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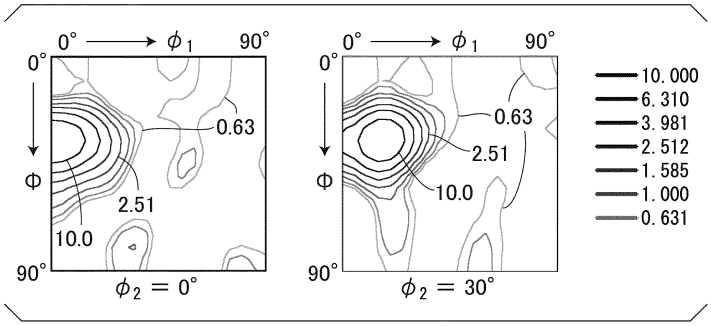
(54) **TITANIUM PLATE**

(57) A titanium plate according to an aspect of the present invention includes, as a chemical composition, in mass%, O: 0.02% to 0.15%, Fe: 0.02% to 0.20%, N: 0 to 0.08%, C: 0 to 0.100%, and H: 0 to 0.013%, and a remainder including Ti and impurities, in which when the crystal orientation of an α phase is represented by an Euler angle g = (φ_1, Φ, φ_2), the area fraction of the α phase having a crystal orientation in which the absolute value of an orientation difference with respect to (0°, 90°, 0°) is within 30° is defined as X1, the area fraction of the α phase having a crystal orientation in which the absolute value of an orientation difference with respect to (0°, 90°, 30°) is within 30° is defined as X2, and the area fraction of the α phase having a crystal orientation in which absolute values of orientation differences with respect to both (0°, 90°, 0°) and (0°, 90°, 30°) are within 30° is defined as X1&2, X1 + X2 - X1&2 is 0.075 or less.

FIG. 2



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Description

[Technical Field of the Invention]

[0001] The present invention relates to a titanium plate.

[Related Art]

[0002] Titanium constituting a titanium plate is classified into pure titanium and a titanium alloy depending on its composition. Pure titanium has a content of an alloy component smaller than that of a titanium alloy, and has a crystal structure called a hexagonal close-packed (hcp) structure at normal temperature in a crystal structure. The hexagonal close-packed structure is also called hexagonal crystal or α phase.

[0003] An hcp crystal constituting pure titanium has poor symmetry as a crystal structure. Therefore, characteristics of pure titanium greatly change depending on the orientation of the crystal orientation, that is, a texture. When a titanium sheet is manufactured through hot rolling, (optional annealing of hot rolled plate), cold rolling, and final annealing, which are general manufacturing methods of a titanium plate, a texture mainly having a crystal orientation (split-TD) in which a c axis ([0001] axis) of hcp is inclined by about 35° from ND (sheet surface normal direction) to TD (sheet width direction) is formed. The texture mainly having the split-TD orientation is excellent in bulging formability in plane strain with TD as a major principal strain. For this reason, when a pure titanium sheet is strictly formed, a deformation mode of a portion where a strain is most concentrated may be designed to be a plane strain in a sheet width direction.

[0004] Patent Document 1 discloses a titanium plate which is pure titanium containing a predetermined component and in which a proportion of grains in which an angle formed by RD (rolling direction) and a c axis is 0 to 50° or 70 to 90° is 90.0% or more and 95% or less.

[Citation List]

[Patent Document]

[0005] [Patent Document 1]
Japanese Unexamined Patent Application, First Publication No. 2017-226858

[Summary of Invention]

[Problems to be Solved by the Invention]

[0006] However, in recent years, there is an increasing demand for workability of a titanium plate. Specifically, there is a demand for a titanium plate having further improved bulging formability in plane strain with TD as a major principal strain.

[0007] An object of the present invention is to provide a titanium plate having more excellent bulging formability in plane strain with TD as a major principal strain than conventional ones.

[Means for Solving the Problem]

[0008] The gist of the present invention is as follows.

[0009]

(1) A titanium plate according to an aspect of the present invention includes, as a chemical composition, in mass%, O: 0.02% to 0.15%, Fe: 0.02% to 0.20%, N: 0 to 0.0800%, C: 0 to 0.1000%, and H: 0 to 0.0130%, and a remainder including Ti and impurities, in which when the crystal orientation of an α phase is represented by an Euler angle g = (φ_1, Φ, φ_2), the area fraction of the α phase having a crystal orientation in which the absolute value of an orientation difference with respect to (0°, 90°, 0°) is within 30° is defined as X1, the area fraction of the α phase having a crystal orientation in which the absolute value of an orientation difference with respect to (0°, 90°, 30°) is within 30° is defined as X2, and the area fraction of the α phase having a crystal orientation in which absolute values of orientation differences with respect to both (0°, 90°, 0°) and (0°, 90°, 30°) are within 30° is defined as X1&2, X1 + X2 - X1&2 is 0.075 or less.

(2) In the titanium plate according to (1), when the area fraction of the α phase having a crystal orientation in which the absolute value of an orientation difference with respect to (0°, 35°, 0°) is within 15° is defined as X3, the area fraction of the α phase having a crystal orientation in which the absolute value of an orientation difference with

respect to (0°, 35°, 30°) is within 15° is defined as X4, and the area fraction of the α phase having a crystal orientation in which absolute values of orientation differences with respect to both (0°, 35°, 0°) and (0°, 35°, 30°) are within 15° is defined as X3&4, (X3 + X4 - X3&4)/(X1 + X2 - X1&2) may be 5.0 or more.

(3) In the titanium plate according to (1) or (2), the average grain size of the α phase may be 70.0 μm or less.

(4) In the titanium plate according to (1) or (2), the average grain size of the α phase may be 20.0 μm or less.

(5) In the titanium plate according to any one of (1) to (4), a coefficient of variation of a grain size of the α phase, which is a value obtained by dividing a standard deviation of the grain size of the α phase by the average grain size of the α phase, may be 0.75 or less.

[Effects of the Invention]

[0010] According to the present invention, it is possible to provide a titanium plate having more excellent bulging formability in plane strain with TD as a major principal strain than conventional ones.

[Brief Description of the Drawings]

[0011]

FIG. 1A is a view showing a notation method by Euler angle in which the crystal orientation is expressed in three dimensions.

FIG. 1B is a view showing a notation method by Euler angle in which the crystal orientation is expressed in three dimensions.

FIG. 1C is a view showing a notation method by Euler angle in which the crystal orientation is expressed in three dimensions.

FIG. 1D is a view showing a notation method by Euler angle in which the crystal orientation is expressed in three dimensions.

FIG. 2 is a diagram in which an orientation distribution function ODF is displayed in contour lines in a space of Euler angles for the titanium plate according to the present embodiment.

FIG. 3 is a diagram in which an orientation distribution function ODF is displayed in contour lines in a space of Euler angles for a titanium plate of a conventional example.

[Embodiment of the Invention]

[0012] The present inventors have found that in pure titanium manufactured by a conventional manufacturing method, in addition to the above split-TD, the crystal orientation (T-texture) in which a c axis is oriented parallel to a sheet width direction (TD) also slightly exists. As a result of studies by the present inventors, it has been found that the presence of the T-texture deteriorates bulging formability in plane strain with TD as a major principal strain of a titanium plate. Therefore, as a result of further studies on a method of suppressing occurrence of T-texture, the present inventors have found that the occurrence of T-texture can be suppressed and the bulging formability in plane strain with TD as a major principal strain of a titanium plate can be dramatically improved by introducing a strain when hot rolling pure titanium and coiling and cooling the titanium plate so as to maintain the strain. Hereinafter, a titanium plate according to the present embodiment will be described in detail.

«Chemical composition of titanium plate»

[0013] Examples of the titanium plate according to the present invention include first and second types specified in JIS H4600 (2012), corresponding Grades 1 to 2 specified in ASTM B265, and titanium (also referred to as pure titanium for industrial use) specified in 3-7025, 3·7035, and 3·7055 standardized by DIN 17850. A chemical composition of the titanium plate according to the present embodiment will be specifically described as follows. Note that, a unit "%" of a content of an element means mass%.

O: 0.02% or more and 0.15% or less

[0014] O is an element always contained in titanium, and improves 0.2% proof stress. However, when an amount of O is too large, ductility decreases, and bulging formability in plane strain with TD as a major principal strain is deteriorated. In order to obtain a 0.2% proof stress improving effect by addition of O, a lower limit of an O content is 0.02%, preferably 0.03%. From the viewpoint of formability, the upper limit of the O content is 0.15%, preferably 0.10%, and more preferably 0.08%.

Fe: 0.02% or more and 0.20% or less

[0015] Fe is an element always contained in titanium, and has an effect of improving 0.2% proof stress. However, when an amount of Fe is too large, a β phase is precipitated during final annealing, which adversely affects formability. In order to obtain the 0.2% proof stress improving effect, a lower limit of an Fe content is 0.02%, preferably 0.03%. On the other hand, from the viewpoint of formability, the upper limit of the Fe content is 0.20%, preferably 0.10%, and more preferably 0.08%.

