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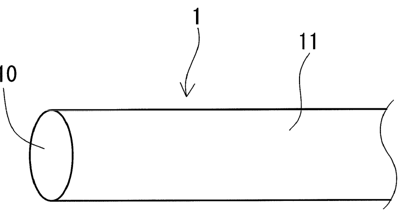
(54) ALUMINUM ALLOY, ALUMINUM ALLOY WIRE, AND METHOD FOR MANUFACTURING ALUMINUM ALLOY WIRE

(57) An aluminum alloy of the present disclosure has a composition including silicon in an amount of 0.6 mass% to 1.5 mass%, magnesium in an amount of 0.5 mass% to 1.3 mass%, copper in an amount of 0.1 mass% to 1.2 mass%, and manganese in an amount of 0.2 mass% to 1.15 mass%, with the balance consisting of aluminum and inevitable impurities. An average of degrees of orientation of a 111 plane determined by X-ray diffraction of a whole area of a section in a state of having been subjected to solution treatment and aging treatment is 50% or more, and a variance of the degrees of orientation of the 111 plane is 45% or less.

FIG. 1



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Description

TECHNICAL FIELD

[0001] The present disclosure relates to an aluminum alloy, an aluminum alloy wire, and a method of manufacturing an aluminum alloy wire.
This application claims priority based on Japanese Patent Application No. 2021-089504 filed on May 27, 2021, and the entire contents of the Japanese patent application are incorporated herein by reference.

BACKGROUND ART

[0002] PTL 1 discloses an aluminum alloy wire which is a wire composed of an aluminum alloy including silicon and magnesium and has high tensile strength after being subjected to solution treatment and aging treatment. The aluminum alloy wire can be used as a raw material for an aluminum alloy member. The aluminum alloy member is manufactured by performing predetermined plastic working on the aluminum alloy wire and then subjecting solution treatment and aging treatment on the aluminum alloy wire.

CITATION LIST

PATENT LITERATURE

[0003] PTL 1: Japanese Unexamined Patent Application Publication No. 2015-124409

SUMMARY OF INVENTION

[0004] An aluminum alloy of the present disclosure has a composition including silicon in an amount of 0.6 mass% to 1.5 mass%, magnesium in an amount of 0.5 mass% to 1.3 mass%, copper in an amount of 0.1 mass% to 1.2 mass%, and manganese in an amount of 0.2 mass% to 1.15 mass%, with the balance consisting of aluminum and inevitable impurities. An average of degrees of orientation of a 111 plane determined by X-ray diffraction of a whole area of a section in a state of having been subjected to solution treatment and aging treatment is 50% or more, and a variance of the degrees of orientation of the 111 plane is 45% or less.
[0005] The aluminum alloy wire of the present disclosure is composed of an aluminum alloy of the present disclosure.
[0006] A method of manufacturing an aluminum alloy wire of the present disclosure includes performing plastic working on a cast product of an aluminum alloy to manufacture a worked product, the aluminum alloy having a composition including silicon in an amount of 0.6 mass% to 1.5 mass%, magnesium in an amount of 0.5 mass% to 1.3 mass%, copper in an amount of 0.1 mass% to 1.2 mass%, and manganese in an amount of 0.2 mass% to 1.15 mass%, with the balance consisting of aluminum and inevitable impurities, performing first drawing on the worked product under cold conditions to manufacture a first drawn product, performing softening treatment on the first drawn product to manufacture a softened product, and performing second drawing on the softened product under cold conditions to manufacture a second drawn product. A degree of working in the second drawing is 20% or more and is also higher than a degree of working in the first drawing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007]

FIG. 1 is a perspective view showing an example of an aluminum alloy wire of an embodiment.
FIG. 2 is a diagram showing an example of the distribution of the degrees of orientation of a 111 plane in a cross section of an aluminum alloy wire of sample No. 3 of test example 1.
FIG. 3 is a diagram showing an example of the distribution of the degrees of orientation of a 111 plane of an aluminum alloy wire of sample No. 3 of test example 1 by contour lines.
FIG. 4 is a diagram showing an example of the distribution of the degrees of orientation of a 111 plane in a cross section of an aluminum alloy wire of sample No. 1 of test example 1.
FIG. 5 is a diagram showing an example of the distribution of the degrees of orientation of a 111 plane of an aluminum alloy wire of sample No. 1 of test example 1 by contour lines.
FIG. 6 is a diagram showing a method of measuring the distribution of the degrees of orientation of a 111 plane in a whole area of a section of the sample.

DETAILED DESCRIPTION

[Problems to be Solved by Present Disclosure]

[0008] It is desired to further improve the strength of an aluminum alloy member used in a state of having been subjected to solution treatment and aging treatment as described above. Further, an aluminum alloy capable of constituting such a high-strength aluminum alloy member is desired.

[0009] Accordingly, it is an object of the present disclosure to provide an aluminum alloy having high-strength in a state of having been subjected to solution treatment and aging treatment. Another object of the present disclosure is to provide an aluminum alloy wire composed of the aluminum alloy described above. Another object of the present disclosure is to provide a method of manufacturing an aluminum alloy wire, with which the aluminum alloy wire can be manufactured.

[Advantageous Effects of Present Disclosure]

[0010] The aluminum alloy of the present disclosure and the aluminum alloy wire of the present disclosure have high-strength in a state of having been subjected to solution treatment and aging treatment. The aluminum alloy wire of the present disclosure can be manufactured with the method of manufacturing the aluminum alloy wire of the present disclosure.

[Description of Embodiments of Present Disclosure]

[0011] First, embodiments of the present disclosure will be listed and explained. (1) An aluminum alloy according to an embodiment of the present disclosure has a composition including silicon in an amount of 0.6 mass% to 1.5 mass%, magnesium in an amount of 0.5 mass% to 1.3 mass%, copper in an amount of 0.1 mass% to 1.2 mass%, and manganese in an amount of 0.2 mass% to 1.15 mass%, with the balance consisting of aluminum and inevitable impurities. In the aluminum alloy, an average of degrees of orientation of a 111 plane determined by X-ray diffraction of a whole area of a section in a state of having been subjected to solution treatment and aging treatment is 50% or more, and a variance of the degrees of orientation of the 111 plane is 45% or less.

[0012] The 111 plane in the present disclosure means a crystal plane denoted by (111) in crystallography. The degree of orientation of the 111 plane in the present disclosure is determined using values obtained by normalizing each of the following three diffraction intensities obtained by X-ray diffraction of the whole area of the section. The degree of orientation of the 111 plane in the present disclosure is the ratio of the normalized value of the diffraction intensity of the 111 plane to the sum of the three normalized values. The three diffraction intensities are the diffraction intensity of the 111 plane, the diffraction intensity of the 200 plane, and the diffraction intensity of the 220 plane. The 200 plane and the 220 plane mean crystal planes each denoted by (200) and (220) in crystallography, respectively. The average of the degrees of orientation of the 111 plane in the present disclosure is a value obtained by averaging the above-described ratio at each measurement point of the whole area of the section. The variance of the degrees of orientation of the 111 plane in the present disclosure is a value obtained from the above average. Methods for measuring the average and the variance of the degrees of orientation of the 111 plane in the present disclosure are described below. In the measurement method to be described below, the whole area of the section is set as a measurement target of X-ray diffraction, and the orientation state of the 111 plane is specified using the value obtained by normalizing the diffraction intensity, so that the degrees of orientation of the 111 plane in the whole area of the section can be appropriately evaluated.

In the present disclosure, the section of the aluminum alloy is, for example, the following section. When the aluminum alloy has a relatively long shape such as a wire, a pipe, or a plate, the section is a section cut along a plane perpendicular to the longitudinal direction of the aluminum alloy.

In the present disclosure, the conditions of solution treatment and the conditions of aging treatment are as follows.

(Conditions of Solution Treatment)

[0013] The heating temperature is a temperature selected from a range of 530°C to 580°C. The heating time is a time selected from a range of 15 minutes to 120 minutes.

(Conditions of Aging Treatment)

[0014] The heating temperature is a temperature selected from a range of 150°C to 180°C. The heating time is a time selected from a range of 4 hours to 100 hours.

[0015] Since the aluminum alloy of the present disclosure has the above-described specific composition, the aluminum alloy has a high tensile strength due to precipitation hardening in a state of having been subjected to solution treatment and aging treatment. In particular, in the aluminum alloy of the present disclosure, the state in which the 111 plane of the crystal grains is oriented occurs not in a part of the section but over the whole area of the section. The aluminum alloy of the present disclosure having such a section is hard to break, for example, when it is pulled in a direction perpendicular to the section as a pulling direction. Also from this point of view, the aluminum alloy of the present disclosure has high tensile strength. Preferably the aluminum alloy of the present disclosure has a higher tensile strength than the aluminum alloy described in PTL 1. As described above, the aluminum alloy of the present disclosure has high-strength in the state of having been subjected to solution treatment and aging treatment.

[0016] In addition, the aluminum alloy of the present disclosure has well-balanced heat resistance, corrosion resistance, and strength in the state of having been subjected to solution treatment and aging treatment, similarly to an alloy called a 6000 series alloy by the International Alloy Designations. The aluminum alloy of the present disclosure can be suitably used as an aluminum alloy member required to have higher strength in addition to heat resistance and corrosion resistance and as a raw material for the aluminum alloy member. The aluminum alloy member is, for example, an automobile part or various structural members. Automotive parts and various structural members may take the form of wires, rods, pipes and the like. The raw material is, for example, aluminum alloy wire, aluminum alloy plate or the like.

