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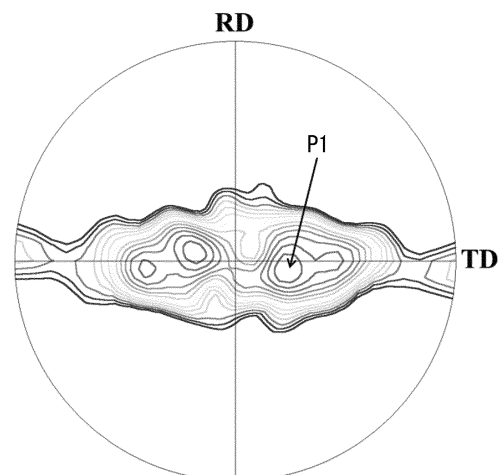
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(54) **TITANIUM ALLOY PLATE, TITANIUM ALLOY COIL, METHOD FOR PRODUCING TITANIUM ALLOY PLATE AND METHOD FOR PRODUCING TITANIUM ALLOY COIL**

(57) This titanium alloy sheet contains predetermined chemical components, an area ratio of an α -phase is 80% or more, an area ratio of the α -phase having an equivalent circle diameter of 1 μm or more is more than 53%, and in a (0001) pole figure in a sheet thickness direction, an angle formed between the sheet thickness direction and a direction indicating a peak of intensity calculated by texture analysis in a case in which a series rank is 16 and the Gaussian half width is 5° for an inverse pole figure using a spherical harmonics method of an electron backscatter diffraction method is 65° or less, and the average sheet thickness is 2.5 mm or less.

FIG. 1



Description

[Technical Field]

5 **[0001]** The present disclosure relates to a titanium alloy sheet, a titanium alloy coil, a method for manufacturing a titanium alloy sheet, and a method for manufacturing a titanium alloy coil.

[Background Art]

10 **[0002]** Titanium is a material that is lightweight and has high strength and excellent corrosion resistance, and a material that can be applied to the field of aircrafts from the viewpoint of reduction in weight and improvement in fuel efficiency. For that reason, titanium alloys have been actively developed in accordance with characteristics required for each of constituent members of aircrafts.

15 **[0003]** For example, Patent Document 1 discloses an $\alpha+\beta$ type titanium alloy wire containing 1.4% or more and less than 2.1% Fe, 4.4% or more and less than 5.5% Al, and a remainder of titanium and impurities.

[0004] Patent Document 2 discloses an $\alpha+\beta$ type titanium alloy bar containing 0.5% or more and less than 1.4% Fe, 4.4% or more and less than 5.5% Al, and a remainder of titanium and impurities.

20 **[0005]** Patent Document 3 discloses a method for manufacturing a Ti-6Al-4V alloy sheet by pack rolling characterized in that, in a method for manufacturing a sheet in which a pack-rolled material is formed by covering one or a plurality of sheet-shaped core materials with spacer materials and cover materials and the pack material is rolled to reduce thicknesses of the core materials, initial sheet thicknesses of each material are set by setting sheet thicknesses of the cover materials such that the ratio of the core materials to the pack material is at least 0.25 or more.

25 **[0006]** Patent Document 4 discloses a method for manufacturing a Ti-6Al-4V alloy sheet by pack rolling characterized in that, in a method for manufacturing a sheet in which a pack material is formed by covering one or more sheet-shaped core materials with spacer materials and cover materials, and the pack material is rolled to reduce the thicknesses of the core materials, the rolling rate per pass is set to 15% or more for rolling in which the sheet thickness reduction ratio between before and after reduction in thickness of the pack material is 3 or more.

30 **[0007]** Patent Document 5 discloses a method for manufacturing a titanium alloy sheet characterized in that a hot-rolled and annealed titanium alloy sheet containing, in weight percent, Al: 2.5 to 3.5%, V: 2.0 to 3.0%, and a remainder of Ti and ordinary impurities is cold-rolled in the same direction as a hot rolling direction at a total rolling rate of 67% or more, and then annealed at a temperature between 650 and 900°C.

35 **[0008]** Patent Document 6 discloses a method for manufacturing an $\alpha+\beta$ type titanium alloy sheet characterized by performing intermediate annealing after cold rolling in a manufacturing process of an $\alpha+\beta$ type titanium alloy cold-rolled sheet under conditions of an annealing temperature: a temperature range of [β transformation point-25°C] or higher and less than the β transformation point, an annealing time: 0.5 to 4 hours, a cooling rate after heating and holding: 0.5 to 5 °C/sec, and a temperature range for cooling at the above cooling rate: 300°C or lower.

40 **[0009]** Patent Document 7 discloses an $\alpha+\beta$ type titanium alloy sheet characterized by containing at least one complete solid-solution type β -stabilizing element at 2.0 to 4.5% by mass in Mo equivalent, at least one eutectoid-type β -stabilizing element at 0.3 to 2.0% by mass in Fe equivalent, at least one α -stabilizing element at more than 3.0% by mass and 5.5% by mass or less in Al equivalent, and a remainder of Ti and unavoidable impurities, in which the average grain size of an α -phase is 5.0 μm or less, the maximum grain size of the α -phase is 10.0 μm or less, the average aspect ratio of the α -phase is 2.0 or less, and the maximum aspect ratio of the α -phase is 5.0 or less.

45 **[0010]** Patent Document 8 discloses an $\alpha+\beta$ type titanium alloy sheet having excellent cold rolling properties and cold handling properties characterized in that an $\alpha+\beta$ type titanium alloy hot-rolled sheet is formed such that, when (a) a normal direction (a sheet thickness direction) of a hot-rolled sheet is defined as ND, a hot rolling direction is defined as RD, a width direction of the hot-rolled sheet is defined as TD, a normal direction of a (0001) plane of an α -phase is defined as a c axis orientation, an angle formed by the c axis orientation and ND is defined as θ , and an angle formed by a surface including the c axis orientation and ND and a surface including ND and TD is defined as Φ , (b1) the strongest intensity among (0002) reflection relative intensities of X-rays of crystal grains in which θ is 0 degrees or more and 30 degrees or less and Φ falls within the entire circumference (-180 degrees to 180 degrees) is defined as XND, and (b2) the strongest intensity among (0002) reflection relative intensities of X-rays of crystal grains in which θ is 80 degrees or more and less than 100 degrees and Φ falls within ± 10 degrees is defined as XTD, (c) XTD/XND is 5.0 or more.

50 **[0011]** Patent Document 9 discloses a high-strength $\alpha+\beta$ type titanium alloy sheet having excellent cold coil (strip) handling properties characterized in that a high-strength $\alpha+\beta$ type titanium alloy hot-rolled sheet containing, in % by mass, Fe: 0.8 to 1.5%, Al: 4.8 to 5.5%, and N: 0.030% or less, O and N in the range satisfying $Q(\%)=0.14$ to 0.38, which is defined by $Q(\%)=[O]+2.77\cdot[N]$ when the O content (% by mass) is defined as [O] and the N content (% by mass) is defined as [N], and the balance including Ti and unavoidable impurities is formed such that, when (a) the normal direction of a hot-rolled sheet is defined as ND, the hot rolling direction is defined as RD, the sheet width direction of the hot-rolled

sheet is defined as TD, the normal direction of a (0001) plane of an α -phase is defined as a c axis orientation, an angle formed by the c axis orientation and ND is defined as θ , and an angle formed by a surface including the c axis orientation and ND and a surface including ND and TD is defined as φ , (b1) the strongest intensity among (0002) reflection relative intensities of X-rays of crystal grains in which θ is 0 degrees or more and 30 degrees or less and φ falls within the entire circumference (-180 degrees to 180 degrees) is defined as XND, and (b2) the strongest intensity among (0002) reflection relative intensities of X-rays of crystal grains in which θ is 80 degrees or more and less than 100 degrees and φ falls within ± 10 degrees is defined as XTD, (c) XTD/XND is 4.0 or more.

[0012] Patent Document 10 discloses a method for manufacturing an $\alpha+\beta$ type titanium alloy sheet characterized in that an $\alpha+\beta$ type titanium alloy sheet manufactured by rolling or forging is cold-rolled with a rolling reduction of 20% or more and then annealed at a temperature of 700°C or higher and a β transformation point or lower, thereby obtaining a sheet having a fine equiaxed α structure.

[0013] Non-Patent Document 1 discloses an $\alpha+\beta$ titanium alloy sheet having anisotropy in strength in a rolling direction and in a direction perpendicular to the rolling direction.

[0014] Non-Patent Document 2 discloses an $\alpha+\beta$ titanium alloy sheet obtained by hot rolling at a temperature higher than a β transformation point to reduce anisotropy in strength in a rolling direction and in a direction perpendicular to the rolling direction.

[Citation List]

[Patent Document]

[0015]

[Patent Document 1]

Japanese Unexamined Patent Application, First Publication No. H07-62474

[Patent Document 2]

Japanese Unexamined Patent Application, First Publication No. H07-70676

[Patent Document 3]

Japanese Unexamined Patent Application, First Publication No. 2001-300603

[Patent Document 4]

Japanese Unexamined Patent Application, First Publication No. 2001-300604

[Patent Document 5]

Japanese Unexamined Patent Application, First Publication No. S61-147864

[Patent Document 6]

Japanese Unexamined Patent Application, First Publication No. H01-127653

[Patent Document 7]

Japanese Unexamined Patent Application, First Publication No. 2013-227618

[Patent Document 8]

PCT International Publication No. WO 2012/115242

[Patent Document 9]

PCT International Publication No. WO 2012/115243

[Patent Document 10]

Japanese Unexamined Patent Application, First Publication No. S62-33750

[Non-Patent Document]

[0016]

[Non-Patent Document 1]

KOBE STEEL ENGINEERING REPORTS/Vol. 59, No. 1 (2009), p. 81-84

[Non-Patent Document 2]

KOBE STEEL ENGINEERING REPORTS/Vol. 60, No. 2 (2010), p. 50-54

[Summary of the Invention]

[Problems to be Solved by the Invention]

[0017] Incidentally, titanium materials used for members requiring higher strength among constituent elements of

aircrafts contain a large amount of Al, but have a high deformation resistance in hot rolling or cold rolling, and thus an allowable load of a rolling mill may be exceeded in the case of manufacturing a sheet. For that reason, it is difficult to manufacture a high-strength titanium alloy sheet by known hot rolling methods or cold rolling methods.

[0018] The present disclosure has been made in view of the above problems, and an object of the present disclosure is to provide a titanium alloy sheet and a titanium alloy coil which have high strength, a method for manufacturing the same titanium alloy sheet, and a method for manufacturing the same titanium alloy coil.

[Means for Solving the Problem]

[0019] The present inventors have found that, when a titanium alloy sheet contains a predetermined amount of Al and has a texture in which there is a peak of intensity of crystal grains within a predetermined angle with respect to a width direction of final rolling in a (0001) pole figure in a sheet thickness direction, it has high strength and excellent workability. In addition, the present inventors have found a method for manufacturing the titanium alloy sheet by cold rolling, which can achieve such a chemical composition and texture at the same time, and reached the present disclosure.

[0020] The gist of the present disclosure completed on the basis of the above findings is as follows.

(1) A titanium alloy sheet according to an aspect of the present disclosure contains, in % by mass, Al: more than 4.0% and 6.6% or less, Fe: 0% or more and 2.3% or less, V: 0% or more and 4.5% or less, Si: 0% or more and 0.60% or less, C: 0% or more and less than 0.080%, N: 0% or more and 0.050% or less, O: 0% or more and 0.40% or less, Ni: 0% or more and less than 0.15%, Cr: 0% or more and less than 0.25%, Mn: 0% or more and less than 0.25%, and a remainder of Ti and impurities, in which the area ratio of an α -phase is 80% or more, the area ratio of an α -phase having an equivalent circle diameter of 1 μm or more is more than 53%, and in a (0001) pole figure in a sheet thickness direction, an angle formed between the sheet thickness direction and a direction indicating a peak of intensity calculated by texture analysis in a case in which a series rank is 16 and the Gaussian half width is 5° for an inverse pole figure using a spherical harmonics method of an electron backscatter diffraction method is 65° or less, and the average sheet thickness is 2.5 mm or less.

(2) The titanium alloy sheet according to the above (1) may have a microstructure including an equiaxed structure with an aspect ratio of 3.0 or less and a longitudinally elongated band structure with an aspect ratio of more than 3.0, in which the equiaxed structure may have an average grain size of 0.1 μm or more and 20.0 μm or less, and the area ratio of the band structure with respect to the area of the microstructure may be 10.0% or less.

(3) The titanium alloy sheet described in the above (1) or (2) may contain, in % by mass, either Fe: 0.5% or more and 2.3% or less or V: 2.5% or more and 4.5% or less.

(4) The titanium alloy sheet described in any one of the above (1) to (3) may contain, in % by mass, one element or two or more elements selected from the group including Ni: less than 0.15%, Cr: less than 0.25%, and Mn: less than 0.25% in place of a part of the Fe or the V.

(5) The titanium alloy sheet according to any one of the above (1) to (4), in which the smaller of a 0.2% proof stress in a longitudinal direction at 25°C and a 0.2% proof stress in a width direction at 25°C may be 700 MPa or more and 1200 MPa or less.

(6) The titanium alloy sheet according to any one of the above (1) to (5), in which, in a (0001) pole figure in a sheet thickness direction, an angle formed between a width direction and a direction indicating a peak of intensity calculated by texture analysis in a case in which a series rank is 16 and the Gaussian half width is 5° for an inverse pole figure using a spherical harmonics method of an electron backscatter diffraction method may be 10° or less, and a ratio of a 0.2% proof stress in the width direction to a 0.2% proof stress in a longitudinal direction may be 1.05 or more and 1.18 or less.

(7) The titanium alloy sheet according to any one of the above (1) to (5), in which, in a (0001) pole figure in a sheet thickness direction, an angle formed between the sheet thickness direction and a direction indicating a peak of intensity calculated by texture analysis in a case in which a series rank is 16 and the Gaussian half width is 5° for an inverse pole figure using a spherical harmonics method of an electron backscatter diffraction method is 35° or less, and a ratio of a 0.2% proof stress in a width direction to a 0.2% proof stress in a longitudinal direction is 0.85 or more and 1.10 or less.

(8) The titanium alloy sheet according to any one of the above (1) to (7), in which a dimensional accuracy of a sheet thickness may be 5.0% or less with respect to the average sheet thickness.

(9) A titanium alloy coil according to another aspect of the present disclosure contains, in % by mass, Al: more than 4.0% and 6.6% or less, Fe: 0% or more and 2.3% or less, V: 0% or more and 4.5% or less, Si: 0% or more and 0.60% or less, C: 0% or more and less than 0.080%, N: 0% or more and 0.050% or less, O: 0% or more and 0.40% or less, Ni: 0% or more and less than 0.15%, Cr: 0% or more and less than 0.25%, Mn: 0% or more and less than 0.25%, and a remainder of Ti and impurities, in which an area ratio of an α -phase is 80% or more, an area ratio of an α -phase having an equivalent circle diameter of 1 μm or more is more than 53%, and in a (0001) pole figure in

a sheet thickness direction, an angle formed between the sheet thickness direction and a direction indicating a peak of intensity calculated by texture analysis in a case in which a series rank is 16 and the Gaussian half width is 5° for an inverse pole figure using a spherical harmonics method of an electron backscatter diffraction method is 65° or less, and the average sheet thickness is 2.5 mm or less.