N: 0 to 0.0800%

[0016] N may not be contained in the titanium plate. N lowers workability of the titanium plate. Therefore, a lower limit of an N content is 0%. The upper limit of the N content is 0.080%. However, the N content may be 0.0001% or more, 0.0003% or more, or 0.0005% or more in consideration of a cost for reducing the N content. The N content may be 0.0700% or less, 0.0600% or less, or 0.0500% or less.

C: 0 to 0.1000%

[0017] C may not be contained in the titanium plate. Therefore, a lower limit of a C content is 0%. The upper limit of the C content is 0.1000%. However, the C content may be 0.0001% or more, 0.0003% or more, or 0.0005% or more in consideration of a cost for reducing the C content. The C content may be 0.0800% or less, 0.0500% or less, or 0.0300% or less.

H: 0 to 0.0130%

[0018] H may not be contained in the titanium plate. H causes embrittlement of the titanium plate. Therefore, a lower limit of an H content is 0%. The upper limit of the H content is 0.0130%. However, the H content may be 0.0001% or more, 0.0002% or more, or 0.0003% or more in consideration of a cost for reducing the H content. The H content may be 0.0100% or less, 0.0080% or less, 0.0060% or less, 0.0040% or less, or 0.0030% or less.

[0019] A remainder of the chemical composition of the titanium plate according to the present embodiment may be Ti and impurities. Specific examples of the impurities include Cl, Na, Mg, Si, and Ca mixed in refining, and Al, Zr, Sn, Mo, Nb, Ta, and V mixed from scrap. When these impurities are contained, each of contents thereof is, for example, 0.1% or less, and if the total content is 0.5% or less, there is no problem.

«Crystal structure of titanium plate»

[0020] Since the titanium plate according to the present embodiment has the above-described composition, it is industrially referred to as pure titanium. In pure titanium, due to the composition, an α phase (hcp) is a main crystal structure. The fact that an α phase is a main crystal structure means that an α phase fraction in an entire evaluation surface is 95% or more in terms of area fraction. This fraction is preferably 97% or more, and more preferably 99% or more. The crystal structure other than the α phase is a β phase.

<<Description of texture by Euler angle>>

[0021] In the titanium plate according to the present embodiment, in order to express a crystal orientation in a texture in three dimensions, a notation method by Euler angle is used. Hereinafter, the notation method by Euler angle (Bunge notation method) will be described.

[0022] As a premise for expressing the crystal orientation by Euler angle, first, three coordinate axes of RD, TD, and ND orthogonal to each other are assumed as a sample coordinate system (coordinate system of a plate material). RD is a rolling direction of the titanium plate, TD is a sheet width direction of the titanium plate, and ND is a sheet surface normal direction of the titanium plate. RD and TD can be specified based on, for example, an elongation direction of a roll mark formed on a surface of the titanium plate, a dimension of the titanium plate, or an elongation direction of a crystal in the titanium plate.

[0023] Next, three coordinate axes of an X axis, a Y axis, and a Z axis orthogonal to each other are assumed as a crystal coordinate system (in the case of a titanium α phase, a coordinate system based on a direction of an hcp microstructure). The Z axis in the crystal coordinate system is a [0001] direction expressed by Miller indices. The X axis in the crystal coordinate system may be in a [10-10] direction (normal direction of a column surface) or in a [1-210] direction. In the titanium plate according to the present embodiment, the X axis is the [1-210] direction. In this case, the Y axis is the [10-10] direction (normal direction of a column surface).

(A) In the notation method by Euler angle, as shown in FIG. 1A, a state in which the sample coordinate system and the crystal coordinate system coincide with each other (the X axis matches RD, the Y axis matches TD, and the Z axis matches ND) is used as a reference.
(B) It is assumed that this reference crystal is rotated by φ_1° about the Z axis in the crystal coordinate system as shown in FIG. 1B. The crystal coordinate system of the rotated crystal is denoted as (X', Y', Z) in FIG. 1B.
(C) Next, as shown in FIG. 1C, it is assumed that this crystal is rotated by Φ° about the X (X') axis after rotation by φ_1°. The axes of the crystal coordinate system of the rotated crystal are denoted as (X', Y", Z') in FIG. 1C.
(D) Finally, as shown in FIG. 1D, it is assumed that this crystal is rotated by φ_2° about the Z (Z') axis after rotation by φ_1° and rotation by Φ°. The axes of the crystal coordinate system of the rotated crystal are denoted as (X", Y‴, Z') in FIG. 1D.

[0024] In the notation method by Euler angle, the crystal orientation (such as a direction of a c axis) of an arbitrary grain is expressed using these three angles of φ_1°, Φ°, and φ_2°. That is, the crystal orientation of a crystal shown in FIG. 1A is denoted by Euler angle as (0, 0, 0), the crystal orientation of a crystal shown in FIG. 1B is denoted by Euler angle as (φ_1, 0, 0), the crystal orientation of a crystal shown in FIG. 1C is denoted by Euler angle as (φ_1, Φ, 0), and the crystal orientation of a crystal shown in FIG. 1D is denoted by Euler angle as (φ_1, Φ, φ_2). Since a crystal structure of the α phase, which is a microstructure of a main phase of the titanium plate, is a hexagonal crystal, it can be denoted by φ_1 (0 to 90°), Φ (0 to 90°), and φ_2 (0 to 60°).

[0025] In Miller indices described in FIGS. 1A to 1D, an overlined value is a negative value. On the other hand, in the specification, a minus sign is used instead of the overline in order to denote a negative value in the Miller indices. Therefore, notation of some crystal orientations in the drawings is rewritten as follows in the specification.

[Table 1]

	Drawing	Specification
X axis (RD)	$[1\bar{2}10]$	[1-210]
Y axis (TD)	$[10\bar{1}0]$	[10-10]

[0026] The crystal orientation distribution of a polycrystal is represented by a function f(φ_1, Φ, φ_2) using the above-described Euler angle (φ_1, Φ, cpz), and this function is called an orientation distribution function (ODF). When the crystal orientation (φ_1, Φ, φ_2) is g, ODF can be expressed as f(g). The higher a value of f(g), the more crystals oriented in the crystal orientation g.

[0027] A texture (split-TD), which is a general texture of a titanium plate manufactured by a conventional normal method and in which an orientation in which a c axis is inclined by about 35° with respect to TD is set as a preferential orientation, will be expressed below using the Euler angle (φ_1, Φ, φ_2). In order to denote a three-dimensional orientation distribution function on a two-dimensional paper surface, f(g) at specific φ_2 is expressed by contour lines in a space with a horizontal axis: φ_1 (0 to 90°) and a vertical axis: Φ (0 to 90°). In titanium, typical orientations are represented by φ_2 = 0° and 30° (FIGS. 2 and 3). As is clear from FIGS. 2 and 3, it is clear that a peak having a high value of f(g) exists in the vicinity of Φ = 35° and φ_1 = 0° at any φ_2. Each of these crystal orientations indicates an orientation in which a c axis of an hcp structure is inclined by 35° from ND to TD, and when φ_2 = 0°, [1-210] is oriented to RD, and when φ_2 = 30°, [0-110] is oriented to RD. In these orientations, since crystal orientations represented by (0°, 35°, 0°) and (0°, 35°, 30°), which are main orientations, are extremely excellent in bulging formability in plane strain with TD as a major principal strain, press working utilizing this characteristic is performed.

[0028] FIG. 3 is a diagram of a pure titanium plate manufactured by a conventional manufacturing method. In FIG. 3, when φ_1 = 0° and Φ is 35 to 90°, an orientation of a crystal orientation is confirmed. Among them, Φ = 90° indicates a crystal orientation in which a c axis of hcp is parallel to TD. These crystal orientations (T-texture) represented by (0°, 90°, 0°) and (0°, 90°, 30°) deteriorate bulging formability in plane strain with TD as a major principal strain. In a normal manufacturing method, it is difficult to reduce the crystal orientations represented by (0°, 90°, 0°) and (0°, 90°, 30°), and bulging formability in plane strain with TD as a major principal strain has been insufficient in some cases.

<<Presence ratio of T-texture>>

[0029] In the titanium plate according to the present embodiment, a presence ratio of T-texture in the titanium plate is defined as follows. That is, when the crystal orientation of the α phase is represented by an Euler angle g = (φ_1, Φ, φ_2), the area fraction of the α phase having a crystal orientation in which the absolute value of an orientation difference with respect to (0°, 90°, 0°) is within 30° is defined as X1, and the area fraction of the α phase having a crystal orientation in which the absolute value of an orientation difference with respect to (0°, 90°, 30°) is within 30° is defined as X2.

Further, the area fraction of the α phase having a crystal orientation in which absolute values of orientation differences with respect to both (0°, 90°, 0°) and (0°, 90°, 30°) are within 30° is defined as X1&2. X1&2 is the area fraction of the α phase calculated for both X1 and X2. Then, X1 + X2 - X1 &2 is used as the presence ratio of T-texture.

