a result of examining the relationship between the amount of Al, Ti, O and Zr and the occurrence of cracks, it is found that excellent formability is exhibited when $(0.4 \times \text{Al} + 0.5 \times \text{Zr} + 0.1 \times \text{Ti})/\text{O}$ is 12.0 or more. Therefore, the ferritic stainless-steel sheet according to the present embodiment preferably satisfies $(0.4 \times \text{Al} + 0.5 \times \text{Zr} + 0.1 \times \text{Ti})/\text{O} \geq 12.0$.

- 20 $0.6 \times \text{Cr} + 15 \times \text{Sn} + 8 \times \text{Al} \geq 10.0$

- [0033]** In order to improve cylindrical cup drawability, it is necessary to inhibit wrinkles by pouring the material while minimizing flange wrinkles, and reduce an increase in sheet thickness at the final stage of processing. Since ferritic stainless steel does not have high breaking strength, it is not possible to increase the blank holding force, and thus countermeasures by increasing lubrication are effective. In order to increase lubrication, it is general to use a lubricant, but at the final stage of forming processing, the surface pressure between the material and the mold is very high, and the lubricant is discharged. Under processing conditions in which the lubricant becomes less effective, the influence of the surface film of the material and concentration distribution becomes significant. Stainless steel has a passive film, but phenomena such as oxides generated during the producing process and concentration on the surface layer occur, and concentration distributions of various elements are present. Cr is an essential element in the formation of a passive film, but since molds and mold coatings often contain Cr, some combinations may induce die galling due to affinity. Therefore, when Al, which forms a strong oxide, is present in the passive film, die galling is inhibited and stable formability can be secured. In addition, Sn tends to be present on the surface and is softer than other elements, and thus exhibits an effect of alleviating stress concentration. As a result of examining the relationship between the amount of Cr, Al and Sn and the limiting drawing ratio, it is found that, when $0.6 \times \text{Cr} + 15 \times \text{Sn} + 8 \times \text{Al}$ is 10.0 or more, the limiting drawing ratio stably exceeds 2.30. Therefore, the ferritic stainless-steel sheet according to the present embodiment preferably satisfies $0.6 \times \text{Cr} + 15 \times \text{Sn} + 8 \times \text{Al} \geq 10.0$.

- [0034]** In addition, the ferritic stainless-steel sheet according to the present embodiment may contain, in mass%, one or more of Mo: 0.05 to 0.50%, Ni: 0.05 to 0.50%, and Cu: 0.01 to 1.00%, in place of some Fe.

- 40 **[0035]** Mo, Ni, and Cu are elements that improve corrosion resistance, and in applications for which corrosion resistance is required, as necessary, one or more thereof may be contained. When each of Mo and Ni is contained in an amount of 0.05% or more, corrosion resistance is improved. An excessive amount of Mo and Ni leads to hardening and causes deterioration of formability, and the upper limit is 0.50% or less. A preferable amount of Mo and a preferable amount of Ni are 0.10 to 0.30%. In addition, when Cu is contained in an amount of 0.01% or more, its effects are exhibited, but since an excessive amount of Cu causes deterioration of formability, particularly ductility, the upper limit of the amount of Cu is 1.00% or less. A preferable amount of Cu is 0.30 to 0.80%.

- [0036]** In addition, the ferritic stainless-steel sheet according to the present embodiment may contain, in mass%, one or more of B: 0.0003 to 0.0050%, Ga: 0.0001 to 0.2%, and W: 0.001 to 0.300%, in place of some Fe.

- 50 **[0037]** B is an element that improves secondary processability, and B may be contained in an amount of 0.0003% or more as necessary. However, since an excessive amount of B causes a decrease in elongation, the upper limit of the B content is 0.0050% or less. A preferable amount of B is 0.0010 to 0.0020%.