[0017] (2) The aluminum alloy of the present disclosure may further include at least one element selected from the group consisting of iron, chromium, zinc, titanium, and zirconium. A content ratio of iron is more than 0 mass% and 0.8 mass% or less. A content ratio of chromium is more than 0 mass% and 0.35 mass% or less. A content ratio of zinc is more than 0 mass% and 0.5 mass% or less. A content ratio of titanium is more than 0 mass% and 0.2 mass% or less. A content ratio of zirconium is more than 0 mass% and 0.2 mass% or less.

[0018] The aluminum alloy tends to have a higher tensile strength.

[0019] (3) The aluminum alloy according to (2) above may have the composition including silicon in an amount of 1.0 mass% to 1.3 mass%, magnesium in an amount of 0.5 mass% to 1.2 mass%, iron in an amount of 0.3 mass% to 0.8 mass%, copper in an amount of 0.1 mass% to 0.4 mass%, manganese in an amount of 0.2 mass% to 0.5 mass%, chromium in an amount of more than 0 mass% and 0.3 mass% or less, and titanium in an amount of 0.001 mass% to 0.1 mass%, with the balance consisting of aluminum and inevitable impurities. The aluminum alloy may further include zirconium in an amount of 0.001 mass% to 0.2 mass%.

[0020] The aluminum alloy tends to have a higher tensile strength.

[0021] (4) The aluminum alloy according to (2) above may have the composition including silicon in an amount of 0.6 mass% to 1.5 mass%, magnesium in an amount of 0.7 mass% to 1.3 mass%, iron in an amount of 0.02 mass% to 0.4 mass%, copper in an amount of 0.5 mass% to 1.2 mass%, manganese in an amount of 0.5 mass% to 1.1 mass%, chromium in an amount of more than 0 mass% and 0.3 mass% or less, zinc in an amount of 0.005 mass% to 0.5 mass%, titanium in an amount of 0.01 mass% to 0.2 mass%, and zirconium in an amount of 0.05 mass% to 0.2 mass%, with the balance consisting of aluminum and inevitable impurities.

[0022] The aluminum alloy tends to have a higher tensile strength.

[0023] (5) The aluminum alloy of the present disclosure may have a tensile strength of more than 425 MPa in a state of having been subjected to solution treatment and aging treatment.

[0024] The aluminum alloy has a high tensile strength and thus has a high-strength.

[0025] (6) An aluminum alloy wire according to an embodiment of the present disclosure is composed of the aluminum alloy according to any one of (1) to (5) above.

[0026] Since the aluminum alloy wire of the present disclosure is composed of the aluminum alloy of the present disclosure, it has high-strength in a state of having been subjected to solution treatment and aging treatment. The aluminum alloy wire of the present disclosure can be used as a raw material for a high-strength aluminum alloy member.

[0027] (7) A method of manufacturing an aluminum alloy wire according to an embodiment of the present disclosure includes performing plastic working on a cast product of an aluminum alloy to manufacture a worked product, the aluminum alloy having a composition including silicon in an amount of 0.6 mass% to 1.5 mass%, magnesium in an amount of 0.5 mass% to 1.3 mass%, copper in an amount of 0.1 mass% to 1.2 mass%, and manganese in an amount of 0.2 mass% to 1.15 mass%, with the balance consisting of aluminum and inevitable impurities, performing first drawing on the worked product under cold conditions to manufacture a first drawn product, performing softening treatment on the first drawn product to manufacture a softened product, and performing second drawing on the softened product under cold conditions to manufacture a second drawn product. The degree of working in the second drawing is 20% or more and is also higher than the degree of working in the first drawing.

[0028] According to the method of manufacturing an aluminum alloy wire of the present disclosure, a high-strength aluminum alloy wire can be manufactured in a state of having been subjected to solution treatment and aging treatment. The reason will be described later.

[0029] (8) In the method of manufacturing an aluminum alloy wire of the present disclosure, the aluminum alloy may further include at least one element selected from the group consisting of iron, chromium, zinc, titanium, and zirconium. A content ratio of iron is more than 0 mass% and 0.8 mass% or less. A content ratio of chromium is more than 0 mass% and 0.35 mass% or less. A content ratio of zinc is more than 0 mass% and 0.5 mass% or less. A content ratio of titanium

is more than 0 mass% and 0.2 mass% or less. A content ratio of zirconium is more than 0 mass% and 0.2 mass% or less.
[0030] According to the above method of manufacturing an aluminum alloy wire, an aluminum alloy wire having higher tensile strength can be manufactured.

[Details of Embodiments of Present Disclosure]

[0031] Hereinafter, embodiments of the present disclosure will be specifically described with reference to the drawings as appropriate.

[Aluminum Alloy]

(Summary)

[0032] The aluminum alloy of the embodiment has the following composition and the following sectional structure. The composition of the aluminum alloy of the embodiment includes silicon, magnesium, copper, and manganese in the ranges described below, respectively, and the balance consisting of aluminum and inevitable impurities. The aluminum alloy of the embodiment may further include at least one element selected from the group consisting of iron, chromium, zinc, titanium, and zirconium in the range described below. In the sectional structure of the aluminum alloy of the embodiment, the 111 plane of the crystal grains is oriented in the normal direction of the section in a state of having been subjected to solution treatment and aging treatment. In particular, in many of the crystal grains constituting the section of the aluminum alloy, the 111 plane is oriented in the normal direction of the section. Hereinafter, the composition and the structure will be described in order.

In the following description, the following expressions may be used.

[0033] Silicon, magnesium, copper and manganese are collectively referred to as a first element. Iron, chromium, zinc, titanium, and zirconium are collectively referred to as a second element.
[0034] Each element is indicated by a symbol for element. Si means silicon. Mg means magnesium. Cu means copper. Mn means manganese. Al means aluminum. Fe means iron. Cr means chromium. Zn means zinc. Ti means titanium. Zr means zirconium.
[0035] An aluminum alloy in a state of having been subjected to solution treatment and aging treatment is referred to as a state after heat treatment.

(Composition)

[0036] In the aluminum alloy of the embodiment, the first element is an essential element, and the second element is an optional element. Quantitatively, the aluminum alloy of the embodiment has a composition including silicon in an amount of 0.6 mass% to 1.5 mass%, magnesium in an amount of 0.5 mass% to 1.3 mass%, copper in an amount of 0.1 mass% to 1.2 mass%, manganese in an amount of 0.2 mass% to 1.15 mass%, iron in an amount of 0 mass% to 0.8 mass%, chromium in an amount of 0 mass% to 0.35 mass%, zinc in an amount of 0 mass% to 0.5 mass%, titanium in an amount of 0 mass% to 0.2 mass% and zirconium in an amount of 0 mass% to 0.2 mass% with the balance consisting of aluminum and inevitable impurities. The content ratio of iron in the aluminum alloy of the embodiment including at least one second element is more than 0 mass% and 0.8 mass% or less. The content ratio of chromium is more than 0 mass% and 0.35 mass% or less. The content ratio of zinc is more than 0 mass% and 0.5 mass% or less. The content ratio of titanium is more than 0 mass% and 0.2 mass% or less. The content ratio of zirconium is more than 0 mass% and 0.2 mass% or less.
[0037] Because the content ratio of the first element is equal to or more than the above-described lower limit value, a compound or the like containing the first element is precipitated in a state after the heat treatment. When the precipitates of the compounds or the like are present in a dispersed manner, an effect of improving strength due to precipitation hardening can be obtained. When a part of the first element forms a solid solution in aluminum which is a main component of the matrix phase, an effect of improving strength by solid solution strengthening can also be obtained. When the content ratio of the first element is equal to or less than the upper limit value described above, grain boundary embrittlement due to segregation of the first element is suppressed, or a compound or the like containing the first element is unlikely to become coarse. The coarse particles of the compound or the like can be the starting point of cracking. When the amount of the coarse particles is small, cracks caused by the coarse particles are less likely to occur. From these points of view, the aluminum alloy of the embodiment has a high tensile strength in a state after heat treatment. Since cracks caused by the coarse particles hardly occur in the manufacturing process, plastic working under cold conditions such as drawing under cold conditions can be favorably performed. From this point of view, the aluminum alloy of the em-

bodiment is also excellent in manufacturability.

[0038] When the second element is contained in addition to the first element, at least one effect selected from the group consisting of precipitation hardening, solid solution strengthening, suppression of grain boundary embrittlement, and suppression of coarsening of crystal grains can be expected. Due to such effects, the aluminum alloy of the embodiment containing the second element in addition to the first element tends to have higher tensile strength in a state after the heat treatment. When the content ratio of the second element satisfies the above-described upper limit range, the compound or the like containing the second element is unlikely to become coarse. In addition, depending on the type of the second element, the cast product can have a fine structure. From these points of view, the aluminum alloy of the embodiment containing the second element in addition to the first element is excellent in workability when plastic working is included in the manufacturing process. Depending on the type of the second element, the casting temperature can be lowered. From these points of view, the aluminum alloy of the embodiment containing the second element in addition to the first element is more excellent in manufacturability.

[0039] Specific examples of the composition containing the second element in addition to the first element include the following first composition, second composition, and third composition.

<First Composition>

[0040] The first composition includes silicon in an amount of 1.0 mass% to 1.3 mass%, magnesium in an amount of 0.5 mass% to 1.2 mass%, iron in an amount of 0.3 mass% to 0.8 mass%, copper in an amount of 0.1 mass% to 0.4 mass%, manganese in an amount of 0.2 mass% to 0.5 mass%, chromium in an amount of more than 0 mass% and 0.3 mass% or less, titanium in an amount of 0.001 mass% to 0.1 mass%, and zirconium in an amount of 0 mass% to 0.2 mass%, with the balance consisting of aluminum and inevitable impurities.