[0030] The crystal orientations (T-texture) represented by (0°, 90°, 0°) and (0°, 90°, 30°) deteriorate bulging formability in plane strain with TD as a major principal strain. Therefore, area fractions of crystals having these crystal orientations are preferably small. In order to obtain sufficient formability, in the titanium plate according to the present embodiment, the upper limit of a total of both (X1 + X2 - X1&2) is 0.075, preferably 0.070.

[0031] FIG. 2 shows the titanium plate according to the present embodiment and FIG. 3 shows a conventional titanium plate in which f(g) at φ_2 = 0° and 30° is expressed by contour lines in a space with a horizontal axis: φ_1 (0 to 90°) and a vertical axis: Φ (0 to 90°). A presence ratio (area fraction) (X1 + X2 - X1&2) of a crystal having a crystal orientation (T-texture) in which the absolute value of an orientation difference is indicated within 30° around (0°, 90°, 0°) and (0°, 90°, 30°) is 0.082 in the case of FIG. 3 of a conventional example, whereas it is reduced to 0.062 in FIG. 2 of the titanium plate according to the present embodiment.

<<Presence ratio of split-TD>>

[0032] A presence ratio of split-TD in the titanium plate is defined as follows. That is, the area fraction of the α phase having a crystal orientation in which the absolute value of an orientation difference with respect to (0°, 35°, 0°) is within 15° is defined as X3, and the area fraction of the α phase having a crystal orientation in which the absolute value of an orientation difference with respect to (0°, 35°, 30°) is within 15° is defined as X4. Further, the area fraction of the α phase having a crystal orientation in which absolute values of orientation differences with respect to both (0°, 35°, 0°) and (0°, 35°, 30°) are within 15° is defined as X3&4. X3&4 is the area fraction of the α phase calculated for both X3 and X4. Then, X3 + X4 - X3&4 is used as the presence ratio of split-TD.

[0033] Since the crystal orientations (split-TD) represented by (0°, 35°, 0°) and (0°, 35°, 30°) are extremely excellent in bulging formability in plane strain with TD as a major principal strain, area fractions of crystals having these crystal orientations are preferably large. Therefore, it is preferable that (X3 + X4 - X3&4)/(X1 + X2 - X1&2) is large in consideration of the area fraction (X1 + X2 - X1&2) of (0°, 90°, 0°) and (0°, 90°, 30°) described above. In the titanium plate according to the present embodiment, a lower limit of (X3 + X4 - X3&4)/(X1 + X2 - X1&2) is preferably 5.0 and more preferably 5.5 in order to obtain sufficient formability.

<<Method of evaluating area fractions X1 to X4, X1&2, and X3&4 of α-phase crystal having predetermined crystal orientation>>

[0034] The area fractions X1 to X4 of crystals having the above crystal orientations can be measured as follows. A surface perpendicular to a sheet width direction of the titanium plate (hereinafter also referred to as an "L cross section") was polished to obtain a measurement surface, and by an electron backscatter diffraction (EBSD) method, an EBSD pattern was measured with a step size of 10 μm while scanning an electron beam in a visual field of a total sheet thickness $\times$ 15 mm of this surface with a scanning electron microscope (SEM). For the data, each area fraction was calculated using OIM Analysis ver 7.31 software manufactured by TSL Solutions K.K. For example, by designating a close-packed hexagonal crystal as a crystal structure and designating "simultaneous evaluation of the area fraction of a crystal having a crystal orientation in which the absolute value of an orientation difference is within 30° around (0°, 90°, 0°) and the area fraction of a crystal having a crystal orientation in which the absolute value of an orientation difference is within 30° around (0°, 90°, 30°)", X1 + X2 - X1&2 can be obtained as an evaluation result. X3 + X4 - X3&4 can also be obtained by a similar procedure. For analysis, only analysis data having a confidence of index value (CI value) of 0.1 or more was used. In consideration of symmetry of rolling deformation, crystal orientations that are line-symmetric with respect to each of a sheet thickness direction, a rolling direction, and a sheet width direction were calculated as the same orientation. Measurement conditions were as follows.

- Heating voltage: 15 kV
- Amount of current: about 35 nA
- Magnification: 200 times

<<Average grain size of α phase>>

[0035] When the average grain size of the α phase is too large, wrinkles may occur during press forming. In addition, as the average grain size of the α phase is smaller, strength increases. Therefore, the average grain size of the α phase is preferably 70.0 μm or less, 50.0 μm or less, 25.0 μm or less, and more preferably 20.0 μm or less. On the other hand, when the average grain size of the α phase is less than 2 μm, non-recrystallized grains remain, which may adversely

affect formability. Therefore, the average grain size of the α phase is preferably 2.0 μm or more.

<<Variation in grain size of α phase>>

[0036] A value obtained by dividing a standard deviation of a grain size (equivalent circle diameter) of the α phase by the average value of grain sizes of the α phase is defined as a coefficient of variation of the grain size of the α phase. When the coefficient of variation of the grain size of the α phase is too large, distribution of the grain size becomes non-uniform, and deformation concentrates on specific grains, so that formability may be deteriorated. Therefore, the coefficient of variation of the grain size of the α phase is preferably 0.75 or less, and more preferably 0.70 or less.

<<Method of evaluating average grain size of α phase and coefficient of variation>>

[0037] The average grain size of the α phase is in an arbitrary cross section of the titanium plate, and can be measured by observing a surface perpendicular to a sheet width direction of the titanium plate (L cross section). A surface perpendicular to a sheet width direction of the titanium plate (L cross section) was polished to obtain a measurement surface, and by an electron backscatter diffraction (EBSD) method, an EBSD pattern was measured with a step size of 0.5 μm while scanning an electron beam in a visual field of a total sheet thickness × 1000 μm of this surface with a scanning electron microscope (SEM). For the data, the average grain size of the α phase was calculated using OIM Analysis ver 7.31 software manufactured by TSL Solutions K.K. A boundary having an orientation difference of 15° or more is recognized as a grain boundary, and a region surrounded by this grain boundary is defined as a grain. In this visual field, there are about 1000 or more grains. For the average grain size, the average value of equivalent circle diameters was evaluated as an arithmetical mean. The coefficient of variation was determined by dividing a standard deviation of a grain size (equivalent circle diameter) of the α phase by the average grain size. Measurement conditions of the EBSD pattern other than the measurement visual field and the step size are the same as the conditions for measuring X1 to X4 and the like.

[0038] When the grain size of the α phase is relatively coarse, grains having split-TD preferentially grow in a grain growth process after completion of recrystallization, and a development degree of grains having T-texture tends to decrease. However, when the grain size of the α phase is coarse, wrinkles occur during forming working as described above. On the other hand, a conventional manufacturing method had a problem that when the grain size of the α phase becomes small, T-texture increases. In contrast, in the titanium plate according to the present embodiment, T-texture hardly exists even if the grain size of the α phase is relatively small. For this reason, the present inventors have been able to realize, for the first time, a titanium plate which has both of a characteristic that the α phase is fine grains and wrinkles hardly occur and a characteristic of having excellent bulging formability in plane strain with TD as a major principal strain and which is not included in the conventional art. When the average grain size of the α phase is 70.0 μm or less, T-texture is conventionally present, whereas the titanium plate according to the present embodiment hardly has T-texture, and an effect thereof can be sufficiently exhibited.

<<Titanium plate manufacturing method>>

[0039] The titanium plate according to the present embodiment is characterized by a texture with almost no T-texture, and is excellent in bulging formability in plane strain with TD as a major principal strain. The manufacturing method is not particularly limited, but for example, the texture is achieved by controlling hot rolling to cause a specific dislocation to remain, suppressing T-texture formation, increasing a cold-rolling reduction to increase a development degree of split-TD as a preferential orientation, and decreasing a development degree of T-texture by a manufacturing method whose points are shown below.

[0040] As described above, by controlling a hot rolling finishing temperature and a subsequent cooling rate of pure titanium and performing cold rolling at a large rolling reduction, a texture in which T-texture, which is considered to be a main cause of anisotropy, is hardly present even in the case of fine grains after final annealing is developed, and a titanium sheet in which wrinkles do not occur during forming and having excellent bulging formability in plane strain with TD as a major principal strain can be manufactured.

[0041] Hereinafter, an example of the manufacturing method of the titanium plate according to the present embodiment will be described. As a step flow, melting, blooming, hot rolling, cold rolling, and final annealing are sequentially performed.

"Melting"

[0042] A titanium raw material manufactured to have a predetermined purity is melted by a conventionally known method to form a predetermined ingot. Specifically, a vacuum arc remelting method (VAR method) or an electron beam melting method (EB method) can be applied.

"Blooming"

[0043] Working is performed into a slab shape by conventionally known blooming rolling or forging. The titanium slab obtained through the above blooming may be subjected to cutting, cleaning treatment, or the like by a known method as necessary. This step may be omitted as necessary.