- [0038]** Ga is an element that forms GaS and improves corrosion resistance. It is a very effective element because it can eliminate starting points of rust by inhibiting MnS precipitates. Since no effect is observed when the content is less than 0.0001%, when Ga is contained, it may be contained in an amount of 0.0001% or more. On the other hand, an excessive amount of Ga leads to solid solution hardening. Therefore, the upper limit of the amount of Ga is 0.2% or less.

- 55 **[0039]** Like Nb and Ti, W is an element that fixes C and N, prevents sensitization due to Cr carbonitrides, and improves corrosion resistance. In order to exhibit such an effect, the amount of W is preferably 0.001% or more. On the other hand, when the amount of W exceeds 0.300%, the stainless-steel sheet becomes hard, and the processability deteriorates.

rates. Therefore, the amount of W is preferably 0.300% or less.

[0040] The ferritic stainless-steel sheet according to the present embodiment is composed of Fe and impurities (impurities also include unavoidable impurities) in addition to the elements described above. Furthermore, in addition to the elements described above, they can be contained as long as the effects of the present invention are not impaired. In the present embodiment, for example, Bi, Pb, Se, H and the like may be contained, but in this case, it is preferable to reduce them as much as possible. On the other hand, the amount of these elements is controlled within the limit to achieve the object of the present invention, and as necessary, 0.01% or less of Bi, 0.01% or less of Pb, 0.01% or less of Se, and 0.01% or less of H may be contained.

[0041] In the forming method of the present embodiment, a ferritic stainless-steel sheet having a sheet thickness of 1.0 mm or less is a forming target. A preferable sheet thickness is 0.4 to 0.8 mm. Since the ferritic stainless-steel sheet according to the present embodiment is excellent in stretch formability by adjusting chemical components, it is particularly suitably used for applications for which forming processing with a thin sheet thickness is required such as home appliances and kitchen devices.

Limiting drawing ratio in cylindrical cup drawing: 2.30 or more

[0042] In order to increase the limiting drawing ratio in cylindrical cup drawing, it is necessary to use a blank diameter larger than the diameter of the formed product. Ferritic stainless steel has a high r value suitable for drawing forming, but on the other hand, it has low breaking strength, and if the flow from the flange is blocked, cracks occur on the side wall. High lubrication conditions are applied to promote the material inflow from the flange, but if the blank diameter is large, the contact length at the flange part becomes long, and lubrication shortage tends to occur at the final stage of processing. In this specification, the range of components that are effective even when lubrication shortage occurs at the final stage of processing is limited, and the limiting drawing ratio at which the effect becomes clear is 2.30 or more.

[0043] The limiting drawing ratio in cylindrical cup drawing is measured by the following procedure. Circular blank components having a sheet thickness of 0.8 mm and various diameters are prepared, cylindrical cup drawing is performed on each blank, and a mold with a shape having Die: inner diameter of 43 mm, Die r 4 mm, and Punch: diameter of 40 mm is used for cylindrical cup drawing. The blank holding pressure is 10 kN. Then, the maximum diameter Dmax of the blank that can be formed without breaking is determined, and the ratio (Dmax/d) of Dmax to the diameter d of the punch is defined as a limiting drawing ratio.

[0044] In addition, in the ferritic stainless-steel sheet according to the present embodiment, preferably, the average Lankford value (hereinafter referred to as an average r value, and also referred to as an average plastic strain ratio) is 1.8 or more, and the planar anisotropy (Δr) of the Lankford value is 0.5 or more or more than 0.7. When the average r value is 1.8 or more, in forming using a punch and a die, the sheet thickness is less likely to decrease in the punch shoulder area, the resistance to width shrinkage deformation at the flange part decreases, and the occurrence of cracks during forming processing can be inhibited. In addition, when the planar anisotropy (Δr) is 0.5 or more, the planar anisotropy in deformation of the flange during forming increases, the difference in sheet thickness of the flange part occurs, and thus there is a region in which the lubricant is secured, and the formability can be further improved.