(10) A method for manufacturing a titanium alloy sheet according to another aspect of the present disclosure is a method for manufacturing the titanium alloy sheet according to any one of the above (1) to (8), including: a cold rolling process of performing one or more cold rolling passes in a longitudinal direction of a titanium material containing, in % by mass, Al: more than 4.0% and 6.6% or less, Fe: 0% or more and 2.3% or less, V: 0% or more and 4.5% or less, Si: 0% or more and 0.60% or less, C: 0% or more and less than 0.080%, N: 0% or more and 0.050% or less, O: 0% or more and 0.40% or less, Ni: 0% or more and less than 0.15%, Cr: 0% or more and less than 0.25%, Mn: 0% or more and less than 0.25%, and a remainder of Ti and impurities; and a final annealing process of annealing the titanium material after a final cold rolling pass, in which the rolling rate per cold rolling pass in the cold rolling process is more than 30%, and the total rolling rate is 60% or more.

(11) The method for manufacturing the titanium alloy sheet according to the above (10), in which the cold rolling process may include an intermediate annealing process of annealing the titanium material between a plurality of cold rolling passes in the case of performing the plurality of cold rolling passes, and annealing conditions for the intermediate annealing process and the final annealing process may be conditions in which the annealing temperature is 600°C or higher and (T_{β} -50)°C or lower, and the annealing temperature T (°C) and a holding time t (seconds) at the annealing temperature satisfy the following formula (1),

$$22000 \leq (T+273.15) \times (\log_{10}(t)+20) \leq 27000 \cdots \text{Formula (1)}$$

where, T_{β} is a β transformation point (°C).

(12) A method for manufacturing a titanium alloy sheet according to still another aspect of the present disclosure is a method for manufacturing the titanium alloy sheet according to any one of the above (1) to (8), including: a cold cross-rolling process of performing a cold rolling pass in a longitudinal direction and a width direction of a titanium material containing, in % by mass, Al: more than 4.0% and 6.6% or less, Fe: 0% or more and 2.3% or less, V: 0% or more and 4.5% or less, Si: 0% or more and 0.60% or less, C: 0% or more and less than 0.080%, N: 0% or more and 0.050% or less, O: 0% or more and 0.40% or less, Ni: 0% or more and less than 0.15%, Cr: 0% or more and less than 0.25%, Mn: 0% or more and less than 0.25%, and a remainder of Ti and impurities; and a final annealing process of annealing the titanium material after the cold cross-rolling process, in which the total rolling rate in the cold cross-rolling process is 60% or more, and a cross-rolling ratio, which is a ratio of a rolling rate in the longitudinal direction to a rolling rate in the width direction, is 0.05 or more and 20.00 or less.

(13) The method for manufacturing the titanium alloy sheet according to the above (12), in which the cold rolling process or the cold cross-rolling process may include an intermediate annealing process of annealing the titanium material between a plurality of cold rolling passes in the case of performing the plurality of cold rolling passes, and annealing conditions for the intermediate annealing process and the final annealing process may be conditions in which an annealing temperature is 600°C or higher and (T_{β} -50)°C or lower, and the annealing temperature T (°C) and a holding time t (seconds) at the annealing temperature satisfy the following formula (1),

$$22000 \leq (T+273.15) \times (\log_{10}(t)+20) \leq 27000 \cdots \text{Formula (1)}$$

where, T_{β} is a β transformation point (°C).

(14) A method for manufacturing a titanium alloy coil according to still another aspect of the present disclosure is a method for manufacturing the titanium alloy coil according to the above (9), including: a cold rolling process of performing one or more cold rolling passes in a longitudinal direction of a titanium material containing, in % by mass, Al: more than 4.0% and 6.6% or less, Fe: 0% or more and 2.3% or less, V: 0% or more and 4.5% or less, Si: 0% or more and 0.60% or less, C: 0% or more and less than 0.080%, N: 0% or more and 0.050% or less, O: 0% or more and 0.40% or less, Ni: 0% or more and less than 0.15%, Cr: 0% or more and less than 0.25%, Mn: 0% or more and less than 0.25%, and a remainder of Ti and impurities; and a final annealing process of annealing the titanium material after a final cold rolling pass, in which the rolling rate per cold rolling pass in the cold rolling process is more than 30%, and the total rolling rate is 60% or more.

[Effects of the Invention]

[0021] As described above, according to the present disclosure, it is possible to provide a titanium alloy sheet and a

titanium alloy coil which have high strength, a method for manufacturing the titanium alloy sheet, and a method for manufacturing the titanium alloy coil.

[Brief Description of Drawings]

[0022]

FIG. 1 is an example of a (0001) pole figure in a sheet thickness direction (ND) of a titanium alloy sheet according to an embodiment of the present disclosure.

FIG. 2 is a diagram showing an angle formed between a direction indicating a peak of intensity and a width direction thereof.

FIG. 3 is a diagram showing an example of an optical microscope photograph of the titanium alloy sheet according to the same embodiment.

FIG. 4 is an optical microscope photograph showing an example of a band structure.

FIG. 5 is a schematic diagram showing a method for measuring the average sheet thickness.

[Embodiment(s) for implementing the Invention]

[0023] Preferred embodiments of the present disclosure will be described in detail below with reference to the drawings. Also, the description is given in the following order.

1. Titanium alloy sheet
2. Method for manufacturing titanium alloy sheet

<1. Titanium alloy sheet>

[0024] First, a titanium alloy sheet according to the present embodiment will be described with reference to FIGS. 1 to 5. FIG. 1 is an example of a (0001) pole figure in a sheet thickness direction (ND) of the titanium alloy sheet according to the present embodiment. FIG. 2 is a diagram showing an angle formed between a direction indicating a peak of intensity and a width direction thereof. The (0001) pole figure in the sheet thickness direction (ND) in FIG. 2 is the same as in FIG. 1. FIG. 3 is a diagram showing an example of an optical microscope photograph of the titanium alloy sheet according to the present embodiment. FIG. 4 is an optical microscope photograph showing an example of a band structure. FIG. 5 is a schematic diagram showing a method for measuring the average sheet thickness. Also, although the details will be described later, the titanium alloy sheet according to the present embodiment can be manufactured by a method including a cold rolling process.

(1.1. Chemical composition)

[0025] First, chemical components contained in the titanium alloy sheet according to the present embodiment will be described. The titanium alloy sheet according to the present embodiment contains, in % by mass, Al: more than 4.0% and 6.6% or less, Fe: 0% or more and 2.3% or less, V: 0% or more and 4.5% or less, Si: 0% or more and 0.60% or less, C: 0% or more and less than 0.080%, N: 0% or more and 0.050% or less, O: 0% or more and 0.40% or less, Ni: 0% or more and less than 0.15%, Cr: 0% or more and less than 0.25%, Mn: 0% or more and less than 0.25%, and a remainder of Ti and impurities. Also, hereinafter, in the description of the chemical components, the notation "%" represents "% by mass" unless otherwise specified.

[0026] Al is an α -phase stabilizing element and an element with high solid-solution strengthening ability. When the Al content increases, tensile strength at room temperature increases. If the Al content is more than 4.0%, high tensile strength can be obtained. Further, a hot-rolled sheet before cold rolling can maintain high cold rolling properties. The Al content is preferably 4.5% or more and more preferably 4.6% or more. On the other hand, if the Al content is more than 6.6%, the cold rolling properties of the hot-rolled sheet before cold rolling significantly deteriorate, and a region in which Al is excessively dissolved is locally generated due to solidification segregation or the like, and thus Al is ordered. This Al-ordered region reduces impact toughness of the titanium alloy sheet. Accordingly, the Al content is 6.6% or less, preferably 6.5% or less, and more preferably 6.4% or less.

[0027] Fe is a β -phase stabilizing element. Fe is an element with high solid-solution strengthening ability, and thus when the Fe content increases, tensile strength at room temperature increases. In addition, a β -phase has higher workability than an α -phase, and thus when the Fe content increases, workability of the titanium alloy sheet improves, making it possible to improve dimensional accuracy. Since Fe is not essential in the titanium alloy sheet, a lower limit of its content is 0%. However, in order to obtain a desired tensile strength while maintaining the β -phase having good

workability at room temperature, the Fe content is preferably 0.5% or more. The Fe content is more preferably 0.7% or more. On the other hand, Fe is an element that is very prone to solidification segregation, and thus, when Fe is excessively contained, Fe segregates locally, which may cause variations in properties between a portion in which Fe is segregated and a portion in which Fe is not segregated. Further, when Fe is excessively contained in the titanium alloy sheet, fatigue strength may be lowered. Accordingly, the Fe content is preferably 2.3% or less. The Fe content is more preferably 2.1% or less, and still more preferably 2.0% or less. Also, Fe is less expensive than β -phase stabilizing elements such as V or Si or the like.

[0028] Fe that may be contained in the titanium alloy sheet according to the present embodiment may be replaced with V. V is a complete solid-solution type β -phase stabilizing element and an element with solid-solution strengthening ability. Since V is not essential in the titanium alloy sheet, a lower limit of its content is 0%. However, in order to obtain solid-solution strengthening ability equivalent to that of Fe described above, the V content is preferably 2.5% or more. The V content is more preferably 3.0% or more. Replacing Fe with V increases costs, but since V is less likely to segregate than Fe, variations in properties due to segregation are inhibited. As a result, it becomes easier to obtain stable properties in a longitudinal direction and a width direction of the titanium alloy sheet. In order to inhibit variations in properties due to V segregation, the V content is preferably 4.5% or less. As described above, since V is less likely to segregate than Fe, V is preferably contained in a titanium material in the case of manufacturing a large ingot.

[0029] Although Si is a β -phase stabilizing element, it also dissolves in the α -phase and exhibits high solid-solution strengthening ability. As described above, Fe may segregate when more than 2.3% thereof is contained in the titanium alloy sheet, and thus Si may be contained to increase strength of the titanium alloy sheet, if necessary. In addition, Si has a segregation tendency opposite to that of O described below, and is less likely to solidify and segregate than O, and thus, by including appropriate amounts of Si and O in the titanium alloy sheet, it can be expected to achieve both high fatigue strength and tensile strength. On the other hand, when the Si content is high, an intermetallic compound of Si called a silicide is formed, which may reduce fatigue strength of the titanium alloy sheet. If the Si content is 0.60% or less, generation of a coarse silicide is inhibited, and a decrease in fatigue strength is inhibited. Accordingly, the Si content is preferably 0.60% or less. The Si content is more preferably 0.50% or less, and still more preferably 0.40% or less. Since Si is not essential in the titanium alloy sheet, a lower limit of its content is 0%, but the Si content may be, for example, 0.10% or more.

[0030] When a larger amount of C is contained in the titanium alloy sheet, it may reduce ductility or workability of the titanium alloy sheet. Accordingly, the C content is preferably less than 0.080%. Since C is not essential in the titanium alloy sheet, a lower limit of its content is 0%. Also, C is an unavoidably incorporated substance, and its substantial content is usually 0.0001% or more. The C content is more preferably 0.060% or less.

[0031] Similarly to C, when a large amount of N is contained in the titanium alloy sheet, it may reduce ductility or workability of the titanium alloy sheet. Accordingly, an upper limit of the N content is preferably 0.050%. Since N is not essential in the titanium alloy sheet, a lower limit of its content is 0%. Also, N is an unavoidably incorporated substance, and its substantial content is usually 0.0001% or more. The N content is more preferably 0.04% or less.

[0032] Similarly to C, when a large amount of O is contained in the titanium alloy sheet, it may reduce ductility or workability of the titanium alloy sheet. Accordingly, an upper limit of the O content is preferably 0.40%, more preferably 0.38%, and still more preferably 0.35%. Since O is not essential in the titanium alloy sheet, a lower limit of its content is 0%. Also, O is an unavoidably incorporated substance, and its substantial content is usually 0.01% or more.

[0033] Similarly to Fe or V, Ni is an element that improves tensile strength and workability. However, when the Ni content is 0.15% or more, an intermetallic compound Ti_2Ni , which is an equilibrium phase, is generated, which may deteriorate fatigue strength and room temperature ductility of the titanium alloy sheet. Accordingly, the Ni content is preferably less than 0.15%. The Ni content is more preferably 0.14% or less, or 0.12% or less, and still more preferably 0.11% or less. Since Ni is not essential in the titanium alloy sheet, a lower limit of its content is 0%, but the Ni content may be, for example, 0.01% or more.

[0034] Similarly to Fe or V, Cr is an element that improves tensile strength and workability. However, when the Cr content is 0.25% or more, an intermetallic compound $TiCr_2$, which is an equilibrium phase, is generated, which may deteriorate fatigue strength and room temperature ductility of the titanium alloy sheet. Accordingly, the Cr content is preferably less than 0.25%. The Cr content is more preferably 0.24% or less, or 0.21% or less. Since Cr is not essential in the titanium alloy sheet, a lower limit of its content is 0%, but the Cr content may be, for example, 0.01% or more.

[0035] Similarly to Fe or V, Mn is an element that improves tensile strength and workability. However, when the Mn content is 0.25% or more, an intermetallic compound $TiMn$, which is an equilibrium phase, is generated, which may deteriorate fatigue strength and room temperature ductility of the titanium alloy sheet. Accordingly, the Mn content is preferably less than 0.25%. The Mn content is more preferably 0.24% or less, and still more preferably 0.20% or less. Since Mn is not essential in the titanium alloy sheet, a lower limit of its content is 0%, but the Mn content may be, for example, 0.01% or more.

[0036] Considering the effects of the chemical components mentioned above, the titanium alloy sheet according to the present embodiment contains, as optional elements, either Fe: 0.5 to 2.3% or V: 2.5 to 4.5%, and Si: 0 to 0.60%,

and preferably contains C: less than 0.080%, N: 0.050% or less, and O: 0.40% or less.

[0037] Also, considering the effects of the chemical components mentioned above, in a case in which the titanium alloy sheet according to the present embodiment contains either Fe: 0.5 to 2.3% or V: 2.5 to 4.5%, it preferably contains one element or two or more elements selected from the group including Ni: less than 0.15%, Cr: less than 0.25%, and Mn: less than 0.25% in place of a part of Fe or V.

[0038] In a case in which the titanium alloy sheet according to the present embodiment contains Fe, when it contains one element or two or more elements selected from the group including Ni: less than 0.15%, Cr: less than 0.25%, and Mn: less than 0.25%, the total amount of Fe, Ni, Cr, and Mn is preferably 0.5% or more and 2.3% or less. If the total amount of Fe, Ni, Cr, and Mn is 0.5% or more, high tensile strength is obtained. In addition, if the total amount of Fe, Ni, Cr, and Mn is 0.5% or more, the β -phase having good workability at room temperature is maintained to improve workability of the titanium alloy sheet, and thus it is possible to improve dimensional accuracy. Further, if the total amount of Fe, Ni, Cr, and Mn is 2.3% or less, segregation of these elements is inhibited, which makes it possible to inhibit variations in properties of the titanium alloy sheet.

[0039] Also, in a case in which the titanium alloy sheet according to the present embodiment contains V, when it contains one element or two or more elements selected from the group including Ni: less than 0.15%, Cr: less than 0.25%, and Mn: less than 0.25%, the total amount of V, Ni, Cr, and Mn is preferably 2.5% or more and 4.5% or less. If the total amount of V, Ni, Cr, and Mn is 2.5% or more, high tensile strength is obtained. In addition, if the total amount of V, Ni, Cr, and Mn is 2.5% or more, the β -phase having good workability at room temperature is maintained to improve the workability of the titanium alloy sheet, and thus it is possible to improve dimensional accuracy. Further, if the total amount of V, Ni, Cr, and Mn is 4.5% or less, segregation of these elements is inhibited, which makes it possible to inhibit variations in the properties of the titanium alloy sheet.

[0040] The balance of the chemical composition of the titanium alloy sheet according to the present embodiment may be Ti and impurities. The impurities include, for example, H, Cl, Na, Mg, Ca, and B that are mixed in during a refining process and Zr, Sn, Mo, Nb, Ta, and Cu that are mixed from scraps or the like. If the total amount of the impurities is 0.5% or less, it is a level of not causing problems. Also, the H content is 150 ppm or less. There is a risk that B may form coarse precipitates in an ingot. For that reason, even in a case in which B is contained as an impurity, it is preferable to inhibit the B content as much as possible. In the titanium alloy sheet according to the present embodiment, the B content is preferably 0.01% or less.