<Second Composition>

[0041] The second composition includes silicon in an amount of 0.6 mass% to 1.5 mass%, magnesium in an amount of 0.7 mass% to 1.3 mass%, iron in an amount of 0.02 mass% to 0.4 mass%, copper in an amount of 0.5 mass% to 1.2 mass%, manganese in an amount of 0.5 mass% to 1.1 mass%, chromium in an amount of more than 0 mass% and 0.3 mass% or less, zinc in an amount of 0.005 mass% to 0.5 mass%, titanium in an amount of 0.01 mass% to 0.2 mass%, and zirconium in an amount of 0.05 mass% to 0.2 mass%, with the balance consisting of aluminum and inevitable impurities. The second composition may further include strontium in an amount of 0.005 mass% to 0.05 mass%.

<Third Composition>

[0042] The third composition includes silicon in an amount of 0.9 mass% to 1.3 mass%, magnesium in an amount of 0.8 mass% to 1.2 mass%, iron in an amount of more than 0 mass% and 0.4 mass% or less, copper in an amount of 0.65 mass% to 1.1 mass%, manganese in an amount of 0.55 mass% to 1.15 mass%, chromium in an amount of more than 0 mass% and 0.35 mass% or less, zinc in an amount of 0.12 mass% to 0.25 mass%, titanium in an amount of more than 0 mass% and 0.075 mass% or less, and zirconium in an amount of 0.05 mass% to 0.17 mass%, with the balance consisting of aluminum and inevitable impurities. The third composition generally corresponds to the composition of the alloy indicated by the International Alloy Designation A6056.

[0043] Hereinafter, the content range of the first element and the content range of the second element in the first composition, the second composition, and the third composition will be exemplified.

<First Composition>

[0044] The content ratio of silicon may be more than 1.0 mass% and 1.3 mass% or less, or may be 1.1 mass% to 1.3 mass%.

[0045] The content ratio of magnesium may be 0.6 mass% to 1.1 mass%, or may be 0.7 mass% to 1.0 mass%.

[0046] The content ratio of iron may be 0.3 mass% to 0.7 mass%, or may be 0.3 mass% to 0.6 mass%.

[0047] The content ratio of copper may be 0.2 mass% to 0.4 mass%.

[0048] The content ratio of manganese may be 0.2 mass% to 0.4 mass%, or may be 0.2 mass% to 0.3 mass%.

[0049] The content ratio of chromium may be 0.005 mass% to 0.20 mass%, or may be 0.01 mass% to 0.10 mass%.

[0050] The content ratio of titanium may be 0.005 mass% to 0.05 mass%, or may be 0.01 mass% to 0.05 mass%.

[0051] When zirconium is included, the content ratio of zirconium may be 0.001 mass% to 0.20 mass%, or may be 0.005 mass% to 0.10 mass%.

[0052] The total content ratio of titanium and zirconium may be 0.01 mass% to 0.10 mass%.

<Second Composition>

[0053] The content ratio of silicon may be 0.8 mass% to 1.4 mass%, or may be 1.1 mass% to 1.3 mass%.
[0054] The content ratio of magnesium may be 0.8 mass% to 1.3 mass%, or may be 0.8 mass% to 1.0 mass%.
[0055] The content ratio of iron may be 0.05 mass% to 0.40 mass%.
[0056] The content ratio of copper may be 0.8 mass% to 1.2 mass%.
[0057] The content ratio of manganese may be 0.7 mass% to 1.1 mass%.
[0058] The content ratio of chromium may be 0.01 mass% to 0.30 mass%, or may be 0.05 mass% to 0.30 mass%.
[0059] The content ratio of zinc may be 0.05 mass% to 0.25 mass%.
[0060] The content ratio of titanium may be 0.01 mass% to 0.15 mass%.
[0061] The content ratio of zirconium may be 0.08 mass% to 0.2 mass%.
[0062] The total content ratio of titanium and zirconium may be 0.10 mass% to 0.20 mass%. When strontium is included, the content ratio of strontium may be 0.005 mass% to 0.04 mass%.

<Third Composition>

[0063] The content ratio of silicon may be 0.9 mass% to 1.2 mass%.
[0064] The content ratio of magnesium may be 0.8 mass% to 1.0 mass%.
[0065] The content ratio of iron may be 0.10 mass% to 0.25 mass%.
[0066] The content ratio of copper may be 0.65 mass% to 0.85 mass%.
[0067] The content ratio of manganese may be 0.55 mass% to 0.80 mass%, or may be 0.55 mass% to 0.65 mass%.
[0068] The content ratio of chromium may be 0.01 mass% to 0.10 mass%, or may be 0.02 mass% to 0.05 mass%.
[0069] The content ratio of zinc may be 0.13 mass% to 0.25 mass%.
[0070] The content ratio of titanium may be 0.001 mass% to 0.075 mass%, or may be 0.01 mass% to 0.075 mass%.
[0071] The content ratio of zirconium may be 0.10 mass% to 0.17 mass%.
[0072] The total content ratio of titanium and zirconium may be 0.11 mass% to 0.20 mass%.

<Other Elements>

[0073] When titanium is included, the aluminum alloy of the embodiment may further include boron in a range of 50 ppm by mass or less.

(Structure)

[0074] The inventors have found that an aluminum alloy having a high tensile strength in a state after heat treatment preferably has the following structure. In a whole area of a section of the aluminum alloy, a 111 plane of crystal grains is preferably more oriented than other crystal planes in the crystal grains. That is, most of the crystal grains constituting the section of the aluminum alloy are preferably oriented in the 111 plane. Quantitatively, in the aluminum alloy of the embodiment, an average of a degrees of orientation of a 111 plane determined by X-ray diffraction of a whole area of a section in a state after the heat treatment is 50% or more. Further, a variance of the degrees of orientation of the 111 plane is 45% or less. An aluminum alloy having a plurality of such sections and a plurality of sections arranged in a direction perpendicular to one section is unlikely to break even when pulled in the perpendicular direction as a tensile direction.
[0075] When the average of the degrees of orientation of the 111 plane is 50% or more, the 111 plane is oriented in the normal direction of the section in half or more of the crystal grains constituting the section of the aluminum alloy. When the variance of the degrees of orientation of the 111 plane is 45% or less, the distribution of the oriented crystal planes among the crystal grains constituting the section of the aluminum alloy is a distribution concentrated on the 111 plane. The aluminum alloy of such an embodiment has a high orientation of the 111 plane of crystal grains. In general, the tensile strength of an aluminum alloy tends to increase as the orientation of the 111 plane of crystal grains increases. Therefore, the aluminum alloy of the embodiment has high tensile strength in a state after heat treatment. As the average of the degrees of orientation of the 111 plane increases or as the variance of the degrees of orientation of the 111 plane decreases, the tensile strength tends to increase. From the viewpoint of improving the strength, the average of the degrees of orientation of the 111 plane may be 55% or more, or even 60% or more. The variance of the degrees of orientation of the 111 plane may be 40% or less, or even 38% or less.
[0076] Note that the average of the degrees of orientation of the 111 plane is 50% to 100%. The variance of the degrees of orientation of the 111 plane is more than 0% and 45% or less. In consideration of manufacturability, the average of the degrees of orientation of the 111 plane may be 99% or less, and the variance of the degrees of orientation of the 111 plane may be 1% or more.

[0077] In the aluminum alloy of the embodiment, the orientation of the 111 plane of the crystal grains is evaluated not in a part of the section but in the whole area of the section. In this regard, the aluminum alloy of the embodiment reliably has a higher strength structure in a state after heat treatment than that when only a portion of the section was evaluated.

[0078] When the aluminum alloy of the embodiment is a wire, a section to be measured for the degrees of orientation of the 111 plane is a section cut along a plane perpendicular to the longitudinal direction at an arbitrary position in the longitudinal direction of the wire. Hereinafter, a section taken along a plane perpendicular to the longitudinal direction of the wire composed of the aluminum alloy of the embodiment, that is, an aluminum alloy wire 1 of the embodiment may be referred to as cross section. In the wire, the 111 plane of the crystal grains is more oriented than the other crystal planes in the whole area of each cross section as described above. The orientation direction of the 111 plane in each cross section is the normal direction of the cross section, i.e. the direction along the longitudinal direction of the wire. Such a wire is hardly broken even if it is pulled with the longitudinal direction of the wire as a pulling direction.

[0079] In the aluminum alloy of the embodiment, even in a state where only solution treatment is performed and aging treatment is not performed, the average of the degrees of orientation of the 111 plane is 50% or more and the variance of the degrees of orientation of the 111 plane is 45% or less. That is, it is considered that the orientation of the 111 plane of the crystal grains does not substantially change before and after aging treatment.

(Tensile strength)

[0080] The aluminum alloy of the embodiment have a tensile strength of more than 425 MPa at room temperature in a state after heat treatment, for example. Here, the room temperature is 5°C to 35°C. The aluminum alloy of the embodiment having a tensile strength of more than 425 MPa have excellent strength. The aluminum alloy of embodiment having a tensile strength of more than 427 MPa, 430 MPa or more, or even 440 MPa or more are more excellent in strength. Depending on the composition and manufacturing conditions, the aluminum alloy of embodiment has high tensile strength of 450 MPa or more, 460 MPa or more, or even 470 MPa or more.

[0081] The upper limit of the tensile strength is not particularly limited. In consideration of manufacturability, the tensile strength at room temperature may be more than 425 MPa and 550 MPa or less, for example.

(Usage Mode)

[0082] The aluminum alloy of the embodiment can have various shapes. For example, the aluminum alloy of the embodiment has a somewhat elongated shape. The aluminum alloy of such an embodiment has an end face consisting of a plane perpendicular to its longitudinal direction and a drawn portion extending in the longitudinal direction. The length of the drawn portion along the longitudinal direction is longer than the diameter of a circle having an area equal to the area of the outer peripheral contour of the end face. In the aluminum alloy of the embodiment having the drawn portion, the section to be measured for the degrees of orientation of the 111 plane is obtained by cutting the drawn portion along a plane perpendicular to the longitudinal direction.