"Hot rolling (heating and rolling)"

[0044] In the titanium plate according to the present embodiment, it is important to control a rolling reduction during hot rolling, a finishing temperature during hot rolling, a coiling temperature after hot rolling, and the average cooling rate from the finishing temperature to 300°C.

[0045] Heating before hot rolling may be performed by a conventionally known method, and for example, the slab may be heated to 700 to 1000°C. However, from the viewpoint of accurately adjusting the hot rolling finishing temperature, a heating temperature is preferably equal to or lower than a β transformation point temperature. The "β transformation point temperature" means a boundary temperature at which the α phase starts to be generated when pure titanium or a titanium alloy is cooled from a β phase single phase region. The β transformation point temperature can be obtained from a phase diagram. The phase diagram can be obtained, for example, by a computer coupling of phase diagrams and thermochemistry (CALPHAD) method, and for that purpose, for example, Thermo-Calc, which is an integrated thermodynamic calculation system of Thermo-Calc Software AB, and a predetermined database (TI3) can be used.

[Hot rolling]

"Average rolling reduction per pass in finish rolling" 10% or more

"Interpass time in finish rolling" 2.0 seconds or less

[0046] In finish rolling of hot rolling, it is preferable to set the average rolling reduction per pass to 10% or more and the interpass time to 2.0 seconds or less. This makes it possible to suppress disappearance of dislocations due to recovery and to introduce a large amount of dislocations into the titanium plate. As described later, dislocations have a function of suppressing T-texture formation during cooling of the titanium plate after hot rolling. Therefore, a texture with less T-texture can be developed by performing finish rolling under these conditions.

"Hot rolling finishing temperature" 600°C or higher and 750°C or lower

[0047] In titanium, there are as many as five types of slip systems as plastic deformation mechanisms, and types of active mechanisms vary depending on the temperature. It was found that when dislocations generated by activity of a slip system active at 600°C or higher remain, formation of T-texture can be suppressed during final annealing after cold rolling. The hot rolling finishing temperature is controlled such that the dislocations remain.

[0048] When the hot rolling finishing temperature is lower than 600°C, a density of dislocations that suppress T-texture formation is low, a large amount of T-texture is formed during final annealing, and bulging formability in plane strain with TD as a major principal strain is deteriorated. Therefore, a lower limit of the hot rolling finishing temperature is 600°C, preferably 625°C, and more preferably 650°C. On the other hand, when the hot rolling finishing temperature exceeds 750°C, recovery and recrystallization occur during working, the above dislocations disappear, a large amount of T-texture is formed during final annealing, and bulging formability in plane strain with TD as a major principal strain is deteriorated. Therefore, the upper limit temperature is 750°C, preferably 730°C, and more preferably 720°C. The hot rolling finishing temperature is measured by a radiation thermometer. A coiling temperature and the like described below are also values measured by a radiation thermometer.

"Coiling temperature" 450°C or lower

"Average cooling rate from hot rolling finishing temperature to 300°C" 5.0 °C/s or more

[0049] By increasing a cooling rate after hot rolling, recovery and recrystallization during cooling are suppressed, the above dislocations are caused to remain, and formation of T-texture during final annealing is suppressed.

[0050] When the titanium plate after hot rolling is coiled, the cooling rate of the titanium plate decreases. When the above coiling temperature exceeds 450°C, recovery and recrystallization occur in the coiled titanium plate, the above dislocations disappear, a large amount of T-texture is formed during final annealing, and bulging formability in plane strain with TD as a major principal strain is deteriorated. Therefore, the coiling temperature is 450°C or lower.

[0051] In addition, when the above cooling rate is lower than 5 °C/s, recovery and recrystallization occur during cooling, the above dislocations disappear, a large amount of T-texture is formed during final annealing, and bulging formability in plane strain with TD as a major principal strain is deteriorated. Therefore, a lower limit of the cooling rate is 5.0 °C/s, preferably 10.0 °C/s, and more preferably 20.0 °C/s. The upper limit is not particularly limited, but may be 100 °C/s from the viewpoint of equipment capacity and the like.

"Annealing of hot rolled plate and cold rolling intermediate annealing" should not be performed

[0052] When annealing of hot rolled plate and cold rolling intermediate annealing are performed, the above dislocations disappear, a large amount of T-texture is formed during final annealing, and bulging formability in plane strain with TD as a major principal strain is deteriorated. Therefore, annealing of hot rolled plate and cold rolling intermediate annealing should not be performed after hot rolling until final annealing. Note that annealing of hot rolled plate is annealing performed on a titanium plate after coiling and before start of cold rolling, and cold rolling intermediate annealing is annealing performed on a titanium plate between passes when cold rolling is performed in a plurality of passes.

[0053] The obtained hot-rolled plate may be subjected to removal of oxide scale or the like by pickling or cutting by a known method, a cleaning treatment, or the like.

[Cold rolling]

"Total cold-rolling reduction" 78% or more

[0054] When the total cold-rolling reduction of cold rolling is less than 78%, a development degree of split-TD decreases, and development of T-texture increases. For this reason, the total cold-rolling reduction is 78% or more. More preferably, the total cold-rolling reduction is 81 % or more. The upper limit of the total cold-rolling reduction is preferably 95% from the viewpoint of edge cracks and the like. A sheet thickness of a titanium plate subjected to hot rolling and cold rolling under the above-described conditions is, for example, in a range of 0.3 mm to 1.0 mm.

[0055] "Final annealing" annealing temperature is 500°C or higher and 750°C or lower and a combination of temperature and time that satisfies formula (1)

$$18500 \leq P = (T + 273.15) \times (\mathrm{Log}(t) + 20) \text{ Formula (1)}$$

[0056] P in the above formula (1) is a function called a Larson-Miller parameter, T is an annealing temperature (°C), and t is an annealing time (s).

[0057] When the annealing temperature is lower than 500°C, recrystallization is not completed, and there is a possibility that bulging formability in plane strain with TD as a major principal strain is deteriorated. Therefore, a lower limit of the annealing temperature is 500°C, preferably 550°C. On the other hand, when the annealing temperature is higher than 750°C, the grain size greatly changes with a slight time change, the grain size becomes too coarse, and wrinkles may occur during forming. Therefore, the upper limit of the annealing temperature is 750°C, and more preferably 700°C. In addition, when the Larson-Miller parameter P is less than 18500, recrystallization is not completed, and there is a possibility that bulging formability in plane strain with TD as a major principal strain is deteriorated. Therefore, a lower limit of P is 18500, preferably 19000.

[0058] On the other hand, as a value of the Larson-Miller parameter P decreases, the average grain size of the titanium plate can be reduced. When the Larson-Miller parameter P is 23000 or less, the average grain size is 70.0 μ or less, and occurrence of wrinkles during forming can be suppressed. When the Larson-Miller parameter P is 21500 or less, the average grain size is 25.0 μm or less, and occurrence of wrinkles during forming can be reliably prevented. Therefore, the upper limit of P is preferably set to 21500.

(Manufacturing method in which coefficient of variation in grain size of α phase is 0.75 or less)

[0059] When the cold-rolling reduction is small, a degree of strain accumulation in each grain in a cold-rolled sheet becomes non-uniform, and distribution of the grain size after annealing may become non-uniform. Therefore, the cold-rolling reduction is preferably higher, and is preferably 80% or more.

[Examples]

[0060] First, a titanium ingot as a material of a titanium sheet shown in Table 2 was manufactured by vacuum arc remelting (VAR). Thereafter, a slab having a thickness of 150 mm × a width of 800 mm × a length of 5000 mm was

manufactured by blooming rolling or forging. In Table 2, "Bal." represents a remainder. In Table 2, a description of a content of impurity elements was omitted.

[0061] A method of measuring chemical compositions of the slab was as follows. A content of Fe was measured by IPC emission spectrometry using a sequential ICP emission spectrometer. Contents of O and N were measured by a thermal conductivity/infrared light absorption method using an oxygen/nitrogen simultaneous analyzer. A content of C was measured by an infrared light absorption method using a carbon/sulfur analyzer. H was measured by a thermal conductivity method using a hydrogen analyzer. Chemical compositions of each of the manufactured hot-rolled plates were equal to chemical compositions of the titanium slab shown in Table 2. For titanium materials A to K shown in Table 2, a phase diagram of a titanium alloy was obtained by a CALPHAD method using Thermo-Calc, which is an integrated thermodynamic calculation system of Thermo-Calc Software AB, and a predetermined database (TI3), and a β transformation point Tβ was calculated.

[0062] Subsequently, these slabs were hot rolled under conditions shown in Table 3 or Table 5. The hot-rolled titanium plate (hot-rolled plate) was subjected to annealing of hot rolled plate as necessary, and then shot blasting and pickling were performed. In manufacture of all of Inventive Examples and Comparative Examples, in finish rolling of hot rolling, the average rolling reduction per pass was set to 10% or more, and an interpass time was set to 2.0 seconds or less. The term "hot rolling reduction" described in Tables 3 and 5 is a total rolling reduction in hot rolling. The "hot-rolled plate thickness" described in Tables 3 and 5 is a sheet thickness of the hot-rolled plate after completion of hot rolling.