[0045] Regarding the method of measuring the average r value and Δr , the plastic strain ratio test method according to JIS Z 2254: 2008 can be used for determination. The average r value can be determined by the following Formula (A) according to JIS Z 2254: 2008. In addition, the planar anisotropy (Δr) can be determined by the following Formula (B) according to JIS Z 2254: 2008.

$$\text{Average } r \text{ value} = (r_0 + 2r_{45} + r_{90})/4 \cdots (A)$$

$$\Delta r = (r_0 - 2r_{45} + r_{90})/2 \cdots (B)$$

[0046] Here, in Formula (A) and Formula (B), r_0 indicates the r value in the rolling direction, r_{90} indicates the r value in the direction perpendicular to the rolling direction, and r_{45} indicates the r value at 45 degrees in the rolling direction.

[0047] The ferritic stainless-steel sheet of the present embodiment can be produced by a general method, and is not particularly limited. That is, a slab having desired chemical components is cast through steelmaking and continuous casting, and subjected to hot rolling, annealing after hot rolling, pickling, cold rolling, and final annealing after cold rolling for production. However, in order to increase the limiting drawing ratio and set the average r value and the planar anisotropy (Δr) to be within a preferable range, the cold rolling reduction ratio is set to be in a range of 78 to 94%, the temperature increase rate in the final annealing after cold rolling is set to be in a range of faster than 20°C/sec and is preferably 200°C/sec or slower, the soaking speed and the soaking time in the final annealing are set to be in ranges of 830 to 950°C and 30 seconds or longer and 2 minutes or shorter, and the cooling rate up to 500°C after soaking ends

is preferably set to be in a range of 15 to 30°C/sec.

[0048] When final annealing is performed on stainless steel having chemical components of the present embodiment, during final annealing, P in the steel becomes fine P precipitates, which form a mixed grain structure during recrystallization, and adversely affect formability. However, when the above cold rolling and final annealing are performed, the limiting drawing ratio in cylindrical cup drawing is 2.30 or more, the average Lankford value is 1.8 or more, and the planar anisotropy (Δr) of the Lankford value is 0.5 or more. Thereby, it is possible to obtain a ferritic stainless-steel sheet having excellent formability.

[Examples]

[0049] Hereinafter, the present invention will be described in more detail with reference to examples.

[0050] Ferritic stainless steels having component compositions shown in Table 1A and Table 1B were melted, cast, and hot-rolled to obtain hot-rolled sheets having a thickness of 5.0 mm. Here, in component compositions shown in Table 1A and Table 1B, the remainder was Fe and impurities. Then, the hot-rolled sheets were annealed and pickled, and then cold-rolled, annealed, and pickled to have a thickness of 0.3 to 1.2 mm, and then temper-rolled to obtain steel sheets shown in Table 2.

[0051] Here, for steel sheets Nos. 1 to 33, the cold rolling reduction ratio was as shown in Table 2, the temperature increase rate in the final annealing after cold rolling was set to be in a range of faster than 20°C/sec, the soaking speed and the soaking time in the final annealing were set to be in ranges of 830 to 950°C and 30 seconds to 2 minutes, and the cooling rate up to 500°C after soaking ended was set to be in a range of 15 to 30°C/sec. A cylindrical cup drawing test was performed using the steel sheets obtained in this manner.

[0052] For a forming test, a forming testing machine (Model 145-60, commercially available from Erichsen) was used. The steel sheet was cut into a disk shape to obtain a blank. The size of the blank was $\phi 84$ to 94 mm, and a mold with a shape having Die: inner diameter of 43 mm, Die r 4 mm, and Punch: diameter of 40 mm was used. The blank holding pressure was 10 kN. Johnson Wax #122 was lightly applied as a lubricant to the processed surface. The forming test was performed under fixed forming conditions and at a forming speed of the punch relative to the die of 20 mm/min. Here, it was determined whether forming was possible according to the occurrence of cracks through drawing forming without leaving any flange.