[0083] The aluminum alloy in the embodiment having the drawn portion are, for example, wire, pipe, plate, etc. That is, the drawn portion may be a solid body such as a wire or a plate, or a hollow body such as a pipe.

<Wire>

[0084] Aluminum alloy wire 1 of the embodiment is composed of the aluminum alloy of the embodiment. As shown in FIG. 1, aluminum alloy wire 1 of the embodiment includes an end face 10 and a drawn portion 11. Here, end face 10 is a surface perpendicular to the longitudinal direction of aluminum alloy wire 1. Drawn portion 11 extends in the longitudinal direction. Aluminum alloy wire 1 of the embodiment typically has the same outer peripheral contour and the same wire diameter over the entire length of drawn portion 11 as shown in FIG. 1. Here, the wire diameter is the diameter of a circle having the same area as the area of end face 10 or the area of a section cut along a plane perpendicular to the longitudinal direction. FIG. 1 shows a case in which the outer peripheral contour of end face 10 and the outer peripheral contour of an arbitrary section cut along a plane perpendicular to the longitudinal direction are circular. The outer peripheral contour of end face 10 and the outer peripheral contour of the section may be polygonal shapes such as squares, or may be curved shapes such as ellipses. The wire diameter of aluminum alloy wire 1 of the embodiment is not particularly limited. The wire diameter is, for example, about 3 mm to 15 mm.

[0085] In aluminum alloy wire 1 of the embodiment, a section to be measured for the degrees of orientation of the 111 plane is the cross section. In aluminum alloy wire 1 of the embodiment, an average of the degrees of orientation of the 111 plane determined by X-ray diffraction of the whole area of the cross section is 50% or more. Further, a variance of the degrees of orientation of the 111 plane is 45% or less. In aluminum alloy wire 1 of the embodiment, such cross sections are arranged in the longitudinal direction. Aluminum alloy wire 1 of such an embodiment has a high tensile strength of more than 425 MPa in a state after heat treatment.

<Aluminum Alloy Member>

[0086] The aluminum alloy of the embodiment can constitute an aluminum alloy member. For example, the aluminum alloy member is composed of the aluminum alloy of the embodiment and is subjected to solution treatment and aging treatment. A specific example is an aluminum alloy member in which plastic working is performed on aluminum alloy wire 1 of the embodiment and then solution treatment and aging treatment are performed thereon. Another example is an aluminum alloy member in which plastic working is performed on a plate composed of the aluminum alloy of the embodiment, and then solution treatment and aging treatment are performed thereon. Here, plastic working is performed so that the section of the aluminum alloy member has the above-described specific orientation after solution treatment and aging treatment. Still another example is an aluminum alloy member in which solution treatment and aging treatment are performed on aluminum alloy wire 1 of the embodiment. In other words, the aluminum alloy member may be linear or rod-shaped. In addition, the aluminum alloy member may be tubular.
[0087] For example, the aluminum alloy member is composed of an extruded material obtained by extruding aluminum alloy wire 1 with the longitudinal direction of aluminum alloy wire 1 of the embodiment as the extrusion direction. The aluminum alloy member extends along the extrusion direction. In this aluminum alloy member, the section to be measured for the degrees of orientation of the 111 plane is obtained by cutting the aluminum alloy member along a plane perpendicular to the extrusion direction. The average of the degrees of orientation of the 111 plane determined by X-ray diffraction of the whole area of the section is 50% or more. Further, a variance of the degrees of orientation of the 111 plane is 45% or less.
[0088] The above-described aluminum alloy member has high-strength because it is composed of an aluminum alloy having the above-described specific composition and the above-described specific structure. In addition, the aluminum alloy member is lighter than a metal member composed of an iron-based alloy such as steel. Such an aluminum alloy member can be used for applications in which light weight and high-strength are desired, such as automobile parts and various structural members.

(Method of Manufacturing Aluminum Alloy)

[0089] The inventors have studied a method of manufacturing an aluminum alloy having the above-described specific composition and having excellent strength in a state of having been subjected to solution treatment and aging treatment. As a result, the inventors have found that the plastic working performed just before solution treatment is preferably a cold working and a large degree of working. Based on this finding, when the aluminum alloy of the embodiment is manufactured, for example, the following method of manufacturing an aluminum alloy can be used.
[0090] The method of manufacturing the aluminum alloy includes performing a cold working on a material composed of the aluminum alloy to manufacture a cold worked product. The aluminum alloy has a composition including the above-described first element in the above-described range with the balance consisting of aluminum and inevitable impurities. The material is the worked product which has been subjected to a first plastic working. The cold working is a second plastic working with a degree of working of 20% or more.
The aluminum alloy may have a composition including the second element in addition to the first element in the above-described range.
[0091] In hot working and warm working, dislocation is more easily released than in cold working. On the other hand, since the second plastic working is cold working, strain, i.e., dislocation associated with the second plastic working is easily accumulated in the aluminum alloy as compared with the case of warm working or hot working. As the dislocations are accumulated, the 111 plane of the crystal grains is more likely to be oriented during the subsequent solution treatment. As a result, in a state of having been subjected to solution treatment and aging treatment as described above, a structure in which many 111 planes of crystal grains are oriented is obtained in the whole area of the section of the aluminum alloy.
[0092] Hereinafter, a method of manufacturing the above-described aluminum alloy will be specifically described.

< Material >

[0093] The above-described aluminum alloy material is a cast product subjected to first plastic working. The first plastic working is, for example, a rolling process. The first plastic working is, for example, hot working.

<Initial Softening>

[0094] The material described above can be subjected to a softening treatment under the following conditions. Hereinafter, the softening treatment performed to the material may be referred to as an initial softening treatment.

< <Conditions for Softening Treatment> >

[0095] The heating temperature is a temperature selected from a range of equal to or more than 250°C and less than 500°C. The holding time is a time selected from a range of 1 hour to 100 hours. The atmosphere during softening is, for example, an air atmosphere or a non-oxidizing atmosphere. The non-oxidizing atmosphere is, for example, a reduced-pressure atmosphere, an inert gas atmosphere, or a reducing gas atmosphere, etc.
[0096] The heating temperature may be 300°C to 480°C, or even 300°C to 460°C.
[0097] By subjecting the material to the initial softening treatment, the plastic workability of the aluminum alloy after the initial softening treatment is enhanced. Therefore, the degree of working of the second plastic working can be increased. When the material is not subjected to the initial softening treatment, the dislocations introduced by the first plastic working are accumulated in the aluminum alloy. As a result, it is easy to obtain an aluminum alloy in which many dislocations are accumulated.

<Second Plastic Working>

[0098] The second plastic working performed to the material is a cold working as described above. The second plastic working is, for example, drawing, rolling, extrusion, etc. When the second plastic working is drawing, a wire is obtained. When the second plastic working is a rolling, typically, a plate is obtained. When the second plastic working is extrusion, a wire, a plate, a pipe or the like can be obtained depending on the shape of an extrusion die.

< <Degree of Working>>

[0099] As the degree of working of the second plastic working is larger, the orientation of the 111 plane is increased. From the viewpoint of improvement in strength, the degree of working of the second plastic working may be 30% or more, 40% or more, or 60% or more. Here, the degree of working is a ratio obtained by dividing the difference between the sectional area before the second plastic working and the sectional area after the second plastic working by the sectional area before the second plastic working.

<Intermediate Softening>

[0100] A softening treatment can be performed during the second plastic working. Hereinafter, the softening treatment performed during the second plastic working may be referred to as an intermediate softening treatment. The conditions of the intermediate softening treatment may refer to the conditions of the initial softening treatment described above. By performing cold working before or after the intermediate softening treatment, dislocations are more likely to accumulate in the aluminum alloy than when warm working or hot working is performed as described above. In addition, by performing the intermediate softening treatment, it is possible to increase the degree of working of cold working after the intermediate softening treatment. Therefore, dislocations can be accumulated in the aluminum alloy by cold working after the intermediate softening treatment. As the degree of working of the cold working after the intermediate softening treatment increases, the orientation of the 111 plane increases. When the intermediate softening treatment is performed, the degree of working in the cold working after the intermediate softening treatment is preferably larger than the degree of working in the cold working before the intermediate softening treatment. In particular, the degree of working in cold working after the intermediate softening treatment may be 30% or more, 40% or more, even 60% or more.

(Manufacturing Method of Aluminum Alloy Wire)

[0101] The inventors have found that it is preferable to satisfy the following conditions in order to manufacture aluminum alloy wire 1 of the embodiment. Based on this finding, the method of manufacturing the aluminum alloy wire of the embodiment includes the following first step, second step, third step, and fourth step.

<Conditions>

[0102] Drawing is carried out under cold conditions. During the drawing, a softening treatment is performed. The degree of working of the drawing after the softening treatment is 20% or more and is more than the degree of working of the drawing before the softening treatment.
[0103] The first step is a step of performing plastic working on a cast product of an aluminum alloy containing the above-described first element in the above-described range and the balance consisting of aluminum and inevitable impurities to manufacture a worked product. In addition to the first element, the aluminum alloy constituting the cast product may further include a second element in the range described above.

The second step is a step of performing first drawing on the worked product under cold conditions to manufacture a first drawn product.
The third step is a step of performing softening treatment on the first drawn product to manufacture a softened product.
The fourth step is a step of performing second drawing on the softened product under cold conditions to manufacture a second drawn product.
In the method of manufacturing the aluminum alloy wire of the embodiment, the degree of working in the second drawing is 20% or more. Also, the degree of working in the second drawing is more than the degree of working in the first drawing. The plastic working of the first step corresponds to the first plastic working described above. The softening treatment of the third step corresponds to the intermediate softening treatment described above. The first drawing and the second drawing correspond to the second plastic working described above.