[0063] Subsequently, the obtained hot-rolled plate was subjected to cold rolling and annealing under conditions shown in Table 4 or Table 6 to manufacture a cold-rolled sheet having a thickness of 0.8 mm. In the tables, "Tβ" is a β transformation point, and "Larson-Miller parameter" is a value of $P = (T + 273.15) \times (\mathrm{Log10}(t) + 20)$. T is an annealing temperature (°C) and t is an annealing time (s).

[0064] A method of evaluating area fractions X1 + X2 - X1&2 and X3 + X4 - X3&4 of crystals having crystal orientations in the titanium plate was as follows. First, in order to measure the area fractions X1 + X2 - X1&2 and X3 + X4 - X3&4, a surface perpendicular to a sheet width direction of the titanium plate (hereinafter also referred to as "L cross section") was polished to obtain a measurement surface. In this measurement surface, an observed visual field including an entire region in a sheet thickness direction and having a width of 15 mm along a sheet surface was set. In this observed visual field, by an electron backscatter diffraction (EBSD) method, an EBSD pattern was measured with a step size of 10 μm while scanning an electron beam with a scanning electron microscope (SEM). For the data, each area fraction was calculated using OIM Analysis ver 7.31 software manufactured by TSL Solutions K.K. At this time, for analysis, only analysis data having a confidence of index value (CI value) of 0.1 or more was used. In consideration of symmetry of rolling deformation, crystal orientations that are line-symmetric with respect to each of a sheet thickness direction, a rolling direction, and a sheet width direction were calculated as the same orientation. Measurement conditions of the EBSD pattern were as follows.

- Heating voltage: 15 kV
- Amount of current: about 35 nA
- Magnification: 200 times

[0065] A method of evaluating the average grain size of an α phase and a coefficient of variation was as follows. First, in order to measure the grain size of the α phase, a surface perpendicular to a sheet width direction of the titanium plate (L cross section) was polished to obtain a measurement surface. In this measurement surface, an observed visual field including an entire region in a sheet thickness direction and having a width of 1000 μm along a sheet surface was set. In this observed visual field, by an electron backscatter diffraction (EBSD) method, an EBSD pattern was measured with a step size of 0.5 μm while scanning an electron beam with a scanning electron microscope (SEM). For the data, using OIM Analysis ver 7.31 software manufactured by TSL Solutions K.K., a boundary having an orientation difference of 15° or more was recognized as a grain boundary, a region surrounded by this grain boundary was defined as a grain, and the grain size of the α phase was calculated as an equivalent circle diameter. The average grain size was an arithmetical mean of equivalent circle diameters. The coefficient of variation was determined by dividing a standard deviation of the grain size (equivalent circle diameter) of the α phase by the average grain size.

[0066] Formability of the titanium plate was evaluated by plane strain stretch-expanding height in the sheet width direction. Using a die with a hole diameter of φ 44 mm, a shoulder portion R of 6 mm, and a bead of φ 70 mm, and a spherical head punch of φ 40 mm, formability was evaluated at a wrinkle suppression force of 7 ton and a punch rising speed of 20 mm/min. A blank having a side length of 60 mm parallel to a rolling direction and a side length of 90 mm parallel to a sheet width direction was cut out from the cold-rolled sheet. For lubrication, a poly sheet (NAFLON tape 9001 (0.05 t) manufactured by NICHIAS Corporation) and a highly viscous oil (Press oil #660 manufactured by Nihon Kohsakuyu Co., Ltd.) were used. A displacement at a maximum load, which can be read from the load-displacement curve obtained in the test, was regarded as a stretch-expanding height. A titanium plate having a stretch-expanding height of 24.0 mm or more was evaluated as a titanium plate having good formability, that is, a titanium plate having

more excellent bulging formability in plane strain with TD as a major principal strain than conventional ones.

[0067] Evaluation of wrinkles during forming of a titanium plate was performed based on roughness after a tensile test. From the titanium plate, a JIS 13B tensile test piece was taken so that the rolling direction was a tensile direction. The test piece was subjected to a tensile test up to a nominal strain of 20% at a strain rate of 30%/min. A surface of a parallel portion of the test piece after the tensile test was subjected to roughness measurement using a laser microscope. Using a laser microscope manufactured by KEYENCE CORPORATION, a visual field of 213 μm × 284 μm was measured at a magnification of 500 times for 3 visual fields in a measurement mode: surface shape, measurement area: surface, measurement quality: high definition, Z measurement pitch of 0.01 μm. For the data, using VK Analyzer software ver. 2.5.0.1, after surface inclination correction (automatic) of the sample, the average value of arithmetical average roughness Ra in the rolling direction in each visual field was calculated in accordance with JIS B0601:2001 under a condition that 11 lines were drawn in parallel to the rolling direction so as to divide the sheet width direction into 12 equal parts at cut-off values λc = 0.8 mm and λs = 2.5 μm, and evaluation was performed by the average value of 3 visual fields. When the average Ra was 0.25 μm or less, it was regarded as very good, and when the average Ra was 0.65 μm or less, it was regarded as good. However, an example in which an evaluation result of the stretch-expanding height was good even when wrinkles were more than 0.65 μm was regarded as a titanium plate having more excellent bulging formability in plane strain with TD as a major principal strain than conventional ones. For surface roughness, the same result can be obtained as long as measurement is performed at a parallel portion of the test piece. In this test, measurement was performed at a center portion of a parallel portion.

[Table 2]

Material	Component content (mass%)						Tβ
	Fe	O	N	C	H	Ti	°C
A	0.03	0.04	0.0012	0.0050	0.0005	Bal.	885
B	0.06	0.08	0.0021	0.0062	0.0003	Bal.	889
C	0.18	0.12	0.0025	0.0044	0.0007	Bal.	891
D	0.12	0.18	0.0015	0.0058	0.0007	Bal.	900
E	0.22	0.12	0.0027	0.0060	0.0008	Bal.	890
F	0.18	0.12	0.0992	0.0054	0.0006	Bal.	903
G	0.17	0.12	0.0026	0.1181	0.0006	Bal.	948
H	0.18	0.11	0.0028	0.0063	0.0151	Bal.	888
I	0.06	0.08	0.0755	0.0052	0.0006	Bal.	953
J	0.07	0.09	0.0011	0.0917	0.0008	Bal.	930
K	0.06	0.08	0.0027	0.0068	0.0101	Bal.	889

[Table 3]

No		Material		Hot rolling						Annealing of hot rolled plate
		Component	Tβ (°C)	Heating temperature (°C)	Hot rolling finishing temperature (°C)	Coiling temperature (°C)	Average cooling rate from hot rolling finishing temperature to 300°C (°C/s)	Hot rolling reduction (%)	Hot-rolled plate thickness (mm)	
Inventive Example	1	A	885	850	702	25	23.4	97	3.8	–
	2	A	885	850	702	25	23.4	97	4.4	–
	3	A	885	850	702	25	23.4	96	5.3	–
	4	A	885	850	702	25	23.4	95	8.0	–
	5	A	885	850	702	25	23.4	96	5.3	–
	6	A	885	850	702	25	23.4	96	5.3	–
	7	A	885	850	702	25	23.4	96	5.3	–
	8	A	885	850	702	25	23.4	96	5.3	–
	9	A	885	850	702	25	23.4	96	5.3	–
	10	A	885	850	702	25	23.4	96	5.3	–
	11	A	885	850	702	25	23.4	96	5.3	–
	12	A	885	850	742	25	27.7	96	5.3	–
	13	A	885	850	611	25	19.5	96	5.3	–
	14	A	885	850	648	25	21.3	96	5.3	–
	15	A	885	850	697	25	11.3	96	5.3	–
	16	A	885	850	705	25	5.5	96	5.3	–
	17	A	885	850	707	25	52.3	96	5.3	–
	18	A	885	850	712	25	85.4	96	5.3	–
	19	B	889	850	721	25	25.3	97	4.0	–
	20	B	889	850	721	25	25.3	96	5.3	–
	21	B	889	850	718	25	12.4	96	5.3	–
	22	B	889	850	709	25	6.7	96	5.3	–
	23	B	889	850	746	25	30.4	96	5.3	–
	24	B	889	850	608	25	17.4	96	5.3	–
	25	C	891	850	706	25	20.4	97	4.0	–
	26	C	891	850	706	25	20.4	96	5.3	–
	27	C	891	850	712	25	11.4	96	5.3	–
	28	C	891	850	702	25	5.6	96	5.3	–
	29	C	891	851	739	25	23.8	96	5.3	–
	30	C	891	852	621	25	21.7	96	5.3	–
	31	A	885	850	702	25	23.4	96	5.3	–
	32	A	885	850	702	25	23.4	96	5.3	–
	33	A	885	850	647	420	27.5	97	4.2	–
	34	I	953	850	712	25	19.4	96	5.3	–
	35	J	930	850	708	25	20.5	96	5.3	–
	36	K	889	850	709	25	21.5	96	5.3	–