[0041] In addition, in a case in which the titanium alloy sheet according to the present embodiment contains 0.5 to 2.3% of Fe, V contained in the titanium alloy sheet may be contained in an amount considered as an impurity, and in a case in which the titanium alloy sheet according to the present embodiment contains 2.5 to 4.5% of V, Fe contained in the titanium alloy sheet may be contained in an amount considered as an impurity.

[0042] Further, needless to say, the titanium alloy sheet according to the present embodiment may contain various elements instead of Ti as long as it has high strength and excellent dimensional accuracy can be obtained. Similarly, for the elements provided as exemplary impurities, if the titanium alloy sheet has high strength and excellent dimensional accuracy, it may contain more than the amount considered as an impurity.

[0043] As described above, the titanium alloy sheet according to the present embodiment can have the above chemical components. More specifically, the chemical composition of the titanium alloy sheet according to the present embodiment may be, for example, Ti-6Al-4V, Ti-6Al-4V ELI, or Ti-5Al-1Fe.

(1.2. Texture and microstructure)

[0044] Next, a texture and a microstructure of the titanium alloy sheet according to the present embodiment will be described.

[Texture]

[0045] The titanium alloy sheet according to the present embodiment has a texture in which, in a (0001) pole figure in the sheet thickness direction, an angle formed between the sheet thickness direction and a direction indicating a peak of intensity calculated by texture analysis in a case in which a series rank is 16 and the Gaussian half width is 5° for an inverse pole figure using a spherical harmonics method of an electron backscatter diffraction (EBSD) method is 65° or less. In general, when a titanium alloy is subjected to high speed hot rolling in one direction at a temperature in a β region or in an $\alpha+\beta$ high temperature region with a high proportion of the β -phase, a texture (T-texture) in which a c axis of a hexagonal close-packed (hcp) structure is oriented in a width direction perpendicular to a longitudinal direction on a rolled surface according to variant selection rules is formed during phase transformation from the β -phase to the α -phase. In the texture in which the c axis of hcp is oriented in the width direction, large anisotropy occurs in tensile properties in the width direction and the longitudinal direction. If there is a large anisotropy in the tensile properties between the width direction and the longitudinal direction, problems may occur during processing. The direction indicating

the peak of intensity calculated by texture analysis of the inverse pole figure using the spherical harmonics method of the EBSD method (a series rank=16, and Gauss half width=5°) corresponds to a direction in which the c axis of hcp is most oriented. In the titanium alloy sheet according to the present embodiment, in the (0001) pole figure in the sheet thickness direction, the angle formed between the direction in which the c axis of hcp is most oriented (the direction indicating the peak of intensity) and the sheet thickness direction is 65° or less, which makes it possible to reduce the anisotropy, ensure high workability, and improve the dimensional accuracy. In the (0001) pole figure in the sheet thickness direction, the angle formed between the direction in which the c axis of hcp is most oriented and the sheet thickness direction is preferably 60° or less, more preferably 55° or less, and still more preferably 35° or less. The lower limit of the angle formed between the direction in which the c axis of hcp is most oriented and the sheet thickness direction is not particularly limited, but is 0° or more. In a case in which the titanium alloy sheet is manufactured by rolling in one direction, the lower limit of the angle formed between the direction in which the c axis of hcp is most oriented and the sheet thickness direction is 20° or more.

[0046] In addition, when cold rolling is performed in one direction with respect to the angle formed between the direction indicating the peak of intensity and the sheet thickness direction, the texture in which the c axis of hcp axes may be tilted in the width direction (TD) (a split-TD type texture). The split-TD type texture is excellent in moldability, particularly in bendability. Accordingly, the angle formed between the direction indicating the peak of intensity and the sheet thickness direction is preferably 20° or more and 65° or less, which is the split-TD type texture.

[0047] The (0001) pole figure is obtained by chemically polishing an observation surface of a sample of the titanium alloy sheet and analyzing its crystallographic orientation using EBSD. Specifically, a cross-section (an L cross-section) obtained by cutting the titanium alloy sheet in the sheet thickness direction along the longitudinal direction at a central position in the width direction (TD) is chemically polished, and crystallographic orientation analysis is performed by the EBSD method at 2 to 10 locations at intervals of 1 to 2 μm in a region of (total sheet thickness)×2 mm of the cross-section, so that the (0001) pole figure can be drawn. Peak position data of intensity of a specific orientation in the (0001) pole figure is calculated by the texture analysis of the inverse pole figure using the spherical harmonics method using OIM Analysis™ software (Ver.8.1.0) manufactured by TSL Solutions. In this case, the peak position of intensity is a position of the highest contour line, and a value of the highest intensity at the peak position is defined as the maximum intensity. In addition, an intensity of a specific orientation in the (0001) pole figure indicates how many times a frequency of presence of crystal grains having that orientation is with respect to a structure having a completely random orientation distribution (an intensity of the structure is 1). Also, in the above, the L cross-section at the central position in the width direction is set to the observation surface, but a crystallographic orientation of the titanium alloy sheet is uniformly distributed in the width direction, and thus an L cross-section at an arbitrary sheet width position may be set to the observation surface.

[0048] FIG. 1 shows an example of the (0001) pole figure in the sheet thickness direction (ND) of the titanium alloy sheet according to the present embodiment. In FIG. 1, detected poles of each crystallographic orientation are accumulated in accordance with inclinations in a final rolling direction (RD) and a final rolling width direction (TD), and contour lines of intensity are drawn in the (0001) pole figure. In addition, a peak P1 of crystal grains is located at the highest contour line in the figure. Accordingly, in the present embodiment, the angle formed between the direction indicating the peak P1 of the crystal grains and ND is 65° or less. Normally, the maximum intensity is the intensity of the peak P1 of the crystal grains.

[0049] Also, in the titanium alloy sheet according to the present embodiment, in the (0001) pole figure in the sheet thickness direction, the angle formed between the width direction and the direction indicating the peak of intensity calculated by the texture analysis in the case in which a series rank is 16 and the Gaussian half width is 5° for the inverse pole figure using the spherical harmonics method of the electron backscatter diffraction method may be 10° or less. As shown in FIG. 2, the angle formed between the direction indicating the peak of intensity and the width direction is an angle θ2 formed between the width direction (TD) and a direction from a center of the (0001) pole figure in the sheet thickness direction to a position indicating the peak of intensity. From the viewpoint of manufacturing and a method for observing the structure, the angle is preferably 5° or less, and more preferably 3° or less.

[0050] Further, in the titanium alloy sheet according to the present embodiment, in the (0001) pole figure in the sheet thickness direction, the angle formed between the sheet thickness direction and the direction indicating the peak of intensity calculated by the texture analysis in the case in which a series rank is 16 and the Gaussian half width is 5° for the inverse pole figure using the spherical harmonics method of the electron backscatter diffraction method may be 35° or less.

[Microstructure]

[0051] In the titanium alloy sheet according to the present embodiment, an area ratio of the α-phase is 80% or more. The titanium alloy sheet according to the present embodiment contains a large amount of the α-stabilizing element in order to increase the strength. For that reason, when an amount of addition of the β-stabilizing element is further increased,

the strength becomes too high, and thus manufacturing by cold rolling becomes impossible. Accordingly, in the titanium alloy sheet according to the present embodiment, the area ratio of the α -phase is 80% or more. The area ratio of the α -phase may be, for example, 82% or more. The upper limit of the area ratio of the α -phase is not particularly limited, and the area ratio of the α -phase may be, for example, 100% or less, or 98% or less. A structure of the titanium alloy sheet according to the present embodiment includes the α -phase and the balance structure, and the balance structure contains the β -phase, TiFe, Ti₃Al, and a silicide.

[0052] In the titanium alloy sheet according to the present embodiment, the area ratio of the α -phase having an equivalent circle diameter of 1 μm or more is more than 53%. When the area ratio of the α -phase having an equivalent circle diameter of 1 μm or less is high, ductility at room temperature may be poor, and thus the area ratio of the α -phase having an equivalent circle diameter of 1 μm or more is more than 53%. The area ratio of the α -phase having the diameter of 1 μm or more may be 55% or more, or may be 60% or more. An upper limit of the area ratio of the α -phase having an equivalent circle diameter of 1 μm or more is not particularly limited, and the area ratio of the α -phase having an equivalent circle diameter of 1 μm or more may be, for example, 98% or less. The microstructure of the titanium alloy sheet according to the present embodiment is, for example, as shown in FIG. 3. The upper limit of the equivalent circle diameter of the α -phase is not particularly limited, and the equivalent circle diameter of the α -phase is, for example, 20 μm or less.

[0053] The area ratio of the α -phase and the area ratio of the α -phase having an equivalent circle diameter of 1 μm or more are measured by the following method. The cross-section (L cross-section) obtained by cutting the titanium alloy sheet in the thickness direction along the longitudinal direction at the central position in the width direction (TD) is chemically polished, and the crystallographic orientation analysis is performed by the EBSD method for the region of (total sheet thickness) $\times$ 200 μm in the cross-section while targeting about 2 to 5 fields of view at steps of 1 to 5 μm . The α -phase is identified through the crystallographic orientation analysis by this EBSD. An area ratio of the α -phase to an area of the region is defined as the area ratio of the α -phase. In addition, the equivalent circle diameter of the α -phase observed in the above fields of view (area $A = \pi \times (\text{grain size } D/2)^2$) is calculated, and the total area of the α -phase having an equivalent circle diameter of 1 μm or more with respect to the area of the above region is defined as the area ratio of the α -phase having an equivalent circle diameter of 1 μm or more. Crystal grains of the α -phase having an equivalent circle diameter of 1 μm or more include a band structure, which will be described later. Also, in the above, the area ratio of the α -phase and the area ratio of the α -phase having an equivalent circle diameter of 1 μm or more are measured on the basis of the L cross-section at the central position in the width direction, but the α -phase is uniformly distributed in the width direction, and thus the area ratio of the α -phase and the area ratio of the α -phase having an equivalent circle diameter of 1 μm or more may be measured on the basis of the L cross-section at an arbitrary sheet width position.

[0054] The titanium alloy sheet according to the present embodiment has a microstructure including an equiaxed structure with an aspect ratio of 3.0 or less and a longitudinally elongated band structure with an aspect ratio of more than 3.0, in which the average grain size of the equiaxed structure is 0.1 μm or more and 20.0 μm or less, and the area ratio of the band structure to an area of the microstructure is preferably 10.0% or less. Each structure will be described below.

[0055] When a titanium alloy is hot-rolled at a temperature in an $\alpha + \beta$ range or a β range, it may form a structure called a "band structure" as shown in FIG. 4. The band structure mentioned here is, for example, a longitudinally elongated structure as shown in FIG. 4. Specifically, the band structure indicates crystal grains having an aspect ratio of more than 3.0, which is represented by the major axis/minor axis of a crystal grain. The titanium alloy sheet according to the present embodiment may have a longitudinally elongated band structure. Formation of the band structure may cause strength anisotropy or defects during molding. For that reason, it is preferable that the band structure be as small as possible. The area ratio of the band structure to the area of the microstructure is preferably 10.0% or less. The area ratio of the band structure is more preferably 8.0% or less. On the other hand, since it is better not to have this band structure, its lower limit is 0%.

[0056] The aspect ratio and the area ratio of the band structure can be calculated as follows. The cross-section (L cross-section) obtained by cutting the titanium alloy sheet in the sheet thickness direction along the longitudinal direction at the central position in the width direction (TD) is chemically polished, and the crystallographic orientation analysis is performed by the EBSD method for the region of (total sheet thickness) $\times$ 200 μm in the cross-section while targeting about 2 to 5 fields of view at steps of 1 to 5 μm . From results of the crystallographic orientation analysis by this EBSD, the aspect ratio is calculated for each crystal grain. After that, the area ratio of crystal grains with an aspect ratio exceeding 3.0 is calculated. Also, in the above, the aspect ratio and the area ratio of the band structure are calculated on the basis of the L cross-section at the central position in the width direction, but the band structure is uniformly distributed in the width direction, and thus the aspect ratio and the area ratio of the band structure may be calculated on the basis of the L cross-section at an arbitrary sheet width position.

[0057] The balance of the microstructure other than the band structure is preferably an equiaxed structure formed by recrystallization. From the viewpoint of moldability, the titanium alloy sheet preferably has the equiaxed structure, and in particular, the titanium alloy sheet preferably has fine grains because it may be formed by utilizing its superplasticity.

From the viewpoint of moldability and superplasticity, the average grain size of the equiaxed structure is preferably 20.0 μm or less. The average grain size of the equiaxed structure is more preferably 15.0 μm or less, still more preferably 10.0 μm or less, and even more preferably 8.0 μm or less. On the other hand, when the average grain size of the equiaxed structure is less than 0.5 μm , the strength may become too large due to a grain refinement effect, and the ductility may be significantly lowered. As a result, in particular, cold (room temperature) workability may deteriorate. For that reason, the average grain size of the equiaxed structure is preferably 0.5 μm or more. The average grain size of the equiaxed structure is more preferably 1.0 μm or more.

[0058] Also, more than 80% of the equiaxed structure and the band structure are α -phases, and there are β -phases between the α -phases.

[0059] Presence or absence of recrystallized grains can be determined by measuring aspect ratios (ratios of the major axis/minor axis) of crystal grains. If the aspect ratio is 3.0 or less, the grain can be determined to be a recrystallized grain. Also, the lower limit of the aspect ratio of the equiaxed structure is 1.0.

[0060] The average grain size of the equiaxed structure can be calculated as follows. An equivalent circle grain size (area $A = \pi \times (\text{grain size } D/2)^2$) of the equiaxed structure is obtained from a grain area measured by EBSD, and a number-based average value thereof is set to the average grain size of the equiaxed structure.

(1.3. 0.2% proof stress)

[0061] The smaller of a 0.2% proof stress in the longitudinal direction at 25°C and a 0.2% proof stress in the width direction at 25°C of the titanium alloy sheet according to the present embodiment is preferably 700 MPa or more. In the following, the smaller of the 0.2% proof stress in the longitudinal direction and the 0.2% proof stress in the width direction is simply referred to as a 0.2% proof stress. In the field of aircrafts or the like, tensile strength close to the tensile strength at 25°C of Ti-6Al-4V, which is a generalpurpose $\alpha+\beta$ type titanium alloy, is often required. If the 0.2% proof stress of the titanium alloy sheet is 700 MPa or more, it can be used for applications requiring high strength. The 0.2% proof stress at 25°C of the titanium alloy sheet is more preferably 730 MPa or more. On the other hand, if strength is too high, strength of a hot-rolled sheet before cold rolling is also high, and thus the hot-rolled sheet is less likely to be cold-rolled, which may cause a plurality of cold rolling passes and an increase in cost. In addition, if the strength is too high, notch sensitivity increases, and thus sheet fracture may occur. Accordingly, the 0.2% proof stress at 25°C of the titanium alloy sheet is preferably 1200 MPa or less. The 0.2% proof stress at 25°C of the titanium alloy sheet is more preferably 1150 MPa or less. Further, if the 0.2% proof stress at 25°C of the titanium alloy sheet is 1000 MPa or less, cracks during rolling are further inhibited, and thus the 0.2% proof stress at 25°C of the titanium alloy sheet is even more preferably 1100 MPa or less. The 0.2% proof stress can be measured by a method based on JIS Z2241:2011. That is, the 0.2% proof stress in the longitudinal direction and the 0.2% proof stress in the width direction can be measured by a method based on JIS Z2241:2011. Also, the longitudinal direction mentioned here is the final rolling direction. For those skilled in the art, the final rolling direction is easy to identify and the final rolling direction is obvious.