[0053] The formed products after forming were evaluated as NG when cracks or shape defects occurred, or evaluated as OK when no cracks or shape defects occurred. The results are shown in Table 2.

[0054] The 0.2% yield strength and elongation of the steel sheets were measured using a JIS No. 13 B test piece, and samples were taken from the 0° direction parallel to the rolling direction according to the conditions described in JIS Z 2241. In addition, the average r value and Δr were measured under conditions in which the 16% strain was applied to samples taken from the 0°, 45°, and 90° directions as the test piece sampling direction with respect to the rolling direction.

[0055] The limiting drawing ratio in cylindrical cup drawing was measured by the following procedure. Circular blank components having a sheet thickness of 0.8 mm and various diameters were prepared, cylindrical cup drawing was performed on each blank, and a mold with a shape having Die: inner diameter of 43 mm, Die r 4 mm, and Punch: diameter of 40 mm was used for cylindrical cup drawing. The blank holding pressure was 10 kN. Then, the maximum diameter D_{max} of the blank that could be formed without breaking was determined, and the ratio (D_{max}/d) of D_{max} to the diameter d of the punch was defined as a limiting drawing ratio.

[0056] As shown in Table 1A, Table 1B and Table 2, when forming was performed under conditions within the scope of the present invention, no cracks or shape defects occurred in the formed product, and the formed product also had favorable quality of design.

[0057] On the other hand, when forming was performed under conditions outside the scope of the present invention, cracks and shape defects occurred in the formed product.

[Table 1A]

Steel type	Chemical composition (mass%). Remainder: Fe and impurities													Note
	C	Si	Mn	P	S	Cr	Nb	Ti	N	Sn	Zn	Al	O	
A	0.0056	0.11	0.05	0.025	0.0004	18.6	0.012	0.16	0.011	0.030	0.002	0.018	0.0017	Steel of present invention
B	0.0087	0.21	0.34	0.025	0.0013	17.2	0.080	0.09	0.008	0.008	0.012	0.045	0.0022	Steel of present invention
C	0.0054	0.09	0.01	0.030	0.0009	16.1	0.068	0.07	0.008	0.006	0.021	0.067	0.0027	Steel of present invention
D	0.0073	0.11	0.16	0.030	0.0008	14.1	0.112	0.08	0.009	0.133	0.003	0.025	0.0016	Steel of present invention
E	0.0081	0.61	0.22	0.025	0.0014	11.8	0.018	0.16	0.007	0.273	0.014	0.036	0.0022	Steel of present invention
F	0.0034	0.05	0.41	0.025	0.0011	13.5	0.011	0.14	0.010	0.089	0.003	0.084	0.0012	Steel of present invention
G	0.0079	0.13	0.18	0.030	0.0006	18.2	0.049	0.18	0.006	0.008	0.017	0.066	0.0008	Steel of present invention
H	0.0069	0.48	0.19	0.025	0.0004	16.4	0.041	0.17	0.008	0.180	0.005	0.051	0.0021	Steel of present invention
I	0.0087	0.09	0.48	0.025	0.0021	13.8	0.083	0.16	0.009	0.094	0.003	0.065	0.0006	Steel of present invention
J	0.0092	0.13	0.18	0.025	0.0015	17.2	0.180	0.08	0.011	0.005	0.007	0.075	0.0010	Steel of present invention
K	0.0071	0.26	0.19	0.030	0.0006	16.7	0.264	0.09	0.008	0.265	0.004	0.053	0.0007	Steel of present invention
AA	0.0168	0.12	0.36	0.030	0.0021	18.7	0.270	0.07	0.014	0.041	0.004	0.031	0.0036	Comparative steel
AB	0.0076	0.86	0.65	0.025	0.0012	17.2	0.112	0.12	0.008	0.053	0.002	0.020	0.0034	Comparative steel
AC	0.0096	0.15	1.12	0.030	0.0017	16.2	0.261	0.06	0.012	0.051	0.005	0.014	0.0017	Comparative steel
AD	0.0087	0.32	0.41	0.040	0.0059	14.2	0.021	0.08	0.011	0.087	0.008	0.034	0.0026	Comparative steel
AE	0.0054	0.22	0.05	0.025	0.0014	10.2	0.083	0.08	0.009	0.122	0.016	0.028	0.0026	Comparative steel
AF	0.0091	0.65	0.07	0.025	0.0008	16.1	0.006	0.06	0.012	0.223	0.037	0.011	0.0038	Comparative steel
AG	0.0065	0.23	0.12	0.030	0.0006	17.5	0.022	0.03	0.016	0.091	0.007	0.025	0.0026	Comparative steel
AH	0.0022	0.22	0.19	0.030	0.0023	14.7	0.123	0.08	0.008	0.005	0.009	0.043	0.0026	Comparative steel
AI	0.0083	0.37	0.36	0.025	0.0016	16.2	0.238	0.07	0.006	0.003	0.001	0.007	0.0028	Comparative steel
AJ	0.0091	0.51	0.27	0.025	0.0008	13.5	0.085	0.03	0.018	0.217	0.009	0.002	0.0011	Comparative steel
AK	0.0065	0.42	0.26	0.030	0.0008	13.8	0.091	0.07	0.012	0.012	0.070	0.006	0.0054	Comparative steel
AL	0.0044	0.35	0.41	0.025	0.0018	16.6	0.183	0.02	0.017	0.008	0.007	0.102	0.0046	Comparative steel
AM	0.0069	0.37	0.27	0.025	0.0031	16.1	0.121	0.21	0.008	0.005	0.003	0.017	0.0036	Comparative steel