[Table 4]

No		Cold rolling		Final annealing			Metallographic structure				Wrinkle evaluation result	Formability
							Texture		Grain size			
		Total cold-rolling reduction (%)	Intermediate annealing	Annealing temperature (°C)	Annealing time (s)	Larson-Miller parameter P	X1+X2-X1&2	(X3+X4-X3&4)/(X1+X2-X1&2)	Average grain size (μm)	Coefficient of variation		Stretch-expanding height (mm)
Inventive Example	1	79	–	580	14400	20611	0.071	5.1	13.1	0.78	0.16	24.4
	2	82	–	580	14400	20611	0.060	6.5	12.0	0.68	0.17	26.2
	3	85	–	580	14400	20611	0.042	10.7	13.3	0.64	0.14	26.7
	4	90	–	580	14400	20611	0.028	15.4	13.7	0.61	0.15	27.2
	5	85	–	500	14400	18678	0.068	4.8	3.7	0.70	0.06	24.2
	6	85	–	740	15	21455	0.034	11.3	23.6	0.66	0.31	26.5
	7	85	–	550	300	18502	0.073	4.3	2.3	0.71	0.06	24.3
	8	85	–	700	120	21486	0.031	11.7	24.2	0.63	0.28	26.7
	9	85	–	550	14400	19886	0.053	7.6	7.7	0.65	0.09	24.7
	10	85	–	610	14400	21335	0.033	12.3	21.4	0.71	0.32	26.7
	11	85	–	630	3600	21275	0.039	12.1	20.5	0.72	0.28	26.5
	12	85	–	580	14400	20611	0.047	10.6	12.2	0.72	0.13	25.6
	13	85	–	580	14400	20611	0.069	9.8	12.2	0.64	0.16	24.4
	14	85	–	580	14400	20611	0.071	9.3	13.3	0.66	0.15	24.4
	15	85	–	580	14400	20611	0.052	10.5	12.0	0.68	0.16	25.6
	16	85	–	580	14400	20611	0.068	10.4	13.4	0.72	0.14	24.7
	17	85	–	580	14400	20611	0.042	9.2	12.7	0.73	0.16	25.4
	18	85	–	580	14400	20611	0.072	5.5	11.9	0.72	0.15	24.2
	19	80	–	580	14400	20611	0.071	6.3	12.5	0.77	0.17	24.4
	20	85	–	580	14400	20611	0.045	10.6	12.1	0.67	0.16	25.7
	21	85	–	580	14400	20611	0.044	10.6	11.8	0.73	0.13	25.3
	22	85	–	580	14400	20611	0.073	9.5	13.4	0.73	0.16	24.3
	23	85	–	580	14400	20611	0.070	9.7	13.4	0.66	0.15	24.6
	24	85	–	580	14400	20611	0.066	10.2	12.9	0.69	0.14	24.9
	25	80	–	580	14400	20611	0.069	5.7	10.8	0.79	0.14	24.1
	26	85	–	580	14400	20611	0.042	9.4	10.5	0.71	0.14	24.7
	27	85	–	580	14400	20611	0.045	9.5	10.4	0.66	0.14	24.9
	28	85	–	580	14400	20611	0.071	9.2	10.6	0.71	0.17	24.4
	29	85	–	580	14400	20611	0.070	8.7	11.2	0.72	0.13	24.3
	30	85	–	580	14400	20611	0.068	10.3	10.4	0.70	0.13	24.4
	31	85	–	670	14400	22785	0.018	18.6	63.4	0.71	0.62	27.5
	32	85	–	700	14400	23510	0.014	20.1	75.3	0.67	0.68	27.7
	33	81	–	580	14400	20611	0.073	5.2	11.3	0.75	0.15	24.2
	34	85	–	580	14400	20611	0.023	8.2	10.2	0.74	0.16	24.3
	35	85	–	580	14400	20611	0.031	7.9	9.8	0.72	0.17	24.2
	36	85	–	580	14400	20611	0.027	8.0	11.0	0.73	0.14	24.4

[Table 5]

No		Material		Hot rolling						Annealing of hot rolled plate
		Component	Tβ (°C)	Heating temperature (°C)	Hot rolling finishing temperature (°C)	Coiling temperature (°C)	Average cooling rate from hot rolling finishing temperature to 300°C (°C/s)	Hot rolling reduction (%)	Hot-rolled plate thickness (mm)	
Comparative Example	1	A	885	850	763	25	25.4	96	5.3	–
	2	A	885	850	580	25	15.6	96	5.3	–
	3	A	885	850	693	25	4.5	96	5.3	–
	4	A	885	850	702	25	23.4	97	4.0	Performed
	5	A	885	850	702	25	23.4	98	3.2	–
	6	A	885	850	702	25	23.4	97	4.0	–
	7	A	885	850	702	25	23.4	96	5.3	–
	8	A	885	850	702	25	23.4	96	5.3	–
	9	B	889	850	771	25	31.4	96	5.3	–
	10	B	889	850	595	25	18.4	96	5.3	–
	11	B	889	850	724	25	4.7	96	5.3	–
	12	B	889	850	721	25	25.3	96	5.3	Performed
	13	B	889	850	721	25	25.3	98	3.5	–
	14	C	891	850	765	25	30.4	97	4.0	Performed
	15	C	891	850	588	25	14.5	97	4.0	–
	16	C	891	850	684	25	4.3	97	4.0	–
	17	C	891	850	706	25	20.4	98	3.3	–
	18	C	891	850	706	25	20.4	97	4.0	Performed
	19	D	900	850	712	25	25.4	96	5.3	–
	20	E	890	850	718	25	24.8	96	5.3	–
	21	F	903	850	703	25	20.5	96	5.3	–
	22	G	948	850	702	25	21.6	96	5.3	–
	23	H	888	850	697	25	22.0	96	5.3	–
	24	A	885	850	702	25	23.4	97	4.0	–
	25	A	885	850	718	460	6.1	97	3.8	–

[Table 6]

No		Cold rolling		Final annealing			Metallographic structure				Wrinkle evaluation result	Formability
							Texture		Grain size			
		Total cold-rolling reduction (%)	Intermediate annealing	Annealing temperature (°C)	Annealing time (s)	Larson-Miller parameter P	X1+X2-X1&2	(X3+X4-X3&4)/(X1+X2-X1&2)	Average grain size (μm)	Coefficient of variation		Stretch-expanding height (mm)
Comparative Example	1	85	–	580	14400	20611	0.082	5.0	11.9	0.70	0.14	23.7
	2	85	–	580	14400	20611	0.078	5.0	12.2	0.67	0.15	23.6
	3	85	–	580	14400	20611	0.084	4.4	13.5	0.65	0.17	23.4
	4	80	–	580	14400	20611	0.076	4.3	12.0	0.81	0.17	23.6
	5	75	–	580	14400	20611	0.079	5.0	12.5	0.78	0.16	23.4
	6	80	Performed	580	14400	20611	0.076	4.3	12.7	0.79	0.17	23.2
	7	85	–	480	43200	18554	0.092	4.5	Recrystallization not completed	–	0.38	22.8
	8	85	–	505	3600	18330	0.082	4.5	Recrystallization not completed	–	0.42	22.7
	9	85	–	580	14400	20611	0.078	4.4	13.2	0.71	0.16	22.7
	10	85	–	580	14400	20611	0.076	4.7	13.6	0.69	0.14	22.8
	11	85	–	580	14400	20611	0.085	4.4	12.4	0.64	0.13	22.9
	12	85	–	580	14400	20611	0.076	4.3	13.5	0.76	0.13	22.0
	13	77	–	580	14400	20611	0.076	4.9	13.5	0.79	0.17	21.8
	14	80	–	580	14400	20611	0.079	4.4	10.3	0.81	0.17	22.5
	15	80	–	580	14400	20611	0.077	4.7	10.5	0.63	0.14	22.6
	16	80	–	580	14400	20611	0.082	4.4	10.5	0.72	0.14	22.4
	17	76	–	580	14400	20611	0.077	4.3	10.6	0.77	0.15	21.0
	18	80	–	580	14400	20611	0.078	4.9	10.3	0.79	0.15	20.3
	19	85	–	580	14400	20611	0.063	6.5	9.8	0.64	0.13	23.5
	20	85	–	580	14400	20611	0.057	7.2	8.7	0.68	0.17	23.2
	21	85	–	580	14400	20611	0.067	5.8	9.5	0.65	0.14	22.4
	22	85	–	580	14400	20611	0.068	6.1	8.9	0.68	0.16	21.8
	23	85	–	580	14400	20611	0.072	5.9	10.3	0.67	0.14	21.3
	24	–	–	580	14400	20611	0.170	2.5	10.5	0.66	0.15	–
	25	79	–	580	14400	20611	0.078	4.3	10.2	0.67	0.16	23.6

[0068] Examples 1 to 36 in Tables 3 and 4 are Inventive Examples. Examples 1 to 25 in Tables 5 and 6 are Comparative Examples that do not satisfy one or more of the requirements of the present invention. In Tables 2 to 6, numerical values outside the scope of the present invention or numerical values/items outside a preferred range of a manufacturing method are underlined.