[0104] In the method of manufacturing the aluminum alloy wire of the embodiment, as described above, drawing is performed under cold conditions before and after the softening treatment, so that dislocations are likely to be accumulated in the aluminum alloy as compared with the case where warm working or hot working is performed. In addition, by performing the softening treatment, it is possible to increase the degree of working of the second drawing after the softening treatment as described above. Therefore, dislocations can be accumulated in the aluminum alloy by the second drawing after the softening treatment. According to the method of manufacturing aluminum alloy wire of the embodiment, aluminum alloy wire 1 of the embodiment can be manufactured. In addition, a material composed of the aluminum alloy having a specific composition as described above is excellent in drawability under cold conditions. According to the method of manufacturing the aluminum alloy wire of the embodiment using such a material, aluminum alloy wire 1 of the embodiment can be mass- manufactured.

[0105] Hereinafter, each step will be described. The basic operations in the method of manufacturing the aluminum alloy wire of the embodiment can be referred to the known method of manufacturing an aluminum alloy wire.

<First Step>

[0106] In the first step, the cast product is manufactured using, for example, a mold casting method, a continuous casting method, or the like. In the first step, the plastic working is, for example, hot rolling, and the worked product is, for example, a continuous-casted rolled product. When the worked product is a continuous-casted rolled product, a continuous long aluminum alloy wire can be manufactured. In this respect, aluminum alloy wire 1 of the embodiment can be mass-manufactured when the worked product is a continuous-casted rolled product.

[0107] The worked product may be subjected to the initial softening treatment as described above. When the initial softening treatment is performed, the degree of working of the subsequent first drawing can be increased as described above. When the initial softening treatment is not performed, the aluminum alloy wire in which many dislocations are finally accumulated is likely to be obtained as described above.

<Second Step>

[0108] In the second step, the degree of working of the first drawing is preferably 30% or more. When the degree of working of the first drawing is 30% or more, dislocations introduced by the first drawing are likely to remain to some extent after the softening treatment. As a result, it is easy to obtain an aluminum alloy wire in which many dislocations are finally accumulated. The degree of working of the first drawing may be 35% or more, or 40% or more. The degree of working of the first drawing depends on the final wire diameter, but is selected from a range of 30% to 80%, for example. The degree of working of the first drawing is a ratio obtained by dividing the difference between the sectional area before the first drawing and the sectional area after the first drawing by the sectional area before the first drawing.

<Third Step>

[0109] The conditions of the softening treatment in the third step may refer to the conditions of the initial softening treatment described above. By performing the softening treatment in the third step, the processability of the softened product after the softening treatment is enhanced. Therefore, the degree of working of the second drawing in the fourth step can be increased. In particular, the degree of working of the second drawing in the fourth step can be larger than the degree of working of the first drawing in the second step. As a result, dislocations can be accumulated in the aluminum alloy by the second drawing.

<Forth Step>

[0110] As the degree of working of the second drawing in the fourth step is larger, the orientation of the 111 plane is enhanced. When the degree of working of the second drawing is 20% or more, an aluminum alloy wire in which many dislocations are finally accumulated can be easily obtained. Since the degree of working of the second drawing is larger than the degree of working of the first drawing, an aluminum alloy wire in which many dislocations are finally accumulated is likely to be obtained. Since the degree of working of the first drawing is preferably 30% or more as described above, the degree of working of the second drawing may be more than 30%, 40% or more, or even 60% or more. The degree of working of the second drawing is selected from a range of 20% to 99.9% so as to obtain a second drawn product having a predetermined final wire diameter. The degree of working of the second drawing is a ratio obtained by dividing the difference between the sectional area before the second drawing and the sectional area after the second drawing by the sectional area before the second drawing.

(Method of Manufacturing Aluminum Alloy Member)

[0111] A method of manufacturing the above-described aluminum alloy member includes, for example, the following working step and heat treatment step.
[0112] The working step is a step of performing a third plastic working on the above-described second plastic working material subjected to the above-described second plastic working or the above-described second drawn product to manufacture a third worked product.
[0113] The heat treatment step is a step of sequentially performing a solution treatment and an aging treatment on the third worked product to manufacture an aged material.
[0114] The third plastic working is, for example, extrusion, forging, drawing, etc. The conditions of solution treatment and aging treatment are as described above.

[Main Effects of Embodiment]

[0115] The aluminum alloy of the embodiment and aluminum alloy wire 1 of the embodiment have high tensile strength in a state of having been subjected to solution treatment and aging treatment. In the following test example 1, aluminum alloy wire 1 of the embodiment is taken as an example to describe the above effect in detail.
[0116] According to the method of manufacturing the aluminum alloy wire of the embodiment, aluminum alloy wire 1 of the embodiment having high tensile strength in a state of having been subjected to solution treatment and aging treatment can be manufactured.

[Test Example 1]

[0117] The aluminum alloy wire having the composition shown in Table 1 was subjected to solution treatment and aging treatment, and the structure thereof was observed and the tensile strength thereof was measured. The manufacturing conditions of the aluminum alloy wire and the examination results are shown in Tables 2 to 4.

[Table 1]

	COMPONENT (MASS%)								
	Si	Mg	Fe	Cu	Mn	Cr	Zn	Zr+Ti	Ba l .
FIRST COMPOSITION	1.20	0.80	0.50	0.30	0.27	0.01	-	0.02	Al
SECOND COMPOSITION	1.15	0.90	0.30	1.00	1.00	0.25	0.15	0.15	Al
THIRD COMPOSITION	1.05	0.90	0.17	0.70	0.60	0.02	0.15	0.15	Al

(Preparation of Sample)

[0118] The aluminium alloy wire of each sample is basically manufactured by performing drawing on a continuous-casted rolled product under cold conditions. The continuous-casted rolled product can be manufactured with, for example, a known Properzi type continuous casting/rolling apparatus. The softening treatment is performed during the drawing except for some samples among the samples.
[0119] In Tables 2 to 4, the first composition, the second composition, and the third composition in the item of the composition correspond to the first composition, the second composition, and the third composition shown in Table 1, respectively.
[0120] In Tables 2 to 4, the item of softening treatment indicates the heating temperature (°C) and the holding time (hours). For example, "380°C × 10h" means that the heating temperature is 380°C and the holding time is 10 hours.
[0121] The samples whose conditions are described in three items of the degree of working (%) of the first drawing,

the softening treatment, and the degree of working (%) of the second drawing in Tables 2 to 4 will be described. The aluminum alloy wires of these samples are manufactured by sequentially performing first drawing under cold conditions, softening treatment, and second drawing under cold conditions on a continuous-casted rolled product. The aluminum alloy wires of these samples are not subjected to the initial softening treatment.
In Tables 2 to 4, the samples in which a hyphen "-" is described in the degree of working (%) of the first drawing and conditions are described in two items of the softening treatment and the degree of working (%) of the second drawing will be described. The aluminum alloy wires of these samples were manufactured by subjecting a continuous-casted rolled product to a softening treatment and then to the drawing under cold conditions at the degree of working (%) of the second drawing. The aluminum alloy wires of these samples were continuously subjected to the drawing under cold condition after the initial softening treatment of the continuous-casted rolled product, and were not subjected to the intermediate softening treatment.
In Table 2 to Table 4, samples in which conditions are described in two items of the degree of working (%) of the first drawing and the degree of working (%) of the second drawing, and a hyphen "-" is described in the softening treatment will be described. The aluminum alloy wires of these samples are manufactured by subjecting a continuous-casted rolled product to the drawing under cold conditions at the degree of working (%) of the first drawing and then to the drawing under cold conditions at the degree of working (%) of the second drawing without the intermediate softening treatment. That is, the aluminum alloy wires of these samples are continuously subjected to drawing under cold condition on the continuous-casted rolled product, and are not subjected to both the initial softening treatment and the intermediate softening treatment. The total degree of working in this cold drawing is larger than the degree of working listed in the item of degree of working (%) of the second drawing in Tables 2-4.
The wire diameter of the continuous-casted rolled product is selected from a range of 5 mm to 30 mm. The wire diameter of the second drawn product manufactured after the second drawing is a value selected from a range of about 1.0 mm to 21 mm according to the degree of working.

(Structure Observation)

<Degree of Orientation of 111 Plane>

[0122] The obtained aluminum alloy wire of each sample was subjected to solution treatment and aging treatment under the above-described conditions to manufacture a heat-treated wire. The obtained heat-treated wire is cut along a plane perpendicular to the longitudinal direction of the heat-treated wire to obtain a disk-shaped sample. The sample has two circular cross sections. The whole area of one of the two cross sections is smoothed by mechanical polishing. The surface roughness of the cross section after polishing is about 0.2 μm in terms of arithmetic mean roughness Ra. For example, 2000 water-resistant paper can be used for the mechanical polishing. The whole area of the polished cross section is subjected to X-ray diffraction as follows.

[0123] As shown in FIG. 6, a sample 3 is arranged on a surface 51f consisting of a flat plane provided on a movable stage 51. This arrangement is performed so that a cross section 30 of sample 3, which has been mechanically polished as described above, is parallel to surface 51f and cross section 30 is irradiated with an X-ray 6 from a predetermined direction D. Predetermined direction D is a direction corresponding to a predetermined plane index F. Predetermined plane index F is a crystal plane specified by the Miller index. Here, plane index F is any one crystal plane of three crystal planes of the 111 plane, 200 plane, and 220 plane. In FIG. 6, X-ray 6 from an X-ray source (not shown) and a diffracted X-ray 60 are indicated by dashed lines.