(1.4. Anisotropy)

[0062] In the titanium alloy sheet according to the present embodiment, a proof stress ratio σ_T/σ_L , which is a ratio of a 0.2% proof stress σ_T in the width direction at 25°C to a 0.2% proof stress σ_L in the longitudinal direction at 25°C is preferably 0.85 or more and 1.18 or less. Since $\alpha+\beta$ type titanium has an hcp-phase (α -phase) as described above, it exhibits higher anisotropy in a hcp direction. As described above, since the anisotropy increases when the T-texture is formed, it is sometimes desired to reduce the anisotropy as much as possible, especially in the field of aircrafts. Accordingly, it is better for the proof stress ratio σ_T/σ_L to be closer to 1.00, but if the proof stress ratio σ_T/σ_L is 1.18 or less, it is possible to obtain better moldability. The proof stress ratio σ_T/σ_L is more preferably 1.16 or less, even more preferably 1.15 or less, and still more preferably 1.14 or less. In the case of performing cold cross-rolling, in which cold rolling is performed in the longitudinal direction and the width direction, the proof stress ratio σ_T/σ_L can be set to 0.85 or more and 1.10 or less. The proof stress ratio σ_T/σ_L of the titanium alloy sheet manufactured by cold cross-rolling is preferably 0.90 or more, and more preferably 0.95 or more. Further, the proof stress ratio σ_T/σ_L of the titanium alloy sheet manufactured by cold cross-rolling is preferably 1.05 or less. In the case of cold rolling in one direction in the longitudinal direction, it is difficult to make the proof stress ratio σ_T/σ_L less than 1.05, and it is possible to set it to 1.05 or more. Also, since the titanium alloy sheet having a proof stress ratio σ_T/σ_L of greater than 1.18 can be manufactured by cold rolling in one direction, σ_T/σ_L may be greater than 1.18.

(1.5. Average sheet thickness)

[0063] The average sheet thickness of the titanium alloy sheet according to the present embodiment is 2.5 mm or less. For example, the average sheet thickness of the titanium alloy sheet can be reduced to 2.5 mm or less by using

the titanium material containing the above chemical components by a method for manufacturing the titanium alloy sheet, which will be described later. A titanium material having an Al content of more than 4.0% and 6.6% or less has large deformation resistance, and thus in a general rolling mill, an allowable load of the rolling mill may be exceeded when a sheet is manufactured. For that reason, it is difficult to manufacture the titanium alloy sheet containing the above chemical components and having a sheet thickness of 2.5 mm or less. In addition, in the case of performing hot rolling without using pack rolling, when a sheet thickness decreases, a temperature drops sharply, and thus deformation resistance increases. Thus, in the case of hot rolling a high-strength material, the allowable load of the rolling mill may be exceeded, and it is difficult to reduce the average sheet thickness to 2.5 mm or less. On the other hand, there is no particular lower limit for the average sheet thickness of the titanium alloy sheet according to the present embodiment, but in reality, the titanium alloy having the above strength often has an average sheet thickness of 0.1 mm or more. For that reason, the average sheet thickness of the titanium alloy sheet according to the present embodiment is preferably 0.1 mm or more. The thickness of the titanium alloy sheet according to the present embodiment is preferably 2.0 mm or less, and more preferably 1.5 mm or less. Also, the average sheet thickness of the titanium alloy sheet according to the present embodiment is more preferably 0.2 mm or more.

[0064] Here, a method for measuring the average sheet thickness will be described with reference to FIG. 5. Sheet thicknesses at each of the central position in the width direction (TD) and positions at a distance of 1/4 of a sheet width from both ends in the width direction are measured at five or more locations at intervals of 1 m or more in the longitudinal direction using X-rays, a micrometer, or a vernier caliper, and the average value of the measured sheet thicknesses is set to the average sheet thickness.

(1.6. Sheet thickness dimensional accuracy)

[0065] Dimensional accuracy of the sheet thickness of the titanium alloy sheet according to the present embodiment (hereinafter, the dimensional accuracy of the sheet thickness may be simply referred to as sheet thickness dimensional accuracy) is preferably 5.0% or less with respect to the average sheet thickness. In pack rolling, a titanium alloy sheet is manufactured by hot rolling titanium materials that are laminated in multiple layers and wrapped by steel materials, but deformation resistance of the titanium materials laminated in multiple layers varies greatly depending on a temperature distribution, and thus it is difficult to manufacture a sheet with a uniform sheet thickness. However, since the titanium alloy sheet according to the present embodiment is manufactured through the cold rolling, which will be described later, it becomes a titanium alloy sheet having excellent sheet thickness dimensional accuracy. The dimensional accuracy of the titanium alloy sheet according to the present embodiment is more preferably 4.0% or less with respect to the average sheet thickness, and even more preferably 2.0% or less with respect to the average sheet thickness.

[0066] The sheet thickness dimensional accuracy is measured by the following method. The sheet thicknesses at each of the central position in the width direction (TD) and the positions at a distance of 1/4 of the sheet width from both ends in the width direction are measured at five or more locations at intervals of 1 m or more in the longitudinal direction using X-rays, a micrometer, or a vernier caliper. The maximum value of a' calculated by the following formula (101) using an actually measured sheet thickness d and the average sheet thickness d_{ave} is defined as the sheet thickness dimensional accuracy a .

$$a' = (d - d_{ave}) / d_{ave} \times 100 \cdots \text{Formula (101)}$$

[0067] The titanium alloy sheet according to the present embodiment has been described above. Since the titanium alloy sheet according to the present embodiment has the above chemical components and metal structure, it has high strength. The titanium alloy sheet according to the present embodiment described above may be manufactured by any method and can also be manufactured, for example, by a method for manufacturing the titanium alloy sheet according to the present embodiment described below.

<2. Method for manufacturing titanium alloy sheet>

[0068] The method for manufacturing the titanium alloy sheet according to the present embodiment includes: a slab manufacturing process of manufacturing a titanium alloy slab; a hot rolling process of hot rolling the titanium alloy slab; a cold rolling process of cold rolling the titanium material after the hot rolling process; and a temper rolling or tension levelling process of temper rolling or tension levelling the titanium material after the cold rolling process depending on needs. Each process of the method for manufacturing the titanium alloy sheet according to the present embodiment will be described below. In the cold rolling process, cold rolling in one direction in which the titanium material after the hot rolling process is subjected to one or more cold rolling passes only in the longitudinal direction, or cold cross-rolling in which the titanium material is subjected to cold rolling passes in the longitudinal direction and the width direction is

performed. In the following, as a first manufacturing method, a case in which the titanium material after the hot rolling process is subjected to the cold rolling in one direction in the cold rolling process will be described, and as a second manufacturing method, a case in which the titanium material after the hot rolling process is subjected to the cold cross-rolling will be described.

[First manufacturing method]

(2.1. Slab manufacturing process)

[0069] In the slab manufacturing process, the titanium alloy slab is manufactured. The method for manufacturing the titanium alloy slab is not particularly limited, and for example, it can be manufactured according to the following procedure. First, an ingot is produced from sponge titanium by various melting methods such as a vacuum arc melting method, an electron beam melting method, a hearth melting method such as a plasma melting method, and the like. Next, the titanium alloy slab can be obtained by hot forging the obtained ingot at a temperature in a α -phase high-temperature range, an $\alpha+\beta$ two-phase range, or a β -phase single phase range. In addition, the titanium alloy slab may be subjected to pretreatment such as cleaning treatment and cutting, if necessary. Also, in a case in which it is formed into a rectangular shape that can be hot-rolled by the hearth melting method, it may be subjected to hot rolling without performing hot forging or the like. The manufactured titanium alloy slab contains, in % by mass, Al: more than 4.0% and 6.6% or less, Fe: 0% or more and 2.3% or less, V: 0% or more and 4.5% or less, Si: 0% or more and 0.60% or less, C: 0% or more and less than 0.080%, N: 0% or more and 0.050% or less, and O: 0% or more and 0.40% or less, Ni: 0% or more and less than 0.15%, Cr: 0% or more and less than 0.25%, and Mn: 0% or more and less than 0.25%.

(2.2. Hot rolling process)

[0070] In the hot rolling process, the titanium alloy slab is heated and then hot-rolled. For example, the titanium alloy slab may be heated to a temperature range equal to or higher than a β transformation point T_{β} °C, and then rolled such that the total rolling reduction is 80% or higher. However, when hot rolling is started at a temperature below an $\alpha+\beta$ phase temperature range, cracks may occur in the titanium alloy slab, or the metal structure described above may not be obtained even if cracks do not occur. For that reason, in the present process, hot rolling is started from a β -phase temperature range. In addition, a finishing temperature, which is a temperature immediately after the hot rolling, is in the $\alpha+\beta$ phase temperature range and varies depending on a composition of the titanium alloy slab, but it may be set to, for example, $(T_{\beta}-250)^{\circ}\text{C}$ or higher and $(T_{\beta}-50)^{\circ}\text{C}$ or lower, and hot rolling may be performed such that the rolling reduction is the above rolling reduction in one hot rolling, or may be performed multiple times to achieve the above rolling reduction. The titanium material after the present hot rolling process contains, in % by mass, Al: more than 4.0% and 6.6% or less, Fe: 0% or more and 2.3% or less, V: 0% or more and 4.5% or less, Si: 0% or more and 0.60% or less, C: 0% or more and less than 0.080%, N: 0% or more and 0.050% or less, O: 0% or more and 0.40% or less, Ni: 0% or more and less than 0.15%, Cr: 0% or more and less than 0.25%, and Mn: 0% or more and less than 0.25%.

[0071] Also, in the present specification, the " β transformation point" is a boundary temperature at which an α -phase begins to form when a titanium alloy is cooled from a β -phase single phase range. The β transformation point 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. Specifically, the phase diagram of the titanium alloy is obtained by the CALPHAD method using Thermo-Calc, which is an integrated thermodynamic calculation system manufactured by Thermo-Calc Software AB, and a predetermined database (T13), so that the β transformation point can be calculated.

[0072] In the hot rolling process, the titanium alloy slab can be continuously hot-rolled using known continuous hot rolling equipment. In the case of using continuous hot rolling equipment, the titanium alloy slab is hot-rolled and then coiled by a coiling machine to form a titanium alloy hot-rolled coil. Accordingly, the titanium material after the hot rolling process includes a sheet-shaped titanium material and a coil-shaped titanium material more elongated than the sheet-shaped titanium material.

[0073] The titanium material after the hot rolling process may be subjected to annealing by a known method, removal of oxide scale and the like by pickling or cutting, or cleaning treatment and the like, if necessary. For example, the titanium material after the hot rolling process is annealed at a temperature of 650°C or higher and 800°C or lower for a time of 20 minutes or longer and 90 minutes or shorter. Thus, nonrecrystallized grains of the hot-rolled sheet can be precipitated as fine recrystallized grains, and crystals in the metal structure of the finally obtained titanium alloy sheet can be made more uniform and finer. Also, the annealing may be performed in an air atmosphere, an inert atmosphere, or a vacuum atmosphere.

[0074] In addition, in the method for manufacturing the titanium alloy sheet described above, the titanium material after the hot rolling process corresponds to the titanium material according to the present disclosure.

(2.3. Cold rolling process)

[0075] In the present process, the titanium material after the hot rolling process is subjected to one or more cold rolling passes in the longitudinal direction. A rolling rate per cold rolling pass in the cold rolling process is more than 30%, and the total rolling rate is 60% or more. The present cold rolling process causes the c axis of hcp to approach the ND. However, in a case in which the rolling rate per cold rolling pass and the total rolling rate are too small, the crystallographic orientation hardly changes, and the angle formed between the direction indicating the peak of intensity and the sheet thickness direction does not become 65° or less. In this case, anisotropy of the titanium alloy sheet is not improved. Also, the band structure described above is formed by hot rolling, but when the cold rolling rate per cold rolling pass and the total cold rolling rate in the cold rolling after the hot rolling are small, the band structure remains in the titanium material without being destroyed. Accordingly, the rolling rate per cold rolling pass in the cold rolling process is more than 30%, and the total rolling rate is 60% or more. The total rolling rate is preferably 70% or more.

[0076] Also, a cold rolling pass mentioned here indicates continuously performed cold rolling. Specifically, a cold rolling pass indicates cold rolling from after the hot rolling process until the titanium material reaches a final product thickness or from after the hot rolling process to before a temper rolling process, which will be described later, in the case of performing the temper rolling process after the hot rolling process. However, in the case of performing intermediate annealing treatment in the cold rolling process, cold rolling from after the hot rolling process to the intermediate annealing treatment and cold rolling from the intermediate annealing treatment until the titanium material reaches the final product thickness or to before the temper rolling process are respectively called a cold rolling pass. Further, in the case of performing the intermediate annealing treatment a plurality of times, cold rolling from the previous intermediate annealing treatment to the subsequent intermediate annealing treatment is also called a cold rolling pass. Also, the rolling rate of each cold rolling mill may be any rate as long as the rolling rate per pass is more than 30%.

[0077] In the present cold rolling process, it is possible to reduce manufacturing costs by rolling an elongated hot-rolled sheet or a titanium material that is a hot-rolled coil elongated in the rolling direction.

[0078] A cold rolling temperature is preferably 500°C or lower. If the cold rolling temperature is 500°C or lower, high dimensional accuracy can be obtained, and crystal grains are refined during cold rolling, making it easier to develop superplasticity. The cold rolling temperature is more preferably 400°C or lower. The lower limit of the cold rolling temperature is not particularly limited, and the cold rolling temperature can be, for example, room temperature or higher. The room temperature here is intended to 0°C or higher.

[Intermediate annealing process]

[0079] In the case of performing the cold rolling passes a plurality of times, the cold rolling process preferably includes an intermediate annealing process for annealing the titanium material between the plurality of cold rolling passes. In the intermediate annealing process, an intermediate material in the cold rolling process is preferably annealed such that an annealing temperature T is 600°C or higher and $(T_{\beta}-50)^{\circ}\text{C}$ or lower, and an annealing temperature T (°C) and a holding time t (seconds) at the annealing temperature T satisfy the following formula (102). In addition, $(T+273.15)\times(\text{Log}_{10}(t)+20)$ in the following formula (102) is a Larson-Miller parameter.

$$22000 \leq (T+273.15) \times (\text{Log}_{10}(t)+20) \leq 27000 \quad \cdots \text{Formula (102)}$$

[0080] Here, T_{β} is the β transformation point (°C).

[Final annealing process]

[0081] A final annealing process is a process of annealing the titanium material after a final cold rolling pass. Annealing conditions in the final annealing process are not particularly limited, but in order to improve moldability of the titanium alloy sheet, an annealing temperature T is 600°C or higher and $(T_{\beta}-50)^{\circ}\text{C}$ or lower, and an annealing temperature T (°C) and a holding time t (seconds) at the annealing temperature T preferably satisfy the above formula (102).