(continued)

Steel type	Chemical composition (mass%). Remainder: Fe and impurities													Note
	C	Si	Mn	P	S	Cr	Nb	Ti	N	Sn	Zn	Al	O	
AN	0.0066	0.48	0.13	0.030	0.0026	14.3	0.352	0.17	0.009	0.012	0.003	0.024	0.0034	Comparative steel
AD	0.0093	0.46	0.17	0.030	0.0007	18.1	0.065	0.14	0.013	0.345	0.005	0.007	0.0025	Comparative steel
														steel
AP	0.0082	0.12	0.18	0.003	0.0011	18.2	0.089	0.04	0.018	0.234	0.091	0.008	0.0048	Comparative steel
AQ	0.0088	0.17	0.12	0.025	0.0017	16.9	0.129	0.09	0.031	0.251	0.004	0.024	0.0024	Comparative steel
AR	0.0091	0.27	0.11	0.025	0.0037	20.1	0.287	0.08	0.008	0.007	0.005	0.011	0.0019	Comparative steel

The underline indicates outside the scope of the present invention.

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[Table 1B]

Steel type	Chemical composition (mass%). Remainder: Fe and impurities							Note
	(Al)×0.4+Zr×0.5+Ti×0.1)/0	0.6×Cr+15×Sn+8×Al	B	Ni	Cu	Mo	Ga	W
A	14.2	11.75				0.08		
B	15.0	10.80	0.0012			0.14		
C	16.4	10.29		0.18	0.11			
D	12.2	10.66					0.0003	
E	17.0	11.46	0.0003					
F	40.9	10.11	0.0005					0.008
G	66.1	11.57			0.18			
H	19.0	12.95				0.25		
I	72.5	10.21					0.0007	0.044
J	41.5	11.00		0.21				
K	46.0	14.42						
AA	5.9	12.08						
AB	6.2	11.28						
AC	8.3	10.60						
AD	9.8	10.10						
AE	10.5	8.17						
AF	7.6	13.09						
AG	6.3	12.07						
AH	11.4	9.24						
AI	3.7	9.82						
AJ	7.1	11.37						
AK	8.2	8.51						
AL	10.1	10.90						
AM	8.1	9.87						