[0069] In Inventive Examples 1 to 36, the chemical compositions and X1 + X2 - X1&2 were within the scope of the invention. These Inventive Examples were evaluated to be titanium plates having more excellent bulging formability in plane strain with TD as a major principal strain than conventional ones.

[0070] In Comparative Examples 1 to 18, 24, and 25 in Tables 5 and 6, X1 + X2 - X1&2 was outside the scope of the invention. This is presumed to be because the manufacturing methods of Comparative Examples 1 to 18, 24, and 25 were outside the preferred range of the present invention. In Comparative Examples 1 to 18 and 25, bulging formability in plane strain with TD as a major principal strain was inferior to that of the invention. In Comparative Example 24, since cold rolling was not performed and the sheet thickness was extremely large, the stretch-expanding height was not evaluated. However, since X1 + X2 - X1&2 of Comparative Example 24 was outside the scope of the invention, it is estimated that Comparative Example 24 had inferior plane strain formability as in other Comparative Examples.

[0071] Specifically, in the manufacture of Comparative Example 1, Comparative Example 9, and Comparative Example 14, the hot rolling finishing temperature was excessive.

[0072] In the manufacture of Comparative Example 2, Comparative Example 10, and Comparative Example 15, the hot rolling finishing temperature was insufficient.

[0073] In the manufacture of Comparative Example 3, Comparative Example 11, and Comparative Example 16, the average cooling rate from hot rolling finishing temperature to 300°C was insufficient.

[0074] In the manufacture of Comparative Example 4, Comparative Example 12, Comparative Example 14, and Comparative Example 18, annealing of hot rolled plate was performed.

[0075] In the manufacture of Comparative Example 5, Comparative Example 13, and Comparative Example 17, the final cold-rolling reduction was insufficient.

[0076] In the manufacture of Comparative Example 6, intermediate annealing was performed.

[0077] In the manufacture of Comparative Example 7, the annealing temperature in final annealing was insufficient.

[0078] In the manufacture of Comparative Example 8, the Larson-Miller parameter P was insufficient.

[0079] In the manufacture of Comparative Example 24, cold rolling was omitted.

[0080] In the manufacture of Comparative Example 25, the coiling temperature was excessive.

[0081] In Comparative Examples 19 to 23 in Tables 5 and 6, the chemical compositions were outside the scope of the invention. Comparative Examples 19 to 23 also failed in one or both of the wrinkle evaluation result and the stretch-expanding height.

Claims

1. A titanium plate comprising, as a chemical composition, in mass%,

O: 0.02% to 0.15%,
Fe: 0.02% to 0.20%,
N: 0 to 0.0800%,
C: 0 to 0.1000%, and
H: 0 to 0.0130%,
and a remainder including Ti and impurities,
wherein when a crystal orientation of an α phase is represented by an Euler angle g = (φ_1, Φ, φ_2), an area fraction of the α phase having a crystal orientation in which an absolute value of an orientation difference with respect to (0°, 90°, 0°) is within 30° is defined as X1, an area fraction of the α phase having a crystal orientation in which an absolute value of an orientation difference with respect to (0°, 90°, 30°) is within 30° is defined as X2, and an area fraction of the α phase having a crystal orientation in which absolute values of orientation differences with respect to both (0°, 90°, 0°) and (0°, 90°, 30°) are within 30° is defined as X1 &2,
X1 + X2 - X1&2 is 0.075 or less.

2. The titanium plate according to claim 1,

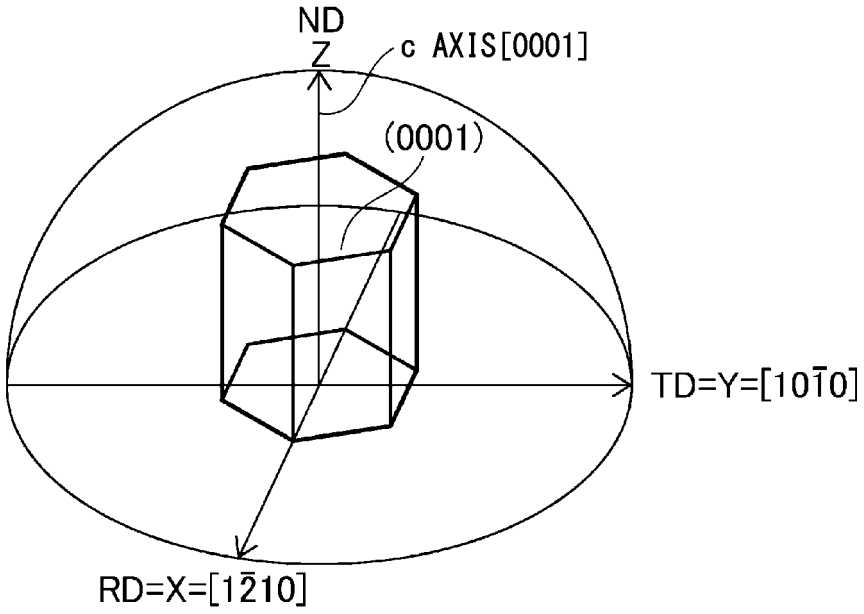
wherein when an area fraction of the α phase having a crystal orientation in which an absolute value of an orientation difference with respect to (0°, 35°, 0°) is within 15° is defined as X3,
an area fraction of the α phase having a crystal orientation in which an absolute value of an orientation difference with respect to (0°, 35°, 30°) is within 15° is defined as X4, and
an area fraction of the α phase having a crystal orientation in which absolute values of orientation differences with respect to both (0°, 35°, 0°) and (0°, 35°, 30°) are within 15° is defined as X3&4,
(X3 + X4 - X3&4)/(X1 + X2 - X1&2) is 5.0 or more.

3. The titanium plate according to claim 1 or 2, wherein an average grain size of the α phase is 70.0 μm or less.

4. The titanium plate according to claim 1 or 2, wherein an average grain size of the α phase is 20.0 μm or less.

5. The titanium plate according to any one of claims 1 to 4, wherein a coefficient of variation of a grain size of the α phase, which is a value obtained by dividing a standard deviation of the grain size of the α phase by an average grain size of the α phase, is 0.75 or less.

FIG. 1A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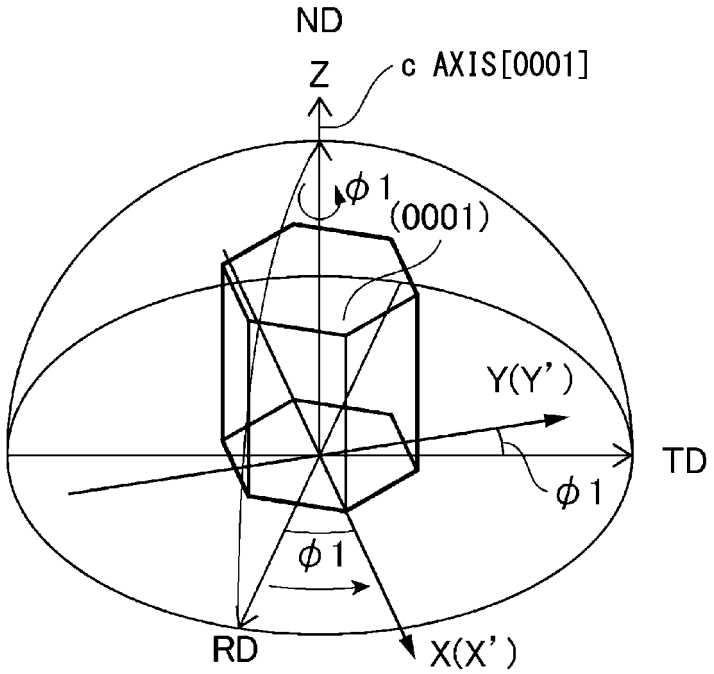
c AXIS[0001]
(0001)
TD=Y=[10$\bar{1}$0]
RD=X=[1$\bar{2}$10]

FIG. 1B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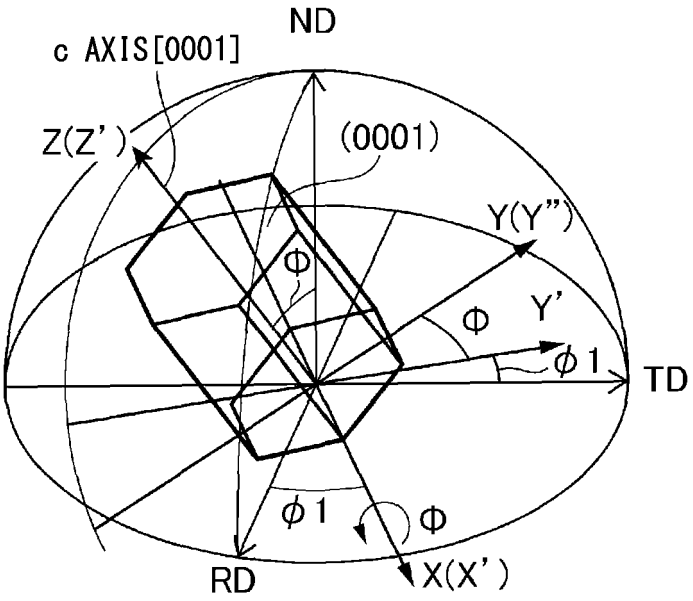
ϕ1
(0001)
Y(Y')
TD
ϕ1
ϕ1
RD
X(X')