[0082] By performing the intermediate annealing process and the final annealing process under the above conditions, uncrystallized grains are recrystallized and the c axis of the α -phase approaches the ND direction. This makes it possible to reduce anisotropy of the titanium alloy sheet. Also, an excessive amount of the band structure in the microstructure is eliminated due to the recrystallization. On the other hand, when the annealing temperature is equal to or higher than the β transformation point T_{β} , phase transformation from the β -phase to the α -phase occurs, and the resulting α -phase has an acicular structure. In addition, even if the annealing temperature is just below the β transformation point, a bimodal structure in which the equiaxed structure and the acicular structure are mixed is formed. Acicular and bimodal structures may cause internal cracks and edge cracks during cold rolling. Further, the acicular or bimodal structure often has coarse

grains, making it difficult to develop superplasticity. In the intermediate annealing process and the final annealing process, by determining the annealing temperature T and the annealing time t such that the annealing temperature T is 600°C or higher and $(T_{\beta}-50)^{\circ}\text{C}$ or lower, and the annealing temperature T and the annealing time t satisfy the above formula (102), the c axis of the α -phase is caused to approach the ND direction due to the recrystallization, so that the anisotropy of the titanium alloy sheet can be further reduced and the band structure in the microstructure can be further reduced. Furthermore, in the intermediate annealing process and the final annealing process, by determining the annealing temperature T and the annealing time t such that the annealing temperature T is 600°C or higher and $(T_{\beta}-50)^{\circ}\text{C}$ or lower, and the annealing temperature T and the annealing time t satisfy the above formula (102), fine equiaxed structures are increased, and thus internal cracks and edge cracks are inhibited during cold rolling, and superplasticity tends to be exhibited.

(2.4. Temper rolling or tension levelling process)

[0083] The titanium alloy sheet is manufactured through the above cold rolling process, but the titanium alloy sheet after the cold rolling process is preferably subjected to temper rolling for adjusting mechanical properties or tension levelling for correcting its shape, if necessary. The rolling reduction in the temper rolling is preferably 10% or less, and the elongation in the tension levelling is preferably 5% or less. Also, the temper rolling and the tension levelling may not be performed if unnecessary.

[0084] According to the first manufacturing method, in the cold rolling process of cold rolling the hot-rolled sheet manufactured using the material of the titanium alloy sheet in the longitudinal direction one or more times, the rolling rate per pass in the cold rolling is more than 30% and the total rolling rate is 60% or more, so that the titanium alloy sheet can be obtained in which, in the (0001) pole figure in the sheet thickness direction, the angle formed between the sheet thickness direction and the direction indicating the peak of intensity calculated by the texture analysis in the case in which a series rank is 16 and the Gaussian half width is 5° for the inverse pole figure using the spherical harmonics method of the EBSD method is 65° or less. In addition, according to the first manufacturing method, the average sheet thickness of the titanium alloy sheet can be set to 2.5 mm or less, and the dimensional accuracy of the sheet thickness can be set to 5.0% or less with respect to the average sheet thickness.

[0085] Also, according to the first manufacturing method, the metal structure of the titanium alloy sheet has the microstructure including the equiaxed structure with an aspect ratio of 3.0 or less and the longitudinally elongated band structure with an aspect ratio of more than 3.0, the average grain size of the equiaxed structure is $0.1\text{ }\mu\text{m}$ or more and $20.0\text{ }\mu\text{m}$ or less, and the area ratio of the band structure to the area of the microstructure is 10.0% or less. Thus, the anisotropy of the titanium alloy sheet is further reduced.

[0086] In addition, according to the first manufacturing method, the ratio of the 0.2% proof stress in the width direction to the 0.2% proof stress in the longitudinal direction can be set to 1.05 or more and 1.18 or less.

[0087] Also, according to the first manufacturing method, due to the cold rolling, the crystal grains become finer, making it easier to exhibit superplasticity, and thus the titanium alloy sheet has excellent workability in molding a sheet.

[0088] According to the method for manufacturing the titanium alloy sheet according to the present embodiment, since it includes the unidirectional cold rolling process, it is possible to manufacture elongated titanium alloy sheets and titanium alloy coils. Accordingly, the above manufacturing method can also be said to be a method for manufacturing a titanium alloy coil. Thus, needless to say, the titanium alloy coil manufactured by the above manufacturing method has the same features as the titanium alloy sheet of the present disclosure. Specifically, the titanium alloy coil of the present disclosure contains, in % by mass, Al: more than 4.0% and 6.6% or less, Fe: 0% or more and 2.3% or less, V: 0% or more and 4.5% or less, Si: 0% or more and 0.60% or less, C: 0% or more and less than 0.080%, N: 0% or more and 0.050% or less, O: 0% or more and 0.40% or less, Ni: 0% or more and less than 0.15%, Cr: 0% or more and less than 0.25%, Mn: 0% or more and less than 0.25%, and a remainder of Ti and impurities, in which the area ratio of the α -phase is 80% or more, the area ratio of the α -phase having an equivalent circle diameter of $1\text{ }\mu\text{m}$ or more is more than 53%, and in the (0001) pole figure in the sheet thickness direction, the angle formed between the sheet thickness direction and the direction indicating the peak of intensity calculated by the texture analysis in the case in which a series rank is 16 and the Gaussian half width is 5° for the inverse pole figure using the spherical harmonics method of the electron backscatter diffraction method is 65° or less, and the average sheet thickness is 2.5 mm or less.

[0089] Also, in the case of manufacturing the titanium alloy coil, the "longitudinal direction" corresponds to a longitudinal direction of the titanium alloy coil, and the "width direction" corresponds to a direction perpendicular to a longitudinal direction of a rolled surface of the titanium alloy coil.

[0090] As described above, the first manufacturing method has been explained.

[Second manufacturing method]

[0091] Next, a second manufacturing method will be explained. The second manufacturing method is different in the

cold rolling process from the first manufacturing method, and other processes are the same as those of the first manufacturing method. For that reason, the cold rolling process will be described in detail here, and description of other processes will be omitted.

[0092] The cold rolling process in the second manufacturing method is a cold cross-rolling process in which the titanium material after the hot rolling process is subjected to cold rolling passes in the longitudinal direction and the width direction.

[0093] The total rolling rate including both rolling in the longitudinal direction and rolling in the width direction in the present process is 60% or more. A final rolling direction in the present process is the longitudinal direction, and a direction orthogonal to the longitudinal direction is the width direction. If the total rolling rate is 60% or more, the c axis of hcp is more oriented in the ND direction, so that the titanium alloy sheet with small anisotropy can be manufactured. As the rolling rate increases, the c axis of the α -phase of the titanium alloy sheet approaches the sheet thickness direction and intensity increases, and thus an upper limit of the rolling rate is not restricted.

[0094] A cross-rolling ratio is not particularly limited and is, for example, 0.05 or more and 20.00 or less. The cross-rolling ratio mentioned here indicates a rolling rate in the longitudinal direction to a rolling rate in the width direction (longitudinal rolling rate/widthwise rolling rate) performed until the sheet thickness reaches a target thickness from 4 mm. If the cross-rolling ratio is 0.05 or more and 20.00 or less, the c axis of hcp is more oriented toward ND, and the sheet with small anisotropy can be manufactured. In addition, it is possible to reduce excessively generated band structures. The cross-rolling ratio is more preferably 0.07 or more and 15.00 or less.

[0095] A rolling rate per cold rolling pass is not particularly limited as long as the total rolling rate is 60% or more. Here, one cold rolling pass indicates cold rolling in the longitudinal direction or cold rolling in the width direction continuously performed on the hot-rolled sheet. Accordingly, in the present cold cross-rolling process, in a case in which each of the cold rolling in the longitudinal direction and the cold rolling in the width direction is performed a plurality of times for the hot-rolled sheet, the total number of times is the number of cold rolling passes. For example, in the case of performing the cold rolling in the longitudinal direction once and the cold rolling in the width direction once for the hot-rolled sheet, the number of cold rolling passes is two. In the second manufacturing method, the rolling in the longitudinal direction or rolling in the width direction may be performed a plurality of times. Also, even if the sheet thickness is 4 mm or less, reheating or the like may be performed. Further, hot rolling in the width direction may be performed whenever hot rolling in the longitudinal direction is performed once or several times.

[0096] Also, the rolling in the width direction may be performed at any timing.

[0097] The rolling rate per cold rolling pass is not particularly limited and can be, for example, 5% or more. The rolling rate per cold rolling pass is preferably 10% or more, more preferably 20% or more. Also, the rolling rate per cold rolling pass may be 80% or less, or may be 75% or less.

[0098] A rolling temperature in the cold cross-rolling process is preferably 500°C or lower. If the rolling temperature is 500°C or lower, high dimensional accuracy can be obtained, and crystal grains are refined during rolling. The rolling temperature is more preferably 400°C or lower. The lower limit of the cold rolling temperature is not particularly limited, and the cold rolling temperature can be, for example, room temperature or higher. The room temperature here is intended to 0°C or higher.

[0099] According to the second manufacturing method, the titanium alloy sheet can be obtained in which, in the (0001) pole figure in the sheet thickness direction, the angle formed between the sheet thickness direction and the direction indicating the peak of intensity calculated by the texture analysis in the case in which a series rank is 16 and the Gaussian half width is 5° for the inverse pole figure using the spherical harmonics method of the electron backscatter diffraction method is 35° or less, and the ratio of the 0.2% proof stress in the width direction to the 0.2% proof stress in the longitudinal direction is 0.85 or more and 1.10 or less. By performing the rolling passes in the longitudinal direction and the rolling passes in the width direction a plurality of times, it is possible to bring the ratio of the 0.2% proof stress in the width direction to the 0.2% proof stress in the longitudinal direction closer to 1.00.

[0100] Also, in a case in which the titanium material contains a large amount of β -phase stabilizing elements such as V, when high speed hot rolling in one direction is performed at a temperature in the β range or the $\alpha+\beta$ high temperature range with a high proportion of the β -phase, the T-texture is easily formed, and the anisotropy of the titanium alloy sheet tends to increase. However, according to the second manufacturing method, since the cold cross-rolling is performed, formation of the T-texture is inhibited even in the case in which the titanium material contains the β -phase stabilizing elements such as V. As a result, the titanium alloy sheet with small anisotropy can be manufactured.

[0101] In addition, according to the second manufacturing method, the metal structure of the titanium alloy sheet has the microstructure including the equiaxed structure with an aspect ratio of 3.0 or less and the longitudinally elongated band structure with an aspect ratio of more than 3.0, the average grain size of the equiaxed structure is 0.1 μm or more and 20.0 μm or less, and the area ratio of the band structure to the area of the microstructure is 10.0% or less. Thus, the anisotropy of the titanium alloy sheet is further reduced.

[Examples]

[0102] Embodiments of the present disclosure will be specifically described below with reference to examples. Also, the examples shown below are merely examples of the present disclosure, and the present disclosure is not limited to the following examples.

(Example 1)

1. Manufacturing titanium alloy sheet

[0103] First, a titanium alloy ingot serving as a material for titanium alloy sheets having the chemical components shown in Table 1 was manufactured by any one of vacuum arc remelting (VAR), electron beam remelting (EBR), and plasma arc melting (PAM), and 150 mm thick×800 mm wide×5000 mm long titanium alloy slabs were then manufactured by blooming or forging. After that, these titanium alloy slabs were subjected to hot rolling, hot-rolled sheet annealing, shot blasting, and pickling to obtain hot-rolled sheets having a thickness of 4 mm. In the hot rolling, the titanium alloy slabs were heated to 1050 to 1100°C so that the temperature is equal to or higher than the β transformation point T_{β} to start the hot rolling from that temperature, and the finishing temperature was adjusted to 800 to 950°C to be the β transformation point T_{β} or lower. Also, elements other than those listed in Table 1 are Ti and impurities.

[0104] Regarding chemical components of hot-rolled sheets, Al, Fe, Si, Ni, Cr, Mn, and V were measured by ICP emission spectrometry. O and N were measured by inert gas fusion, thermal conductivity and infrared absorption methods using an oxygen and nitrogen simultaneous analyzer. C was measured by an infrared absorption method using a carbon-sulfur simultaneous analyzer. Chemical components of each of the manufactured hot-rolled sheets were the same as the chemical components of the titanium alloy slabs shown in Table 1. In addition, for each of the titanium materials A to P shown in Table 1, a phase diagram of a titanium alloy was obtained by the CALPHAD method using Thermo-Calc, which is an integrated thermodynamic calculation system manufactured by Thermo-Calc Software AB, and a predetermined database (Tl3) to calculate the β transformation point T_{β} .

[Table 1]

Material	Chemical components (% by mass) (a remainder of Ti and impurities.)									
	Al	Fe	Si	Ni	Cr	Mn	V	C	N	O
A	4.8	1.0	-	-	-	-	-	0.007	0.009	0.12
B	5.3	1.1	-	-	-	-	-	0.008	0.007	0.18
c	6.1	1.1	-	-	-	-	-	0.007	0.005	0.16
D	5.1	2.0	-	-	-	-	-	0.015	0.005	0.15
E	5.2	1.5	0.25	-	-	-	-	0.007	0.008	0.15
F	4.9	0.9	0.20	-	-	-	-	0.008	0.007	0.13
G	5.3	0.9	-	0.14	-	-	-	0.005	0.007	0.15
H	4.6	0.7	-	-	0.24	-	-	0.006	0.015	0.15
I	5.1	0.8	-	-	-	0.24	-	0.008	0.008	0.15
J	5.1	0.8	-	0.11	0.21	-	-	0.007	0.008	0.17
K	5.1	1.2	-	-	-	-	-	0.007	0.008	0.25
L	5.1	0.9	-	-	-	-	-	0.007	0.008	0.35
M	6.2	-	-	-	-	-	4.1	0.007	0.008	0.17
N	<u>3.0</u>	-	-	-	-	-	2.5	0.007	0.008	0.19
O	5.9	0.2	-	-	-	-	2.5	0.007	0.008	0.17
P	<u>7.5</u>	1.1	-	-	-	-	-	0.007	0.008	0.15

[0105] Next, the obtained hot-rolled sheet was cold-rolled under the conditions shown in Table 2. Inventive Examples 1 to 18, 30, and Comparative Example 3 in Table 2 are examples obtained by repeating cold rolling at a rolling rate per

cold rolling pass of 35 to 60% and intermediate annealing under the conditions shown in Table 2, and performing cold rolling until the total rolling rate reaches 70 to 94%. Inventive Example 19 is an example obtained by repeating cold rolling at a rolling rate per cold rolling pass of 35% and intermediate annealing under the conditions shown in Table 2, and performing cold rolling until the total rolling rate reaches 60%. Inventive Example 20 is an example obtained by performing cold rolling at a cold rolling temperature of 300°C. Inventive Example 21 is an example obtained by repeating cold rolling at a rolling rate per cold rolling pass of 40% and intermediate annealing under the conditions shown in Table 2, and performing cold rolling until the total rolling rate reaches 78%. The intermediate annealing process in Inventive Example 21 is an example of not satisfying the above formula (102). Inventive Examples 22 and 23 are examples obtained by performing cold rolling respectively at rolling rates of 75% and 60% without intermediate annealing. Inventive Examples 24 to 26 are examples obtained by performing cold rolling at a rolling rate in a first cold rolling pass of 75%, then performing intermediate annealing under the conditions shown in Table 2, and subsequently performing cold rolling at a rolling rate in a second cold rolling pass of 50%, thereby adjusting the total rolling rate to 88%. Inventive Examples 27 to 29 are examples obtained by performing cold rolling at a rolling rate in the first cold rolling pass of 50%, then performing a first intermediate annealing under the conditions shown in Table 2, performing cold rolling at a rolling rate in the second cold rolling pass of 50%, performing a second intermediate annealing under the conditions shown in Table 2 after the second cold rolling pass, and performing cold rolling at a rolling rate in a third cold rolling pass of 60%, thereby adjusting the total rolling rate to 90%. The reference example is a hot-rolled sheet that was not subjected to the cold rolling process. Comparative Example 1 is an example in which a rolling rate per pass is 20% and the total rolling rate is 59%. Comparative Example 2 is an example in which the total rolling rate is 50%. In Comparative Example 4 using a titanium material O with a high Al content, surface cracks and severe edge cracks occurred during cold rolling after hot rolling. For that reason, in Comparative Example 4, intermediate annealing and final annealing were not performed. Also, in Table 2, " T_{β} " is the β transformation point, and "Larson-Miller parameter" is the value of $(T+273.15) \times (\log_{10}(t)+20)$. Further, "Pattern A" in Table 2 indicates a cold rolling pattern in which cold rolling was performed at a rolling rate in the first cold rolling pass of 75% and a rolling rate in the second cold rolling pass of 50%. "Pattern B" in Table 2 indicates a cold rolling pattern in which cold rolling was performed at a rolling rate in the first cold rolling pass of 50%, a rolling rate in the second cold rolling pass of 50%, and a rolling rate in the third cold rolling pass of 60%.