[0124] By irradiating cross section 30 of sample 3 with X-ray 6 from predetermined direction D, X-ray 60 diffracted from cross section 30 is detected by a detector 52. The detection of X-ray 60 is repeated while moving sample 3 two dimensionally in a plane parallel to cross section 30 with movable stage 51 so that the whole area of cross section 30 is measured. Thus, the distribution of the diffraction intensity in the whole area of cross section 30 is obtained. When sample 3 is moved two dimensionally, X-ray 6 is not moved. Further, an arithmetic unit 53 described later is set so as to exclude the diffraction intensity from the position where cross section 30 does not exist.

[0125] By changing an angle θ and an angle 2θ in accordance with plane index F, the distribution of the diffraction intensity of the 111 plane, the distribution of the diffraction intensity of the 200 plane, and the distribution of the diffraction intensity of the 220 plane are obtained. Angle θ is an angle formed by plane index F and X-ray 6. Angle 2θ is an angle formed by predetermined direction D and diffracted X-ray 60. A value obtained by normalizing each diffraction intensity is calculated by using a theoretical value based on a predetermined direction D. The normalized value is a value obtained by dividing each diffraction intensity by the theoretical value of the peak intensity of the diffraction intensity of X-ray diffraction. Using the normalized value, a normalized distribution is calculated from the distribution of each diffraction intensity. That is, the normalized distribution of the 111 plane, the normalized distribution of the 200 plane, and the normalized distribution of the 220 plane are calculated. The theoretical value may be acquired from a database of Powder Diffraction File (PDF) published by International Centre for Diffraction Data (ICDD). Instead of the peak intensity of the raw data, the X-ray profile data at each measurement point may be fitted and the maximum value or the integral value of the fitting curve may be used as the peak intensity. The fitting function used for the fitting is, for example, a Lorentz function or a Gauss function.

[0126] For each measurement point, a value obtained by normalizing the diffraction intensity of the 111 plane, a value obtained by normalizing the diffraction intensity of the 200 plane, and a value obtained by normalizing the diffraction intensity of the 220 plane are obtained. Further, the sum of these three normalized values is obtained. Further, the ratio of the value obtained by normalizing the diffraction intensity of the 111 plane to the sum of value is obtained. This ratio is the degree of orientation of the 111 plane. The average of the degrees of orientation of the 111 plane is a value obtained by averaging the degrees of orientation of the 111 plane at all the measurement points. The variance of the degrees of orientation of the 111 plane is obtained from the averaged value.

[0127] As X-ray 6, for example, a BL16 existing in a radiation light facility SAGA-LS can be used. The beam line can be an X-ray with a wave length of λ = 0.0919 nm, for example. For example, 0.5 mm square can be used as the slit width. As detector 52, for example, a commercially available two dimensional detector such as PILATUS 100K manufactured by Dectris can be used. The distance from cross section 30 of sample 3 to the two dimensional detector is 0.512 m. A commercially available computer can be used as arithmetic unit 53.

[0128] Angle θ, 2θ is selected according to the wavelength described above. Angle θ, 2θ is, for example, the following value when λ is 0.0919 nm.

When predetermined plane index F is the 111 plane, 11.3 degrees is used as angle θ formed by the 111 plane of sample 3 and X-ray 6. 22.6 degrees is used as angle 2θ formed by predetermined direction D and diffracted X-ray 60. FIG. 6 shows θ and 2θ, which are larger than the actual values.

When predetermined plane index F is the 200 plane, 13 degrees is used as angle θ formed by the 200 plane of sample 3 and X-ray 6. 26 degrees is used as angle 2θ formed by predetermined direction D and diffracted X-ray 60.

When the predetermined plane index is the 220 plane, 18.6 degrees is used as angle θ formed by the 220 plane of sample 3 and X-ray 6. 37.2 degrees is used as angle 2θ between predetermined direction D and diffracted X-ray 60.

<Tensile Strength>

[0129] The tensile strength (MPa) is measured in accordance with JIS Z 2241:2011. Here, the tensile strength at room temperature is measured.

<Component Analysis>

[0130] The composition of the obtained aluminum alloy wire of each sample is the same as the composition shown in Table 1. That is, the aluminum alloy constituting the aluminum alloy wire of each sample includes the elements shown in Table 1 in the range shown in Table 1, with the balance consisting of Al and inevitable impurities. A known method can be used to analyze the composition of the aluminum alloy wire. For example, an energy variance type X-ray analyzer or the like can be used for the analysis of the composition.

Table 2

SAMPLE No.	COMPOSITION	MANUFACTURING CONDITIONS			ORIENTATION		TENSILE STRENGTH (MPa)
		FIRST DRAWING DEGREE OF WORKING(%)	SOFTENING TREATMENT	SECOND DRAWING DEGREE OF WORKING(%)	DEGREE OF ORIENTATION OF 111 PLANE AVERAGE (%)	DEGREE OF ORIENTATION OF 111 PLANE VARIANCE (%)	
101	FIRST COMPOSITION	30	300°C × 10h	25	38	41	409
1		30	300°C × 10h	40	55	28	428
2		30	300°C × 10h	65	63	20	452
3		30	300°C × 10h	80	90	15	470
4		30	300°C × 10h	90	95	9	491
5		60	300°C × 10h	40	60	24	445
6		60	300°C × 10h	80	93	13	476
7		-	300°C × 10h	80	86	17	462
8		30	380°C × 10h	80	87	16	466
9		30	-	71	84	18	460

Table 3

SAMPLE No.	COMPOSITION	MANUFACTURING CONDITIONS			ORIENTATION		TENSILE STRENGTH (MPa)
		FIRST DRAWING DEGREE OF WORKING(%)	SOFTENING TREATMENT	SECOND DRAWING DEGREE OF WORKING(%)	DEGREE OF ORIENTATION OF 111 PLANE AVERAGE (%)	DEGREE OF ORIENTATION OF 111 PLANE VARIANCE (%)	
102	SECOND COMPOSITION	40	380°C × 10h	5	39	43	424
11		40	380°C × 10h	20	58	31	443
12		40	380°C × 10h	40	65	28	452
13		40	380°C × 10h	85	81	17	487
14		40	380°C × 10h	98	86	15	500
15		65	380°C × 10h	40	74	25	456
16		65	380°C × 10h	85	83	16	490
17		-	380°C × 10h	85	80	18	470
18		40	420°C × 10h	85	76	23	461
19		40	-	75	78	20	467

Table 4

SAMPLE No.	COMPOSITION	MANUFACTURING CONDITIONS			ORIENTATION		TENSILE STRENGTH (MPa)
		FIRST DRAWING DEGREE OF WORKING(%)	SOFTENING TREATMENT	SECOND DRAWING DEGREE OF WORKING(%)	DEGREE OF ORIENTATION OF 111 PLANE AVERAGE (%)	DEGREE OF ORIENTATION OF 111 PLANE VARIANCE (%)	
103	THIRD COMPOSITION	45	380°C × 10h	5	35	50	420
104		25	380°C × 10h	25	37	52	422
21		45	380°C × 10h	20	53	40	427
22		45	380°C × 10h	40	62	37	435
23		45	380°C × 10h	80	79	29	447
24		45	380°C × 10h	98	90	20	478
25		65	380°C × 10h	40	66	35	438
26		65	380°C × 10h	80	82	25	451
27		-	380°C × 10h	80	77	30	443
28		45	420°C × 10h	80	74	32	440
29		45	-	67	75	31	440

[0131] In the following description, sample Nos. 1 to 9, sample Nos. 11 to 19, and sample Nos. 21 to 29 may be collectively referred to as a first sample group. Sample Nos. 101 to 104 may be collectively referred to as a second sample group.

[0132] As shown in Tables 2 to 4, the aluminum alloy wires of the first sample group have higher tensile strength than the aluminum alloy wires of the second sample group. Quantitatively, the aluminum alloy wires of the first sample group have tensile strength more than 425 MPa. Many samples have tensile strength equal to or more than 440 MPa. Depending on the composition, some samples have tensile strength equal to or more than 470 MPa.

[0133] One of the reasons why the above-described results were obtained is considered to be the difference in the degrees of orientation of the 111 plane. In the aluminum alloy wires of the first sample group, the average of the degrees of orientation of the 111 plane is larger and the variance of the degrees of orientation of the 111 plane is smaller than those of the aluminum alloy wires of the second sample group. Quantitatively, in the aluminum alloy wires of the first sample group, the average of the degrees of orientation of the 111 plane is 50% or more, and the variance of the degrees of orientation of the 111 plane is 45% or less. In many samples, the average of the degrees of orientation of the 111 plane is 60% or more, and the variance of the degrees of orientation of the 111 plane is 35% or less. Depending on the composition, the average of the degrees of orientation of the 111 plane is 70% or more and the variance of the degrees of orientation of the 111 plane is 30% or less. This is shown visually with reference to FIGS. 2 to 5.

[0134] FIGS. 2 and 3 show the distribution of the degrees of orientation of the 111 plane for the aluminum alloy wire of sample No. 3. FIGS. 4 and 5 show the distribution of the degrees of orientation of the 111 plane for the aluminum alloy wire of sample No. 1. FIG. 2 and FIG. 4 are diagrams in which the degree of orientation of the 111 plane for each measurement point is converted into gray scale shading in the whole area of the cross section of the aluminum alloy wire. The bars shown on the right side of FIG. 2 and on the right side of FIG. 4 indicate shading according to the number of counts. The degree of orientation of the 111 plane of each measurement point is converted into the number of counts from 0 to 100, for example. Black means that the number of count is 0. White means that the number of count is 100. As the degree of orientation of the 111 plane increases, the number of counts increases, that is, the color becomes closer to white.