(continued)

Steel type	Chemical composition (mass%). Remainder: Fe and impurities								Note
	(Al×0.4+Zr×0.5+Ti×0.1)/0	0.6×Cr+15×Sn+8×Al	B	Ni	Cu	Mo	Ga	W	
AN	<u>8.3</u>	8.95							Comparative steel
AO	<u>7.7</u>	16.09							Comparative steel
AP	<u>11.0</u>	14.49							Comparative steel
AQ	<u>8.6</u>	14.10							Comparative steel
AR	<u>7.8</u>	12.25							Comparative steel

The underline indicates outside the scope of the present invention.

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[Table 2]

No.	Steel type	Cold rolling reduction ratio	Product sheet thickness	0.2% yield strength	Elongation		Average r value	Δr	Limiting drawing ratio	Formability	Note	
		%	mm	MPa		%						
1	A	80%	0.8	312		31	1.8	0.6	2.30	OK	Example of present invention	
2	B	88%	0.6	289		33	1.9	0.5	2.30	OK		
3	C	90%	0.4	301		31	2.1	0.8	2.40	OK		
4	D	90%	0.5	311		31	2.1	0.7	2.35	OK		
5	E	88%	0.6	297		33	2.0	0.6	230	OK	Comparative Example	
6			<u>70%</u>	<u>1.2</u>	276		29	1.8	0.3	<u>2.15</u>		NG
7	F	86%	0.7	302		31	1.9	0.5	230	OK	Example of present invention	
8	G	93%	0.6	317		30	2.2	0.7	2.40	OK		
9			87%	0.8	287		33	1.9	0.6	2.30		OK
10	H	90%	0.5	265		34	2.0	0.5	2.30	OK		
11	I	87%	0.4	311		35	2.1	0.7	2.35	OK	Comparative Example	
12	J	77%	0.8	296		31	1.8	0.5	2.40	OK		
13			90%	0.3	312		30	2.1	0.6	2.35		OK
14			<u>60%</u>	<u>1.2</u>	289		32	1.5	0.5	<u>2.10</u>		NG
15	K	75%	1.0	300		30	1.8	0.6	2.30	OK	Example of present invention	

(continued)

No.	Steel type	Cold rolling reduction ratio %	Product sheet thickness mm	0.2% yield strength MPa	Elongation %	Average r value	Δr	Limiting drawing ratio	Formability	Note
16	AA	80%	0.8	335	29	1.6	0.3	2.20	NG	Comparative Example
17	AB			299	32	1.8	0.4	2.25	NG	
18	AC			300	28	1.4	0.4	2.15	NG	
19	AD			322	29	1.5	0.4	2.15	NG	
20	AE			304	31	1.9	0.5	2.20	NG	
21	AF			327	30	1.5	0.4	2.15	NG	
22	AG			320	31	1.5	0.5	2.20	NG	
23	AH			311	28	1.7	0.3	2.20	NG	
24	AI			304	30	1.5	0.4	2.15	NG	
25	AJ			336	28	1.5	0.4	2.15	NG	
26	AK			315	29	1.5	0.5	2.20	NG	
27	AL			308	30	1.2	0.5	2.20	NG	
28	AM			312	33	1.9	0.4	2.20	NG	
29	AN			318	27	1.5	0.4	2.20	NG	
30	AO			336	30	1.5	0.3	2.15	NG	
31	AP			321	29	1.5	0.5	2.25	NG	
32	AO			304	29	1.7	0.4	2.20	NG	
33	AR			328	30	1.7	0.5	2.20	NG	

The underline indicates outside the scope of the present invention or indicates outside the range of preferable production conditions

[Industrial Applicability]

[0058] The present invention has industrial applicability in that it can provide a ferritic stainless-steel sheet having excellent formability. In particular, the present invention has industrial applicability because, when a formed product having a thin wall thickness required for parts for reducing the weight of home appliances and kitchen devices is produced, since the ferritic stainless-steel sheet according to the present invention can be used as a blank, and favorable formability can be exhibited, it is possible to obtain a formed product that satisfies having dimensional accuracy and quality of design.