FIG. 1C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(0001)
Y(Y")
Φ
Φ
Y'
ϕ1
TD
ϕ1
Φ
RD
X(X')

FIG. 1D

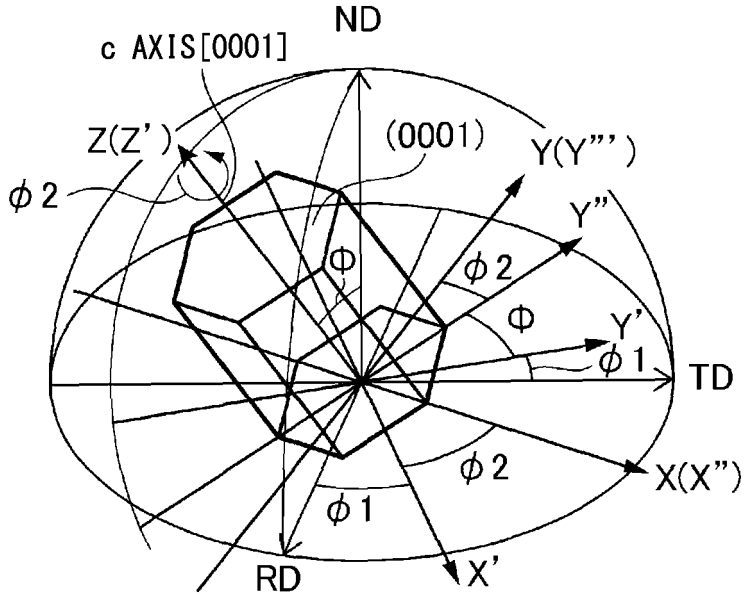
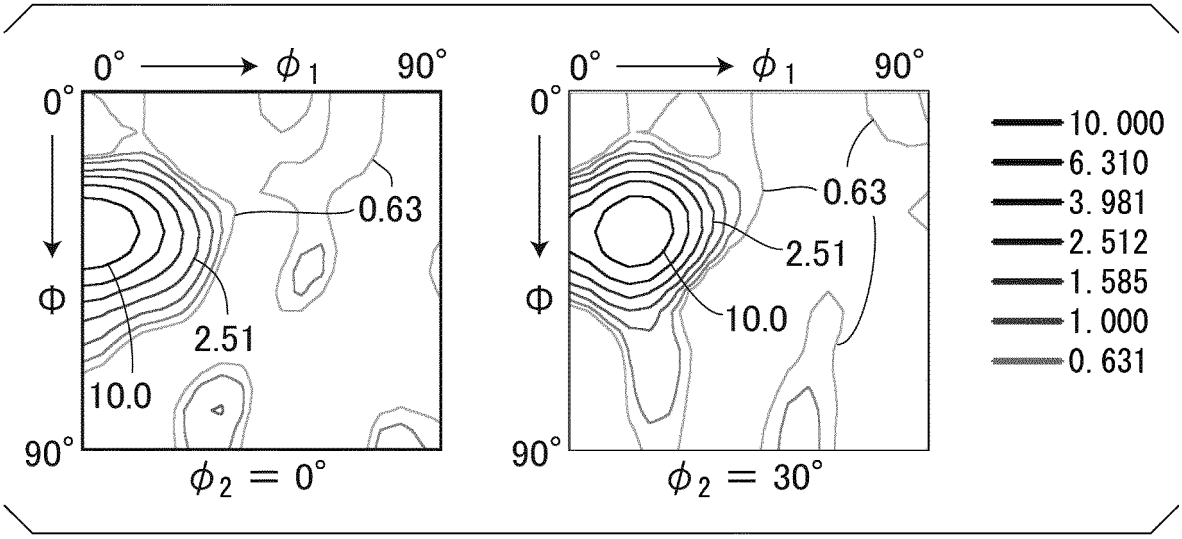

ND
c AXIS[0001]
Z(Z')
(0001)
Y(Y"')
ϕ2
Y"
Φ
ϕ2
Φ
Y'
ϕ1
TD
ϕ2
X(X")
ϕ1
RD
X'

FIG. 2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ϕ_1
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0°
Φ
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2.51
10.0
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10.000
6.310
3.981
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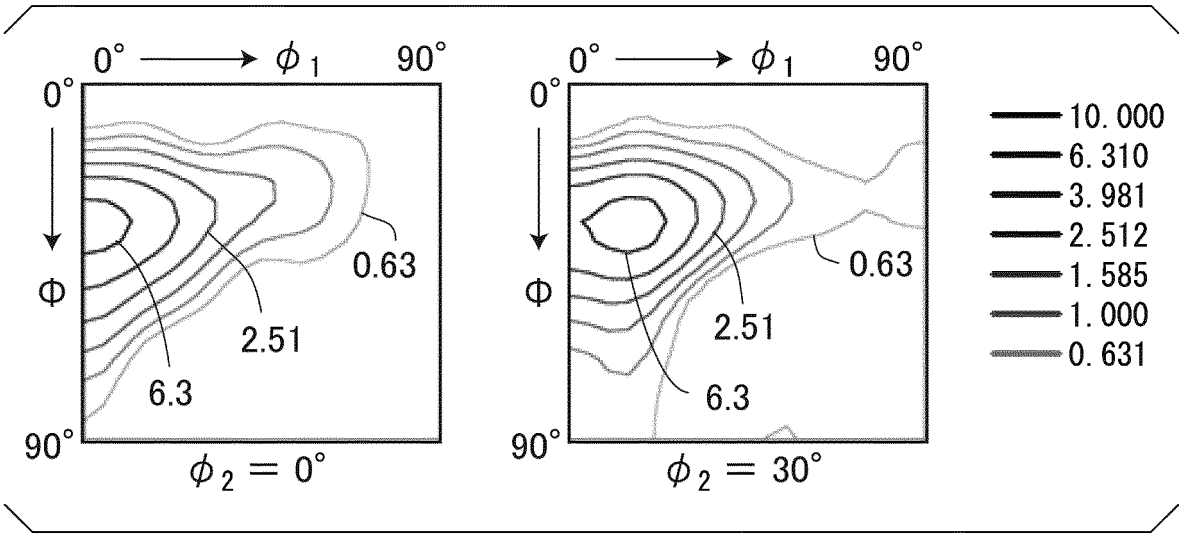
1.585
1.000
0.631

FIG. 3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ϕ_1
90°
0°
Φ
90°
0.63
2.51
6.3
$\phi_2 = 0°$
$\phi_2 = 30°$
10.000
6.310
3.981
2.512
1.585
1.000
0.631

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2021/041769

A. CLASSIFICATION OF SUBJECT MATTER

C22C 14/00(2006.01)i; *C22F 1/00*(2006.01)n; *C22F 1/18*(2006.01)n
FI: C22C14/00 Z; C22F1/18 H; C22F1/00 630K; C22F1/00 683; C22F1/00 685; C22F1/00 623; C22F1/00 694B; C22F1/00 694Z; C22F1/00 692A; C22F1/00 692B; C22F1/00 694A

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)

C22C14/00; C22F1/00; C22F1/18

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 2017/175569 A1 (KOBE STEEL LTD) 12 October 2017 (2017-10-12)	1-5
A	JP 2017-137561 A (KOBE STEEL LTD) 10 August 2017 (2017-08-10)	1-5
A	WO 2020/213713 A1 (NIPPON STEEL CORP) 22 October 2020 (2020-10-22)	1-5
A	JP 2013-181246 A (NIPPON STEEL & SUMITOMO METAL CORP) 12 September 2013 (2013-09-12)	1-5
A	JP 2004-285457 A (KOBE STEEL LTD) 14 October 2004 (2004-10-14)	1-5

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

* Special categories of cited documents:
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 January 2022	**25 January 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.

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

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2021/041769

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
WO 2017/175569 A1	12 October 2017	(Family: none)	
JP 2017-137561 A	10 August 2017	US 2018/0047996 A1	
		WO 2016/152935 A1	
		EP 3276017 A1	
		KR 10-2017-0117579 A	
		CN 107406917 A	
		RU 2017134929 A	
WO 2020/213713 A1	22 October 2020	CN 113710825 A	
		KR 10-2021-0138725 A	
		TW 202104609 A	
JP 2013-181246 A	12 September 2013	(Family: none)	
JP 2004-285457 A	14 October 2004	(Family: none)	

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

REFERENCES CITED IN THE DESCRIPTION

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- JP 2017226858 A **[0005]**