[0135] FIGS. 3 and 5 show the distribution of the degrees of orientation of the 111 plane by contour lines. Each contour line connects measurement points having the same degrees of orientation of the 111 plane. FIG. 2 and FIG. 4 show the following four contours lines. The thin solid line is a contour line connecting measurement points at which the degree of orientation of the 111 plane is 20%. The thin dashed line is a contour line connecting measurement points at which the degree of orientation of the 111 plane is 40%. A thin dotted line is a contour line connecting measurement points at which the degree of orientation of the 111 plane is 60%. A thick solid line is a contour line connecting measurement points at which the degree of orientation of the 111 plane is 80%.

[0136] In the aluminum alloy wire of sample No. 3 having a high tensile strength of 470 MPa, as shown in FIG. 2, there are many white measurement points, a few light gray measurement points, and almost no black measurement points. That is, there are many measurement points with large number of counts, and a variation in the number of counts is small. The fact that there are many measurement points with a large number of count is supported by the fact that a region surrounded by a thick solid line has a large area as shown in FIG. 3. Here, the shape and size of the region surrounded by the thick solid line are substantially close to the shape and the size of the cross section of the aluminum alloy wire of sample No. 3. Further, a region surrounded by other contour lines is hardly included in the region having the large area. The fact that the variation is small is supported by the fact that, as shown in FIG. 3, the regions surrounded by the four types of contour lines draw substantially the same shape. In the aluminum alloy wire of sample No. 3, the 111 plane is uniformly oriented in the normal direction of the cross section over the whole area of the cross section. It is considered that the aluminum alloy wire of sample No. 3 has a high tensile strength due to the structure in which the 111 plane is oriented.

[0137] In the aluminum alloy wire of sample No. 1 having a lower tensile strength than sample No. 3, as shown in FIG. 4, there are more dark gray and black measurement points than in sample No. 3. Dark gray measurement points are scattered. That is, measurement points having a small number of count are included, and a variation in the number of count is large to some extent. The inclusion of measurement points with small number of counts is also supported by the presence of a plurality of regions surrounded by thin solid lines as shown in FIG. 5. The fact that the variation is large to some extent is also supported by the fact that the shapes and the sizes of the regions surrounded by the above-described four types of contour lines are not uniform as shown in FIG. 5. Although there are a plurality of regions surrounded by thick solid lines, the total area is small. From this, it is considered that the aluminum alloy wires of the second sample group having a lower tensile strength than sample No. 1 includes measurement points of which number of count is smaller and has a larger variation in number of count than sample No. 1.

[0138] In addition, this test shows the following. (1) The aluminum alloy wire having the first composition and the second composition tends to have a larger average of the degrees of orientation of the 111 plane and a smaller variance of the degrees of orientation of the 111 plane than the aluminum alloy wire having the third composition. From this point of view, the aluminum alloy wire having the first composition and the second composition has higher strength.

[0139] (2) The aluminum alloy wire in which the average of the degrees of orientation of the 111 plane in a state of having been subjected to solution treatment and aging treatment is large and the variance of the degrees of orientation of the 111 plane is small can be manufactured with the manufacturing method that satisfies the above-described <Conditions>. In the aluminum alloy wires of the first sample group, it is considered that dislocations are accumulated in the state after the second drawing by satisfying the above-described <Conditions>. On the other hand, in the aluminum alloy wires of the second sample group, the degree of working of the second drawing is smaller than that of the aluminum alloy wires of the first sample group. In addition, in the aluminum alloy wires of the second sample group, the degree of working of the second drawing is less than the degree of working of the first drawing or the same as the degree of working of the first drawing. From these facts, it is considered that dislocations are not sufficiently accumulated in the aluminum alloy wires of the second sample group in the state after the second drawing.

[0140] The present disclosure is not limited to these examples, but is defined by the scope of the claims, and is intended to include all modifications within the meaning and scope equivalent to the scope of the claims. For example, in test example 1, the composition of the aluminum alloy may be changed, or the manufacturing conditions such as the degree of working of drawing and the condition of the softening treatment may be changed.

REFERENCE SIGNS LIST

[0141]

1 aluminum alloy wire, 3 sample
10 end face, 11 drawn portion, 30 cross section
6, 60 X-ray
51 movable stage, 51f surface, 52 detector, 53 arithmetic unit
D direction, F plane index, θ, 2θ angle

Claims

1. An aluminum alloy comprising a composition including

   silicon in an amount of 0.6 mass% to 1.5 mass%,
   magnesium in an amount of 0.5 mass% to 1.3 mass%,
   copper in an amount of 0.1 mass% to 1.2 mass%, and
   manganese in an amount of 0.2 mass% to 1.15 mass%, with the balance consisting of aluminum and inevitable impurities,
   wherein an average of degrees of orientation of a 111 plane determined by X-ray diffraction of a whole area of a section in a state of having been subjected to solution treatment and aging treatment is 50% or more, and a variance of the degrees of orientation of the 111 plane is 45% or less.

2. The aluminum alloy according to claim 1, wherein the composition further includes at least one element selected from the group consisting of iron, chromium, zinc, titanium, and zirconium,

   wherein a content ratio of iron is more than 0 mass% and 0.8 mass% or less,
   a content ratio of chromium is more than 0 mass% and 0.35 mass% or less,
   a content ratio of zinc is more than 0 mass% and 0.5 mass% or less,
   a content ratio of titanium is more than 0 mass% and 0.2 mass% or less, and
   a content ratio of zirconium is more than 0 mass% and 0.2 mass% or less.

3. The aluminum alloy according to claim 2, wherein the composition includes

   silicon in an amount of 1.0 mass% to 1.3 mass%,
   magnesium in an amount of 0.5 mass% to 1.2 mass%,
   iron in an amount of 0.3 mass% to 0.8 mass%,
   copper in an amount of 0.1 mass% to 0.4 mass%,
   manganese in an amount of 0.2 mass% to 0.5 mass%,
   chromium in an amount of more than 0 mass% and 0.3 mass% or less, and
   titanium in an amount of 0.001 mass% to 0.1 mass%, with the balance consisting of aluminum and inevitable impurities.

4. The aluminum alloy according to claim 2, wherein the composition includes

silicon in an amount of 0.6 mass% to 1.5 mass%,
magnesium in an amount of 0.7 mass% to 1.3 mass%,
iron in an amount of 0.02 mass% to 0.4 mass%,
copper in an amount of 0.5 mass% to 1.2 mass%,
manganese in an amount of 0.5 mass% to 1.1 mass%,
chromium in an amount of more than 0 mass% and 0.3 mass% or less,
zinc in an amount of 0.005 mass% to 0.5 mass%,
titanium in an amount of 0.01 mass% to 0.2 mass%, and
zirconium in an amount of 0.05 mass% to 0.2 mass%, with the balance consisting of aluminum and inevitable impurities.

5. The aluminum alloy according to any one of claims 1 to 4, having a tensile strength of more than 425 MPa in a state of having been subjected to solution treatment and aging treatment.

6. An aluminum alloy wire composed of
the aluminum alloy according to any one of claims 1 to 5.

7. A method of manufacturing an aluminum alloy wire, the method comprising:

performing plastic working on a cast product of an aluminum alloy to manufacture a worked product, the aluminum alloy having a composition including silicon in an amount of 0.6 mass% to 1.5 mass%, magnesium in an amount of 0.5 mass% to 1.3 mass%, copper in an amount of 0.1 mass% to 1.2 mass%, and manganese in an amount of 0.2 mass% to 1.15 mass%, with the balance consisting of aluminum and inevitable impurities;
performing first drawing on the worked product under cold conditions to manufacture a first drawn product;
performing softening treatment on the first drawn product to manufacture a softened product; and
performing second drawing on the softened product under cold conditions to manufacture a second drawn product,
wherein a degree of working in the second drawing is 20% or more and is also higher than a degree of working in the first drawing.

8. The method of manufacturing an aluminum alloy wire according to claim 7,

wherein the aluminum alloy further includes at least one element selected from the group consisting of iron, chromium, zinc, titanium, and zirconium,
a content ratio of iron is more than 0 mass% and 0.8 mass% or less,
a content ratio of chromium is more than 0 mass% to 0.35 mass% or less,
a content ratio of zinc is more than 0 mass% and 0.5 mass% or less,
a content ratio of titanium is more than 0 mass% and 0.2 mass% or less, and
a content ratio of zirconium is more than 0 mass% and 0.2 mass% or less.