Claims

1. A ferritic stainless-steel sheet comprising, in mass%,

C: 0.0200% or less,
Si: 0.70% or less,
Mn: 1.00% or less,
P: 0.030% or less,
S: 0.005% or less,
Cr: 11.0 to 19.5%,
N: 0.020% or less,
Al: 0.005 to 0.100%,
O: 0.0050% or less,
Ti: 0.03 to 0.20%,
Nb: 0.010 to 0.300%,
Sn: 0.001 to 0.300%, and
Zr: 0.001 to 0.080%, with
a remainder of Fe and impurities,

and having a component composition that satisfies the following Formula (1) and Formula (2), having a sheet thickness of 1.0 mm or less, and a limiting drawing ratio in cylindrical cup drawing of 2.30 or more:

$$(0.4 \times \text{Al} + 0.5 \times \text{Zr} + 0.1 \times \text{Ti}) / \text{O} \geq 12.0 \dots (1)$$

$$0.6 \times \text{Cr} + 15 \times \text{Sn} + 8 \times \text{Al} \geq 10.0 \dots (2)$$

where, element symbols in Formula (1) and Formula (2) represent the amount (mass%) of the elements in the ferritic stainless-steel sheet.

2. The ferritic stainless-steel sheet according to claim 1, comprising, in mass%, one or more of Mo: 0.05 to 0.50%, Ni: 0.05 to 0.50%, and Cu: 0.01 to 1.00%, in place of some Fe.

3. The ferritic stainless-steel sheet according to claim 1 or 2, comprising, in mass%, one or more of B: 0.0003 to 0.0050%, Ga: 0.0001 to 0.2%, and W: 0.001 to 0.300%, in place of some Fe.

4. The ferritic stainless-steel sheet according to any one of claims 1 to 3, wherein the average Lankford value is 1.8 or more, and the planar anisotropy (Δr) of the Lankford value is 0.5 or more.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2021/042235

A. CLASSIFICATION OF SUBJECT MATTER

C21D 9/46(2006.01)n; C22C 38/00(2006.01)i; C22C 38/28(2006.01)i; C22C 38/54(2006.01)i
 FI: C22C38/00 302Z; C22C38/28; C22C38/54; C21D9/46 R

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)

C21D9/46; C22C38/00; C22C38/28; C22C38/54

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
 Published unexamined utility model applications of Japan 1971-2022
 Registered utility model specifications of Japan 1996-2022
 Published registered utility model applications of Japan 1994-2022

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2021/100687 A1 (NIPPON STEEL STAINLESS STEEL CORP.) 27 May 2021 (2021-05-27)	1-4
A	JP 2019-173042 A (NIPPON STEEL STAINLESS STEEL CORP.) 10 October 2019 (2019-10-10)	1-4
A	WO 2015/113937 A1 (TATA STEEL ILMUIDEN B.V.) 06 August 2015 (2015-08-06)	1-4
A	WO 2014/069543 A1 (NIPPON STEEL & SUMIKIN STAINLESS STEEL CORP.) 08 May 2014 (2014-05-08)	1-4

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

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 24 January 2022	Date of mailing of the international search report 01 February 2022
Name and mailing address of the ISA/JP Japan Patent Office (ISA/JP) 3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915 Japan	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/JP2021/042235

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
WO 2021/100687 A1	27 May 2021	(Family: none)	
JP 2019-173042 A	10 October 2019	(Family: none)	
WO 2015/113937 A1	06 August 2015	(Family: none)	
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Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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- JP 6050701 B [0008]