[Table 2]

No	Material		Cold rolling process							Final annealing			
	Composition	T_{β} (°C)	Rolling temperature (°C)	Rolling rate per pass (%)	Intermediate annealing			Total rolling rate (%)	Annealing temperature T (°C)	Holding time t (s)	Larson- Miller parameter	Holding time t (s)	Larson- Miller parameter
					Annealing temperature T (°C)	Holding time t (s)	Larson- Miller parameter						
Inventive Example 1	A	1003	25	50	850	60	24460	75	900	120	25902	120	25902
Inventive Example 2	B	1024	25	50	800	60	23371	75	850	240	25136	240	25136
Inventive Example 3	C	1033	25	50	850	60	24460	75	930	120	26565	120	26565
Inventive Example 4	D	994	25	50	850	60	24460	75	850	120	24798	120	24798
Inventive Example 5	E	1009	25	50	900	60	25549	75	900	120	25902	120	25902
Inventive Example 6	F	1008	25	50	850	60	24460	75	900	120	25902	120	25902
Inventive Example 7	G	1016	25	50	850	60	24460	75	680	28800	23313	28800	23313
Inventive Example 8	H	1004	25	50	850	60	24460	75	650	28800	22580	28800	22580
Inventive Example 9	I	1019	25	50	850	60	24460	75	900	120	25902	120	25902
Inventive Example 10	J	1019	25	45	850	60	24460	75	850	60	24460	60	24460
Inventive Example 11	K	1034	25	50	850	60	24460	75	800	120	23694	120	23694
Inventive Example 12	L	1062	25	50	850	60	24460	75	700	28800	23803	28800	23803
Inventive Example 13	M	988	25	50	850	60	24460	94	800	120	23694	120	23694

(continued)

No	Material		Cold rolling process							Final annealing		
	Composition	T _β (°C)	Rolling temperature (°C)	Rolling rate per pass (%)	Intermediate annealing			Total rolling rate (%)	Annealing temperature T (°C)	Holding time t (s)	Larson- Miller parameter	
Inventive Example 14	B	1024	25	50	850	120	24798	88	900	120	25902	
Inventive Example 15	F	1008	25	50	800	120	23694	88	850	120	24798	
Inventive Example 16	M	988	200	50	800	120	23694	88	850	120	24798	
Inventive Example 17	B	1024	25	60	800	120	23694	94	850	120	24798	
Inventive Example 18	F	1008	25	50	680	28800	23313	88	700	14400	23510	
Inventive Example 19	B	1024	25	35	900	60	25549	73	850	14400	27133	
Inventive Example 20	M	988	300	50	900	60	25549	88	850	14400	27133	
Inventive Example 21	B	1024	25	40	700	300	21874	78	850	14400	27133	
Inventive Example 22	B	1024	25	75	-	-	-	75	680	14400	23027	
Inventive Example 23	B	1024	25	60	-	-	-	60	850	7200	26795	
Inventive Example 24	B	1024	25	Pattern A	850	120	24798	88	900	120	25902	
Inventive Example 25	F	1008	25	Pattern A	850	120	24798	88	900	120	25902	
Inventive Example 26	M	988	25	Pattern A	850	120	24798	88	900	120	25902	

(continued)

No	Material		Cold rolling process										
	Composition	T _β (°C)	Rolling temperature (°C)	Rolling rate per pass (%)	Intermediate annealing			Total rolling rate (%)	Final annealing				
					Annealing temperature T (°C)	Holding time t (s)	Larson- Miller parameter		Annealing temperature T (°C)	Holding time t (s)	Larson- Miller parameter		
Inventive Example 27	B	1024	25	Pattern B	850	120	24798	90	900	120	25902		
Inventive Example 28	F	1008	25	Pattern B	850	120	24798	90	900	120	25902		
Inventive Example 29	M	988	25	Pattern B	850	120	24798	90	900	120	25902		
Inventive Example 30	O	1006	25	40	850	300	24121	92	800	300	24121		
Reference	B	1024	25	-	-	-	-	-	-	-	-		
Example													
Comparative Example 1	B	1024	25	20	700	60	21193	59	700	60	21193		
Comparative Example 2	B	1024	25	50	-	-	-	50	850	14400	27133		
Comparative Example 3	N	947	25	40	800	300	24121	78	680	14400	23027		
Comparative Example 4	P	1062	25	-	-	-	-	-	-	-	-		

2. Evaluation

[0106] The following items were evaluated for the titanium alloy sheets according to each of the inventive examples, the reference example, and the comparative examples.

2.1. Chemical components

[0107] Chemical components of the titanium alloy sheets according to each of the inventive examples, the reference example, and the comparative examples were measured by the same method as a method for measuring chemical components of hot-rolled sheets.

2.2. Peak position of intensity

[0108] An observation surface of a sample of the titanium alloy sheet according to each of the inventive examples, the reference example, and the comparative examples was chemically polished, and crystallographic orientation analysis was performed using the electron backscatter diffraction method, thereby obtaining a (0001) pole figure. Specifically, an L cross-section is chemically polished at a central position in a width direction (TD) of each sample, and in the cross-section, crystallographic orientation analysis was performed by the EBSD method targeting about 2 to 10 fields of view at intervals of 1 to 2 μm in a region of (total sheet thickness) $\times$ 2 mm, and thus the (0001) pole figure was drawn. The peak position data of the degrees 53f accumulation of a specific orientation in the (0001) pole figure was calculated by texture analysis of an inverse pole figure using a spherical harmonics method (a series rank=16 and the Gaussian half width=5°) using the OIM Analysis software manufactured by TSL Solutions.

2.3. Area ratio of α -phase and area ratio of α -phase having equivalent circle diameter of 1 μm or more

[0109] The area ratio of the α -phase and an area ratio of the α -phase having an equivalent circle diameter of 1 μm or more were measured by the following method. The titanium alloy sheet was chemically polished at its cross-section cut perpendicularly to the width direction at the central position in the width direction (TD), and crystallographic orientation analysis was performed by the EBSD method targeting about 2 to 5 fields of view at steps of 1 to 5 μm in a region of (total sheet thickness) $\times$ 200 μm in the cross-section. An area ratio of the α -phase with respect to an area of the region was defined as the area ratio of the α -phase. In addition, the equivalent circle diameter of the α -phase observed in the above fields of view (area $A=\pi\times(\text{grain size } D/2)^2$) was calculated, and a ratio of the total area of the α -phase having an equivalent circle diameter of 1 μm or more to the area of the region was defined as the area ratio of the α -phase having an equivalent circle diameter of 1 μm or more. Crystal grains of the α -phase having an equivalent circle diameter of 1 μm or more were assumed to include the band structures, which will be described later.

2.4. Aspect ratio and area ratio of band structure

[0110] The sample of each of the titanium alloy sheets was chemically polished at the cross-section cut perpendicularly to the width direction at the central position in the width direction (TD), and crystallographic orientation analysis is performed by the EBSD method targeting about 2 to 5 fields of view at steps of 1 to 5 μm in the region of (total sheet thickness) $\times$ 200 μm in the cross-section. From results of the crystallographic orientation analysis by the EBSD, an aspect ratio was calculated for each crystal grain. As the area ratio of the band structures, an area ratio of the crystal grains having an aspect ratio exceeding 3.0 was calculated.

2.5. Average grain size of equiaxed structure

[0111] The average grain size of the equiaxed structure is obtained by obtaining an equivalent circle grain size (area $A=\pi\times(\text{grain size } D/2)^2$) from an area of a crystal grain measured by EBSD for each equiaxed structure, and a number-based average value thereof was set to as the average grain size of the equiaxed structure.

2.6. 0.2% proof stress

[0112] The 0.2% proof stress σ at 25°C of the titanium alloy sheet according to each of the inventive examples, the reference example, and the comparative examples was measured based on JIS Z 2241:2011.

2.7. Average sheet thickness d_{ave}

[0113] The average sheet thickness d_{ave} of the titanium alloy sheet according to each of the inventive examples, the reference example, and the comparative examples was measured by the following method. Sheet thicknesses at each of a central position in the width direction and positions at a distance of 1/4 of a sheet width from both ends in the width direction of each of the manufactured titanium alloy sheets were measured using X-rays, a micrometer, or a vernier caliper at 5 or more locations at intervals of 1 m or more in the longitudinal direction, and the average value of the measured sheet thicknesses was set to the average sheet thickness d_{ave} .

2.8. Sheet thickness dimensional accuracy a

[0114] The sheet thickness dimensional accuracy a of the titanium alloy sheet according to each of the inventive examples, the reference example, and the comparative examples is obtained such that, using a sheet thickness d actually measured by the above method and the average sheet thickness d_{ave} , the maximum value of a' calculated by the following formula (101) was defined as the dimensional accuracy a .

$$a' = (d - d_{ave}) / d_{ave} \times 100 \cdots \text{Formula (101)}$$

3. Results

[0115] The above evaluation results are shown in Table 3. Also, " θ " shown in Table 3 is the angle formed between the sheet thickness direction and the direction indicating the peak of intensity calculated by the texture analysis in the case in which a series rank is 16 and the Gaussian half width is 5° for the inverse pole figure using the spherical harmonics method of the electron backscatter diffraction method in the (0001) pole figure in the sheet thickness direction. In addition, " θ_2 " shown in Table 3 is an angle formed between the sheet width direction and a direction from a center of the pole figure indicating the peak of intensity calculated by the texture analysis in the case in which a series rank is 16 and the Gaussian half width is 5° for the inverse pole figure using the spherical harmonics method of the electron backscatter diffraction method in the (0001) pole figure in the sheet thickness direction.

[Table 3]

No	Metal structure						Sheet thickness (mm)			Tensile		properties	
	θ	θ_2	Average grain size of equiaxed structure(μm)	Area ratio of band structure (%)	Area ratio of α -phase	Area ratio of α -phase having size of 1 μm or more	Average sheet thickness dave (mm)	Dimensional accuracy a (%)	σ_L (Mpa)	σ_T (Mpa)	σ_T/σ_L		
Inventive Example 1	51	0	5.0	5.0	87	87	1.0	2.0	789	858	1.09		
Inventive Example 2	48	0	4.0	0.5	88	88	1.0	2.0	806	877	1.09		
Inventive Example 3	57	0	7.0	7.0	86	81	1.0	2.0	841	912	1.08		
Inventive Example 4	48	0	3.3	7.0	90	90	1.0	2.0	837	901	1.08		
Inventive Example 5	52	0	3.8	8.0	90	88	1.0	2.0	902	979	1.09		
Inventive Example 6	52	0	3.0	8.0	90	90	1.0	2.0	907	1010	1.11		
Inventive Example 7	45	0	2.5	7.0	95	95	1.0	2.0	811	901	1.11		
Inventive Example 8	51	0	1.5	7.0	95	90	1.0	2.0	805	895	1.11		
Inventive Example 9	60	0	3.0	2.0	86	86	1.0	2.0	815	880	1.08		
Inventive Example 10	51	5	1.8	9.0	87	87	1.2	4.5	795	890	1.12		
Inventive Example 11	50	0	1.1	7.0	90	90	1.0	2.0	872	949	1.09		
Inventive Example 12	45	0	1.5	7.0	93	90	1.0	2.0	959	1022	1.07		
Inventive Example 13	55	0	3.3	8.0	82	75	1.0	2.0	881	1010	1.15		

(continued)

No	Metal structure						Sheet thickness (mm)		Tensile	properties	
	θ	θ_2	Average grain size of equiaxed structure(μm)	Area ratio of band structure (%)	Area ratio of α -phase	Area ratio of α -phase having size of 1 μm or more	Average sheet thickness dave (mm)	Dimensional accuracy a (%)		σ_L (Mpa)	σ_T / σ_L
Inventive Example 14	35	0	4.0	0.0	87	87	0.5	1.1		805	1.09
Inventive Example 15	30	0	3.5	0.0	88	88	0.5	13		888	1.07
Inventive Example 16	39	0	3.5	0.0	88	88	0.5	2.0		889	1.14
Inventive Example 17	25	0	3.5	0.0	88	88	0.3	2.0		806	1.09
Inventive Example 18	29	0	1.2	0.0	93	92	0.5	0.8		885	1.09
Inventive Example 19	63	9	12.1	0.0	88	88	0.4	2.5		789	1.17
Inventive Example 20	38	0	2.2	4.0	88	88	0.5	3.5		885	1.14
Inventive Example 21	49	0	1.8	5.0	88	88	0.9	2.0		811	1.11
Inventive Example 22	50	0	3.5	15.0	95	90	1.0	2.0		805	1.12
Inventive Example 23	50	0	10.5	20.0	95	90	1.6	2.5		790	1.15
Inventive Example 24	35	0	3.0	0.0	88	88	0.5	1.0		791	1.10
Inventive Example 25	35	3	3.0	0.0	88	88	0.5	1.0		867	1.11
Inventive Example 26	60	0	3.0	0.0	88	88	0.5	1.0		880	1.17

(continued)

No	Metal structure						Sheet thickness (mm)		Tensile	properties	
	θ	θ_2	Average grain size of equiaxed structure (μm)	Area ratio of band structure (%)	Area ratio of α -phase	Area ratio of α -phase having size of 1 μm or more	Average sheet thickness dave (mm)	Dimensional accuracy a (%)		σ^T (Mpa)	σ^T / σ^L
Inventive Example 27	33	0	2.5	0.0	88	88	0.4	1.0	790	865	1.09
Inventive Example 28	33	0	2.5	0.0	88	88	0.4	1.0	863	943	1.09
Inventive Example 29	57	0	2.5	0.0	88	88	0.4	1.0	880	1020	1.16
Inventive Example 30	52	0	3.5	5.0	85	80	1.0	1.5	820	945	1.15
Reference Example	90	0	7.1	85.0	88	88	4.0	5.5	740	934	1.26
Comparative Example 1	80	0	6.2	35.0	93	93	1.2	1.5	750	915	1.22
Comparative Example 2	80	0	5.2	50.0	88	88	1.5	1.5	760	912	1.20
Comparative Example 3	35	0	8.3	0.0	88	88	1.0	1.5	598	670	1.12
Comparative Example 4	-	-	-	-	-	-	-	-	-	-	<

[0116] In any of Inventive Examples 1 to 30, the reference example, and Comparative Examples 1 to 4, the Al, Fe, Si, Ni, Cr, Mn, V, O, N, and C contents in the manufactured titanium alloy sheets were equal to contents of the above elements contained in the respective hot-rolled sheets used.

[0117] In Inventive Examples 1 to 20, the angle θ formed between the direction indicating the peak of intensity in the (0001) pole figure and the sheet thickness direction was 65° or less, and the angle θ_2 formed between the direction indicating the peak of intensity and the width direction was 0° . Also, the average grain size of the equiaxed structure was $0.1\text{ }\mu\text{m}$ or more and $20.0\text{ }\mu\text{m}$ or less, and the area ratio of the band structure was 10% or less. The area ratio of the α -phase was 80% or more in all cases, and the area ratio of the α -phase having an equivalent circle diameter of $1\text{ }\mu\text{m}$ or more was more than 53%. The average sheet thickness was 1.0 to 1.2 mm, and the dimensional accuracy was 0.8 to 4.5%. In addition, the 0.2% proof stress in the longitudinal direction at 25°C was 700 Mpa or more, and the proof stress ratio σ_T/σ_L , which is the ratio of the 0.2% proof stress σ_T in the width direction at 25°C to the 0.2% proof stress σ_L in the longitudinal direction at 25°C , was 1.05 or more and 1.18 or less.

[0118] In Inventive Example 21, the angle θ formed between the direction indicating the peak of intensity in the (0001) pole figure and the sheet thickness direction is 49° , and the angle θ_2 formed between the direction indicating the peak of intensity and the width direction was 0° . Also, the average grain size of the equiaxed structure was $1.8\text{ }\mu\text{m}$, and the area ratio of the band structure was 5.0%. The area ratio of the α -phase was 88% or more, and the area ratio of the α -phase having an equivalent circle diameter of $1\text{ }\mu\text{m}$ or more was 88%. The average sheet thickness was 0.9 mm, and the dimensional accuracy was 2.0%. In addition, the 0.2% proof stress at 25°C was 805 Mpa, and the proof stress ratio σ_T/σ_L was 1.12.

[0119] In both Inventive Examples 22 and 23, the angle θ formed between the direction indicating the peak of intensity in the (0001) pole figure and the sheet thickness direction was 50° , and the angle θ_2 formed between the direction indicating the peak of intensity and the width direction was 0° . Also, the average grain size of the equiaxed structure in Inventive Example 22 was $3.5\text{ }\mu\text{m}$, and the average grain size of the equiaxed structure in Inventive Example 23 was $10.5\text{ }\mu\text{m}$. In both, the area ratios of the band structure were 15.0% and 20.0%, respectively. In both, the area ratios of the α -phase were 80% or more, and the area ratios of the α -phase having an equivalent circle diameter of $1\text{ }\mu\text{m}$ or more were more than 53%. The average sheet thickness was 1.0 mm and 1.6 mm, and the dimensional accuracy was 2.0% and 2.5%. In addition, the 0.2% proof stress at 25°C was 700 MPa or more, and the proof stress ratio σ_T/σ_L was 1.11 and 1.15.

[0120] In Inventive Examples 24 to 26, the angle θ formed between the direction indicating the peak of intensity in the (0001) pole figure and the sheet thickness direction was 65° or less, and the angle θ_2 formed between the direction indicating the peak of intensity and the width direction was 0° . Also, the average grain size of the equiaxed structure was $0.1\text{ }\mu\text{m}$ or more and $20.0\text{ }\mu\text{m}$ or less, and the area ratio of the band structure was 10% or less. The area ratio of the α -phase was 80% or more in all cases, and the area ratio of the α -phase having an equivalent circle diameter of $1\text{ }\mu\text{m}$ or more was more than 53%. The average sheet thickness was all 0.5 mm, and the dimensional accuracy was all 1.0. In addition, the 0.2% proof stress in the longitudinal direction at 25°C was 700 MPa or more, and the proof stress ratio σ_T/σ_L was 1.05 or more and 1.18 or less.

[0121] In Inventive Examples 27 to 29, the angle θ formed between the direction indicating the peak of intensity in the (0001) pole figure and the sheet thickness direction was 65° or less, and the angle θ_2 formed between the direction indicating the peak of intensity and the width direction was 0° . Also, the average grain size of the equiaxed structure was $0.1\text{ }\mu\text{m}$ or more and $20.0\text{ }\mu\text{m}$ or less, and the area ratio of the band structure was 10% or less. The area ratio of the α -phase was 80% or more in all cases, and the area ratio of the α -phase having an equivalent circle diameter of $1\text{ }\mu\text{m}$ or more was more than 53%. The average sheet thickness was all 0.4 mm, and the dimensional accuracy was all 1.0% or less. In addition, the 0.2% proof stress in the longitudinal direction was 700 MPa or more, and the proof stress ratio (σ_T/σ_L) was 1.05 or more and 1.18 or less.

[0122] In Inventive Example 30, the angle θ formed between the direction indicating the peak of intensity in the (0001) pole figure and the sheet thickness direction was 45° , and the angle θ_2 formed between the direction indicating the peak of intensity and the width direction was 0° . Also, the average grain size of the equiaxed structure was $3.5\text{ }\mu\text{m}$, and the area ratio of the band structure was 5.0%. The area ratio of the α -phase was 85% or more, and the area ratio of the α -phase having an equivalent circle diameter of $1\text{ }\mu\text{m}$ or more was 80%. The average sheet thickness was 1.0 mm, and the dimensional accuracy was 1.5%. In addition, the 0.2% proof stress was 800 MPa, and the proof stress ratio σ_T/σ_L was 1.14.

[0123] In the reference example, the angle θ formed between the direction indicating the peak of intensity in the (0001) pole figure and the sheet thickness direction was more than 65° . For that reason, the proof stress ratio σ_T/σ_L exceeded 1.18, indicating strong anisotropy.

[0124] Further, in Comparative Example 1, the rolling rate per pass was as small as 20%, and the total rolling rate was also as small as 59%. For that reason, the angle θ formed between the direction indicating the peak of intensity in the (0001) pole figure and the sheet thickness direction was more than 65° . For that reason, the proof stress ratio σ_T/σ_L exceeded 1.18, indicating strong anisotropy. Also, in Comparative Example 2, although the rolling rate per pass was 50%,

intermediate annealing and cold rolling were not repeated, and the total rolling rate was as small as 50%. For that reason, the angle θ formed between the direction indicating the peak of intensity in the (0001) pole figure and the sheet thickness direction was more than 65°. For that reason, the proof stress ratio σ_T/σ_L exceeded 1.18, indicating strong anisotropy. In Comparative Example 3, the Al content was low, and thus the 0.2% proof stress was as small as 598 MPa. In Comparative Example 4, as described above, surface cracks and severe edge cracks occurred during cold rolling.

(Example 2)

[0125] In the same manner as in Inventive Example 1, hot-rolled sheets with a thickness of 4 mm having the chemical components shown in A, B, C, E, and M in Table 1 were manufactured.

[0126] Next, the obtained hot-rolled sheets were cold-rolled under the conditions shown in Table 4. In Inventive Examples 31 to 37 in Table 2, a plurality of cold rolling passes were performed such that the rolling rate per cold rolling pass was set to 5% or more to obtain the total rolling rate shown in Table 4. Inventive Examples 31 to 35 in Table 4 are examples obtained by repeating a plurality of cold rolling passes at a rolling temperature of 25°C and intermediate annealing under the conditions shown in Table 2, and performing cold cross-rolling until the total rolling rate reaches 60 to 75%. The intermediate annealing was performed at a temperature of 680 to 900°C for 60 to 28800 s, and final annealing was performed at a temperature of 650 to 930°C for 120 to 28800 s. The cross-rolling ratios of Inventive Examples 32 to 36 were set to 0.4 to 7.0. Inventive Example 36 is an example obtained by repeating a plurality of cold rolling passes at a rolling temperature of 400°C and intermediate annealing under the conditions shown in Table 4, and performing cold cross-rolling until the total rolling rate reaches 75%. The intermediate annealing was performed at a temperature of 800°C for 120 s, and the final annealing was performed at a temperature of 850°C for 120 s. The cross-rolling ratio of Inventive Example 36 was set to 13.0. Inventive Example 37 is an example obtained by repeating a plurality of cold rolling passes at a rolling temperature of 25°C and intermediate annealing under the conditions shown in Table 4, and performing cold cross-rolling until the total rolling rate reaches 62%. The intermediate annealing was performed at a temperature of 800°C for 120 s, and the final annealing was performed at a temperature of 850°C for 120 s. The cross-rolling ratio of Inventive Example 37 was set to 0.17. In this case, rolling in a cross direction was performed while cutting is appropriately performed in accordance with the width of a rolling roll to obtain a rollable size.

[Table 4]

No	Material		Cold rolling process								
	Composition	T _β (°C)	Rolling temperature (°C)	Intermediate annealing			Total rolling rate (%)	Cross- rolling ratio	Final annealing		
				Annealing temperature T (°C)	Holding time t (s)	Larson- Miller parameter			Annealing temperature T (°C)	Holding time t (s)	Larson- Miller parameter
Inventive Example 31	A	1003	25	850	60	24460	70	3.00	900	120	25902
Inventive Example 32	C	1033	25	850	60	24460	75	0.50	930	120	26565
Inventive Example 33	E	1009	25	680	28800	23313	75	0.40	900	120	25902
Inventive Example 34	M	988	25	900	60	25549	75	2.00	700	28800	23803
Inventive Example 35	B	1024	25	900	120	25902	60	7.00	650	14400	22302
Inventive Example 36	B	1024	400	800	120	23694	75	15.00	850	120	24798
Inventive Example 37	B	1024	25	800	120	23694	62	0.17	800	120	23694

[0127] For the titanium alloy sheet according to each of the inventive examples, the same items as in Inventive Example 1 were evaluated in the same manner as in Inventive Example 1. The evaluation results were shown in Table 5.

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[Table 5]

No	Metal structure					Sheet thickness (mm)			Tensile	properties	
	θ	Average grain size of equiaxed structure (μm)	Area ratio of band structure (%)	Area ratio of α -phase	Area ratio of α -phase having size of 1 μm or more	Average sheet thickness dave (mm)	Dimension al accuracy a (%)	σL (MPa)		σT (MPa)	$\sigma\text{T}/\sigma\text{L}$
Inventive Example 31	22	5.0	7.0	87	87	1.2	2.2	789	810	1.03	
Inventive Example 32	18	6.7	7.0	86	86	1.0	1.8	841	829	0.99	
Inventive Example 33	19	6.6	8.0	90	90	1.0	1.8	902	884	0.98	
Inventive Example 34	15	3.5	4.0	82	82	1.0	1.5	920	946	1.03	
Inventive Example 35	23	1.5	7.0	93	93	1.8	3.5	800	830	1.04	
Inventive Example 36	25	3.1	0.0	88	88	1.0	1.8	820	860	1.05	
Inventive Example 37	30	3.3	8.1	86	86	1.5	1.8	877	800	0.91	

[0128] In Inventive Examples 31 to 37, the angle θ formed between the direction indicating the peak of intensity in the (0001) pole figure and the sheet thickness direction was 35° or less. Also, the average grain size of the equiaxed structure was $0.1\text{ }\mu\text{m}$ or more and $10.0\text{ }\mu\text{m}$ or less, and the area ratio of the band structure was 10% or less. The area ratio of the α -phase was 80% or more in all cases, and the area ratio of the α -phase having an equivalent circle diameter of $1\text{ }\mu\text{m}$ or more was more than 53%. The average sheet thickness was 1.0 to 1.8 mm, and the dimensional accuracy was 1.5 to 3.5% or less. In addition, the 0.2% proof stress at 25°C was 700 MPa or more, and the proof stress ratio σ_T/σ_L , which is the ratio of the 0.2% proof stress σ_T in the width direction at 25°C to the 0.2% proof stress σ_L in the longitudinal direction at 25°C , was 0.85 or more and 1.10 or less.

[0129] Although the preferred embodiments of the present disclosure have been described in detail above, the present disclosure is not limited to such examples. It is obvious that a person having ordinary knowledge in the technical field to which the present disclosure belongs could conceive various changes or modifications within the scope of the technical idea described in the claims and it is naturally understood that these also fall within the technical scope of the present disclosure.

Claims

1. A titanium alloy sheet containing, in % by mass:

Al: more than 4.0% and 6.6% or less;

Fe: 0% or more and 2.3% or less;

V: 0% or more and 4.5% or less;

Si: 0% or more and 0.60% or less;

C: 0% or more and less than 0.080%;

N: 0% or more and 0.050% or less;

O: 0% or more and 0.40% or less;

Ni: 0% or more and less than 0.15%;

Cr: 0% or more and less than 0.25%;

Mn: 0% or more and less than 0.25%; and

a remainder of Ti and impurities,

wherein an area ratio of an α -phase is 80% or more,

an area ratio of an α -phase having an equivalent circle diameter of $1\text{ }\mu\text{m}$ or more is more than 53%, and

in a (0001) pole figure in a sheet thickness direction, an angle formed between the sheet thickness direction and a direction indicating a peak of intensity calculated by texture analysis in a case in which a series rank is 16 and a Gaussian half width is 5° for an inverse pole figure using a spherical harmonics method of an electron backscatter diffraction method is 65° or less, and

an average sheet thickness is 2.5 mm or less.

2. The titanium alloy sheet according to claim 1 having a microstructure including an equiaxed structure with an aspect ratio of 3.0 or less and a longitudinally elongated band structure with an aspect ratio of more than 3.0,

wherein the equiaxed structure has an average grain size of $0.1\text{ }\mu\text{m}$ or more and $20.0\text{ }\mu\text{m}$ or less, and an area ratio of the band structure with respect to an area of the microstructure is 10.0% or less.

3. The titanium alloy sheet according to claim 1 or 2 containing, in % by mass, either Fe: 0.5% or more and 2.3% or less or V: 2.5% or more and 4.5% or less.

4. The titanium alloy sheet according to any one of claims 1 to 3 containing, in % by mass, one element or two or more elements selected from the group including Ni: less than 0.15%, Cr: less than 0.25%, and Mn: less than 0.25% in place of a part of the Fe or the V.

5. The titanium alloy sheet according to any one of claims 1 to 4, wherein the smaller of a 0.2% proof stress in a longitudinal direction at 25°C and a 0.2% proof stress in a width direction at 25°C is 700 MPa or more and 1200 MPa or less.

6. The titanium alloy sheet according to any one of claims 1 to 5,

wherein, in a (0001) pole figure in a sheet thickness direction, an angle formed between a width direction and

a direction indicating a peak of intensity calculated by texture analysis in a case in which a series rank is 16 and a Gaussian half width is 5° for an inverse pole figure using a spherical harmonics method of an electron backscatter diffraction method is 10° or less, and
 a ratio of a 0.2% proof stress in the width direction to a 0.2% proof stress in a longitudinal direction is 1.05 or more and 1.18 or less.

7. The titanium alloy sheet according to any one of claims 1 to 5,

wherein, in a (0001) pole figure in a sheet thickness direction, an angle formed between the sheet thickness direction and a direction indicating a peak of intensity calculated by texture analysis in a case in which a series rank is 16 and a Gaussian half width is 5° for an inverse pole figure using a spherical harmonics method of an electron backscatter diffraction method is 35° or less, and
 a ratio of a 0.2% proof stress in a width direction to a 0.2% proof stress in a longitudinal direction is 0.85 or more and 1.10 or less.

8. The titanium alloy sheet according to any one of claims 1 to 7, wherein a dimensional accuracy of a sheet thickness is 5.0% or less with respect to the average sheet thickness.

9. A titanium alloy coil containing, in % by mass:

Al: more than 4.0% and 6.6% or less;

Fe: 0% or more and 2.3% or less;

V: 0% or more and 4.5% or less;

Si: 0% or more and 0.60% or less;

C: 0% or more and less than 0.080%;

N: 0% or more and 0.050% or less;

O: 0% or more and 0.40% or less;

Ni: 0% or more and less than 0.15%;

Cr: 0% or more and less than 0.25%;

Mn: 0% or more and less than 0.25%; and

a remainder of Ti and impurities,

wherein an area ratio of an α -phase is 80% or more,

an area ratio of an α -phase having an equivalent circle diameter of 1 μm or more is more than 53%, and

in a (0001) pole figure in a sheet thickness direction, an angle formed between the sheet thickness direction and a direction indicating a peak of intensity calculated by texture analysis in a case in which a series rank is 16 and a Gaussian half width is 5° for an inverse pole figure using a spherical harmonics method of an electron backscatter diffraction method is 65° or less, and
 an average sheet thickness is 2.5 mm or less.

10. A method for manufacturing the titanium alloy sheet according to any one of claims 1 to 8, comprising:

a cold rolling process of performing one or more cold rolling passes in a longitudinal direction of a titanium material containing, in % by mass, Al: more than 4.0% and 6.6% or less, Fe: 0% or more and 2.3% or less, V: 0% or more and 4.5% or less, Si: 0% or more and 0.60% or less, C: 0% or more and less than 0.080%, N: 0% or more and 0.050% or less, O: 0% or more and 0.40% or less, Ni: 0% or more and less than 0.15%, Cr: 0% or more and less than 0.25%, Mn: 0% or more and less than 0.25%, and a remainder of Ti and impurities; and
 a final annealing process of annealing the titanium material after a final cold rolling pass,
 wherein a rolling rate per cold rolling pass in the cold rolling process is more than 30%, and a total rolling rate is 60% or more.

11. The method for manufacturing the titanium alloy sheet according to claim 10, wherein the cold rolling process includes an intermediate annealing process of annealing the titanium material between a plurality of cold rolling passes in the case of performing the plurality of cold rolling passes, and annealing conditions for the intermediate annealing process and the final annealing process are conditions in which an annealing temperature is 600°C or higher and (T_{β} -50)°C or lower, and the annealing temperature T (°C) and a holding time t (seconds) at the annealing temperature satisfy the following formula (1),

$$22000 \leq (T+273.15) \times (\log_{10}(t)+20) \leq 27000 \cdots \text{Formula (1)}$$

where, T_{β} is a β transformation point ($^{\circ}\text{C}$).

12. A method for manufacturing the titanium alloy sheet according to any one of claims 1 to 8, comprising:

a cold cross-rolling process of performing a cold rolling pass in a longitudinal direction and a width direction of a titanium material containing, in % by mass, Al: more than 4.0% and 6.6% or less, Fe: 0% or more and 2.3% or less, V: 0% or more and 4.5% or less, Si: 0% or more and 0.60% or less, C: 0% or more and less than 0.080%, N: 0% or more and 0.050% or less, O: 0% or more and 0.40% or less, Ni: 0% or more and less than 0.15%, Cr: 0% or more and less than 0.25%, Mn: 0% or more and less than 0.25%, and a remainder of Ti and impurities; and

a final annealing process of annealing the titanium material after the cold cross-rolling process, wherein a total rolling rate in the cold cross-rolling process is 60% or more, and a cross-rolling ratio, which is a ratio of a rolling rate in the longitudinal direction to a rolling rate in the width direction, is 0.05 or more and 20.00 or less.

13. The method for manufacturing the titanium alloy sheet according to claim 12, wherein the cold cross-rolling process includes an intermediate annealing process of annealing the titanium material between a plurality of cold rolling passes in the case of performing the plurality of cold rolling passes, and annealing conditions for the intermediate annealing process and the final annealing process are conditions in which an annealing temperature is 600°C or higher and $(T_{\beta}-50)^{\circ}\text{C}$ or lower, and the annealing temperature T ($^{\circ}\text{C}$) and a holding time t (seconds) at the annealing temperature satisfy the following formula (1),

$$22000 \leq (T+273.15) \times (\log_{10}(t)+20) \leq 27000 \cdots \text{Formula (1)}$$

where, T_{β} is a β transformation point ($^{\circ}\text{C}$).

14. A method for manufacturing the titanium alloy coil according to claim 9, comprising:

a cold rolling process of performing one or more cold rolling passes in a longitudinal direction of a titanium material containing, in % by mass, Al: more than 4.0% and 6.6% or less, Fe: 0% or more and 2.3% or less, V: 0% or more and 4.5% or less, Si: 0% or more and 0.60% or less, C: 0% or more and less than 0.080%, N: 0% or more and 0.050% or less, O: 0% or more and 0.40% or less, Ni: 0% or more and less than 0.15%, Cr: 0% or more and less than 0.25%, Mn: 0% or more and less than 0.25%, and a remainder of Ti and impurities; and a final annealing process of annealing the titanium material after a final cold rolling pass, wherein a rolling rate per cold rolling pass in the cold rolling process is more than 30%, and a total rolling rate is 60% or more.

FIG. 1

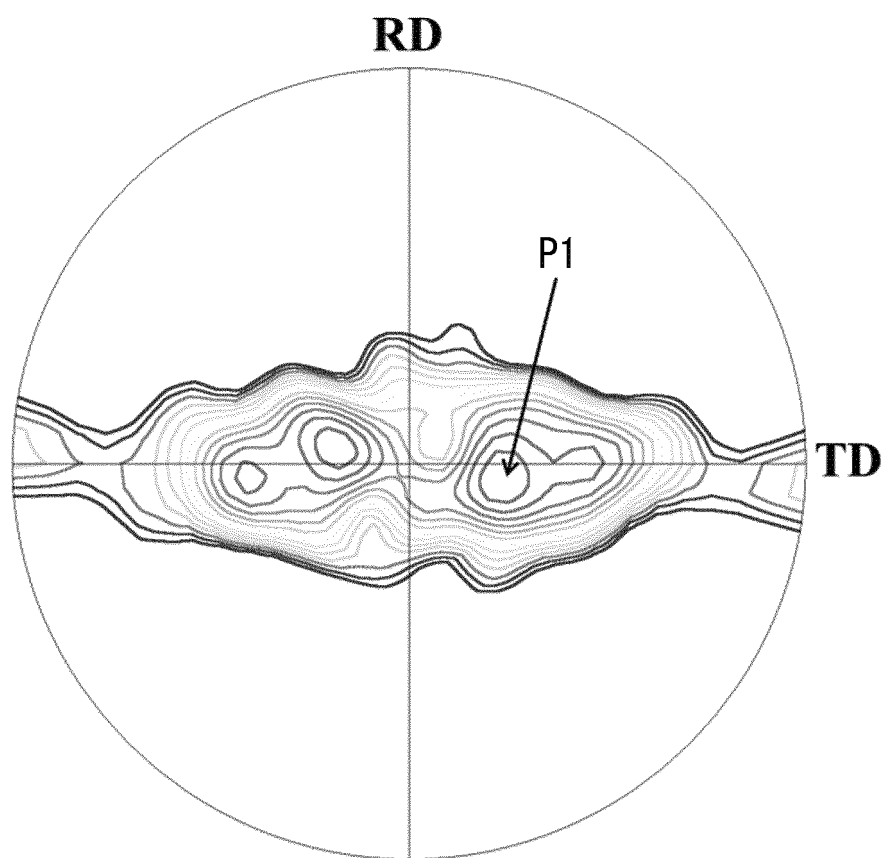


FIG. 2

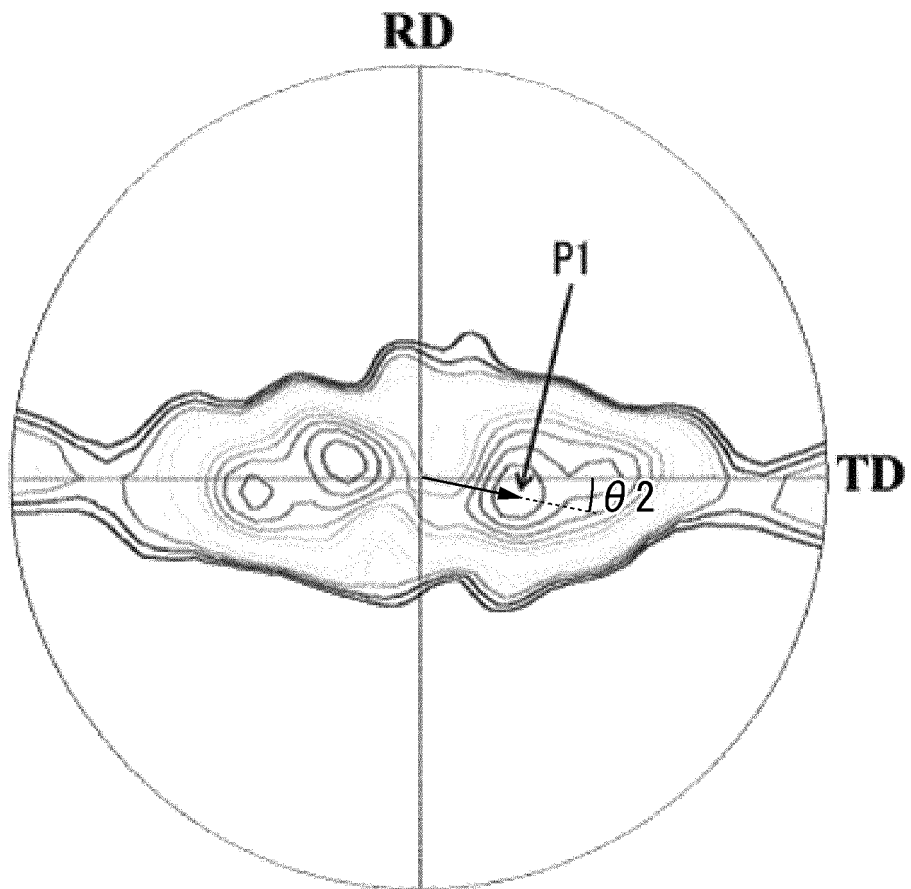


FIG. 3

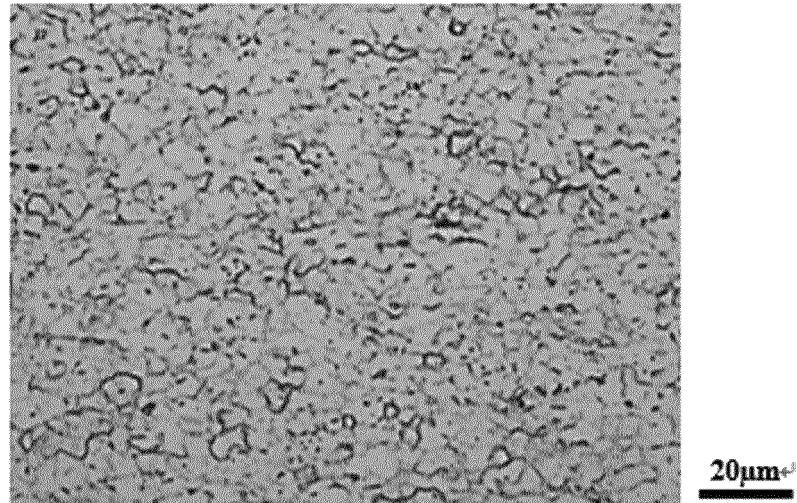


FIG. 4

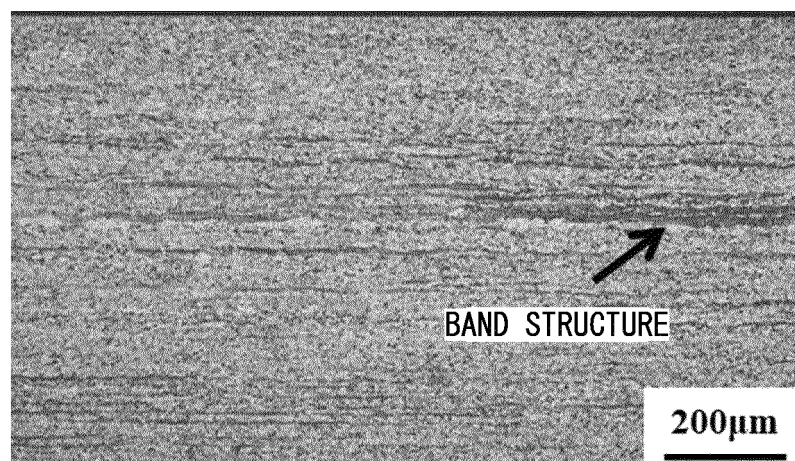
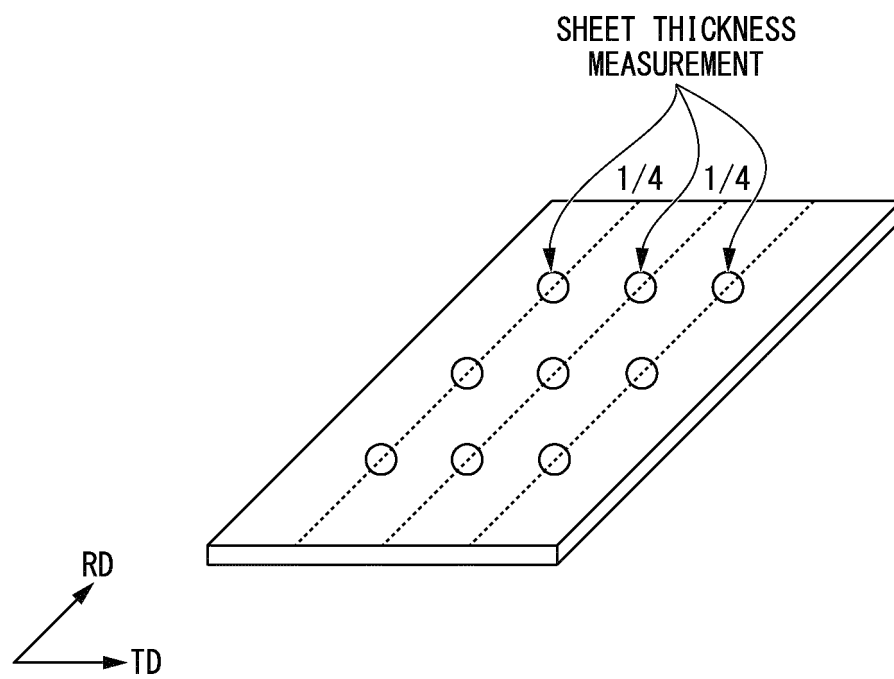


FIG. 5



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2021/002965

A. CLASSIFICATION OF SUBJECT MATTER

C22C 14/00(2006.01)i; C22F 1/00(2006.01)i; C22F 1/18(2006.01)i
 FI: C22C14/00 Z; C22F1/18 H; C22F1/00 623; C22F1/00 630A; C22F1/00
 694A; C22F1/00 691B; C22F1/00 691C; C22F1/00 686Z
 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	1971-2021
Registered utility model specifications of Japan	1996-2021
Published registered utility model applications of Japan	1994-2021

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 2020/213715 A1 (NIPPON STEEL CORPORATION) 22 October 2020 (2020-10-22)	1-14
A	JP 2017-190480 A (KOBE STEEL, LTD.) 19 October 2017 (2017-10-19)	1-14
A	JP 2010-242197 A (KOBE STEEL, LTD.) 28 October 2010 (2010-10-28)	1-14
A	WO 2012/115243 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 30 August 2012 (2012-08-30)	1-14



Further documents are listed in the continuation of Box C.



See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"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
 05 April 2021 (05.04.2021)

Date of mailing of the international search report
 20 April 2021 (20.04.2021)

Name and mailing address of the ISA/
 Japan Patent Office
 3-4-3, Kasumigaseki, Chiyoda-ku,
 Tokyo 100-8915, Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/JP2021/002965

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
WO 2020/213715 A1	22 Oct. 2020	(Family: none)	
JP 2017-190480 A	19 Oct. 2017	(Family: none)	
JP 2010-242197 A	28 Oct. 2010	(Family: none)	
WO 2012/115243 A1	30 Aug. 2012	US 2013/0327448 A1	
		KR 10-2013-0092612 A	
		CN 103403203 A	
		KR 10-2016-0030333 A	
		TW 201239102 A	

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP H0762474 A [0015]
- JP H0770676 A [0015]
- JP 2001300603 A [0015]
- JP 2001300604 A [0015]
- JP S61147864 A [0015]
- JP H01127653 A [0015]
- JP 2013227618 A [0015]
- WO 2012115242 A [0015]
- WO 2012115243 A [0015]
- JP S6233750 A [0015]

Non-patent literature cited in the description

- *KOBE STEEL ENGINEERING REPORTS*, 2009, vol. 59 (1), 81-84 [0016]
- *KOBE STEEL ENGINEERING REPORTS*, 2010, vol. 60 (2), 50-54 [0016]