FIG. 1

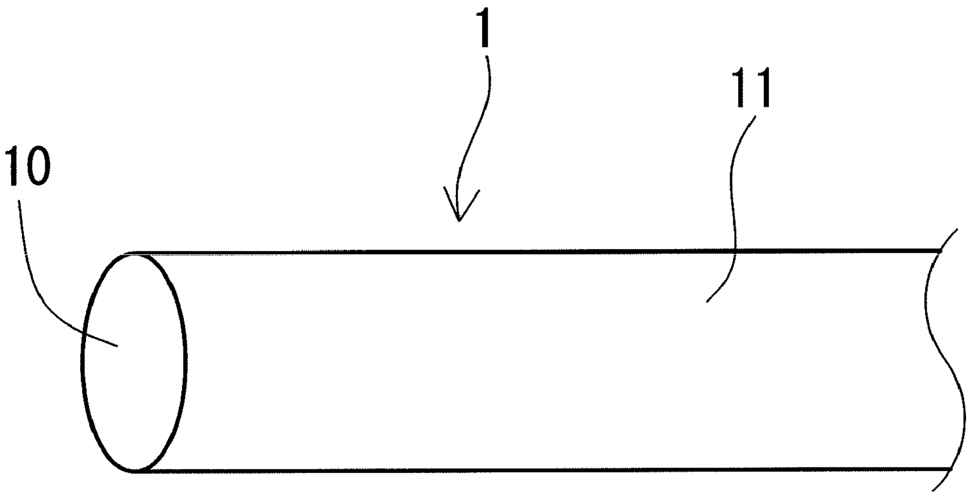


FIG. 2

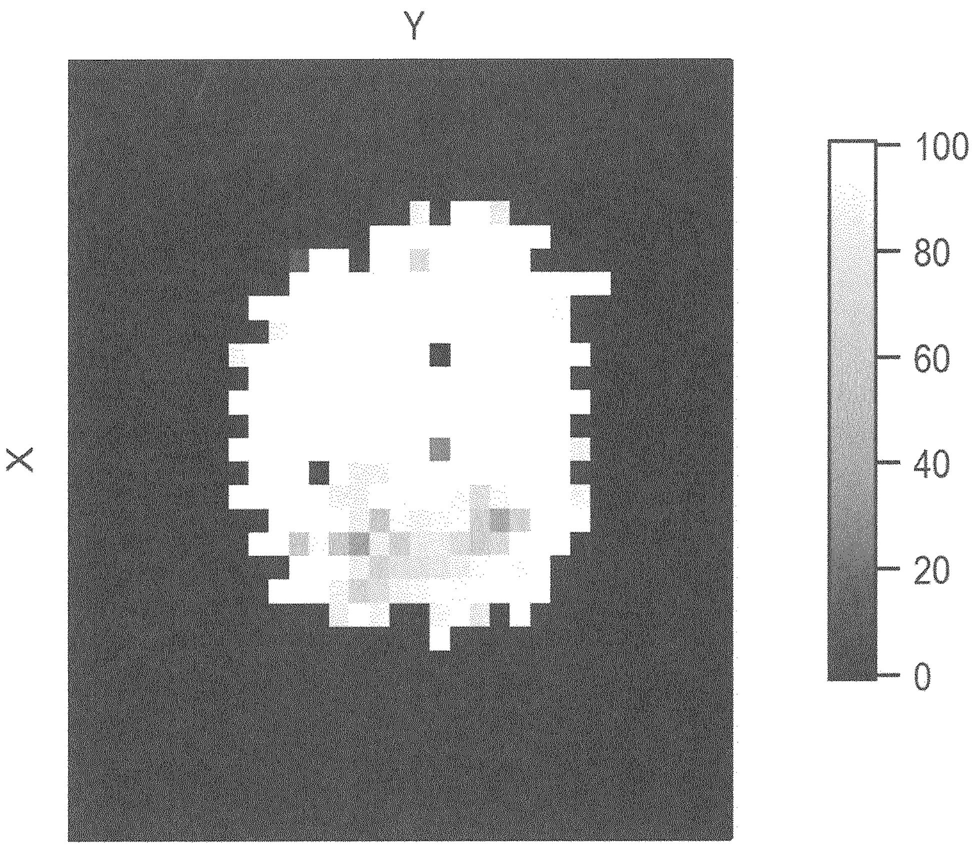


FIG. 3

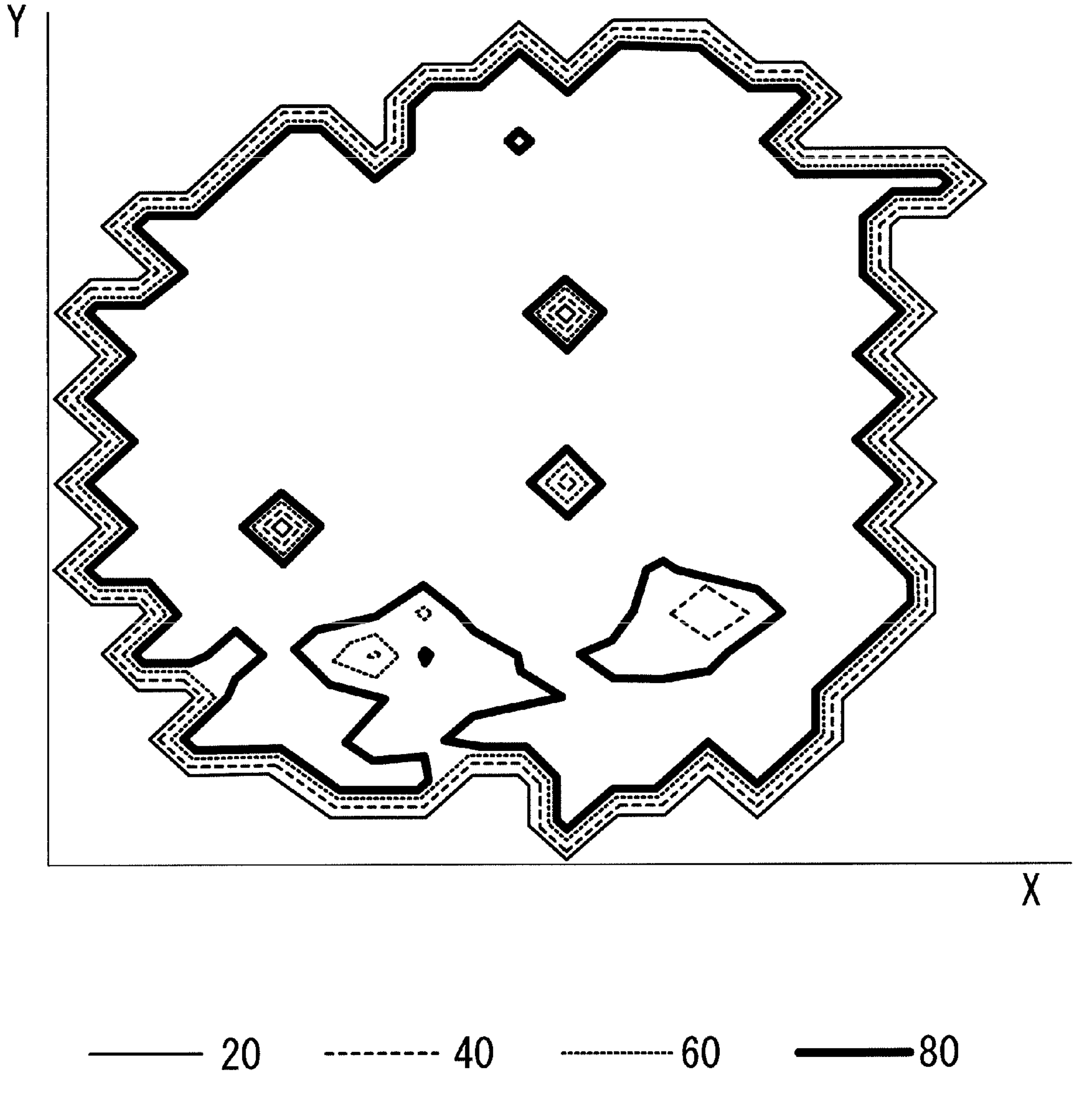


FIG. 4

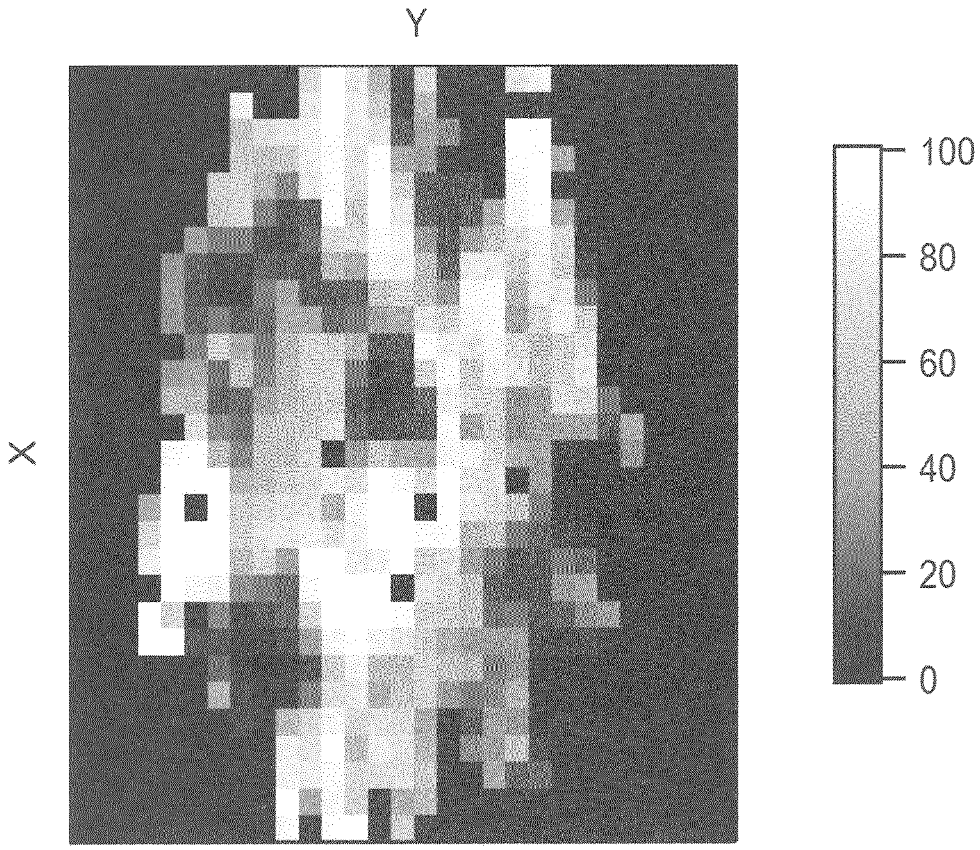


FIG. 5

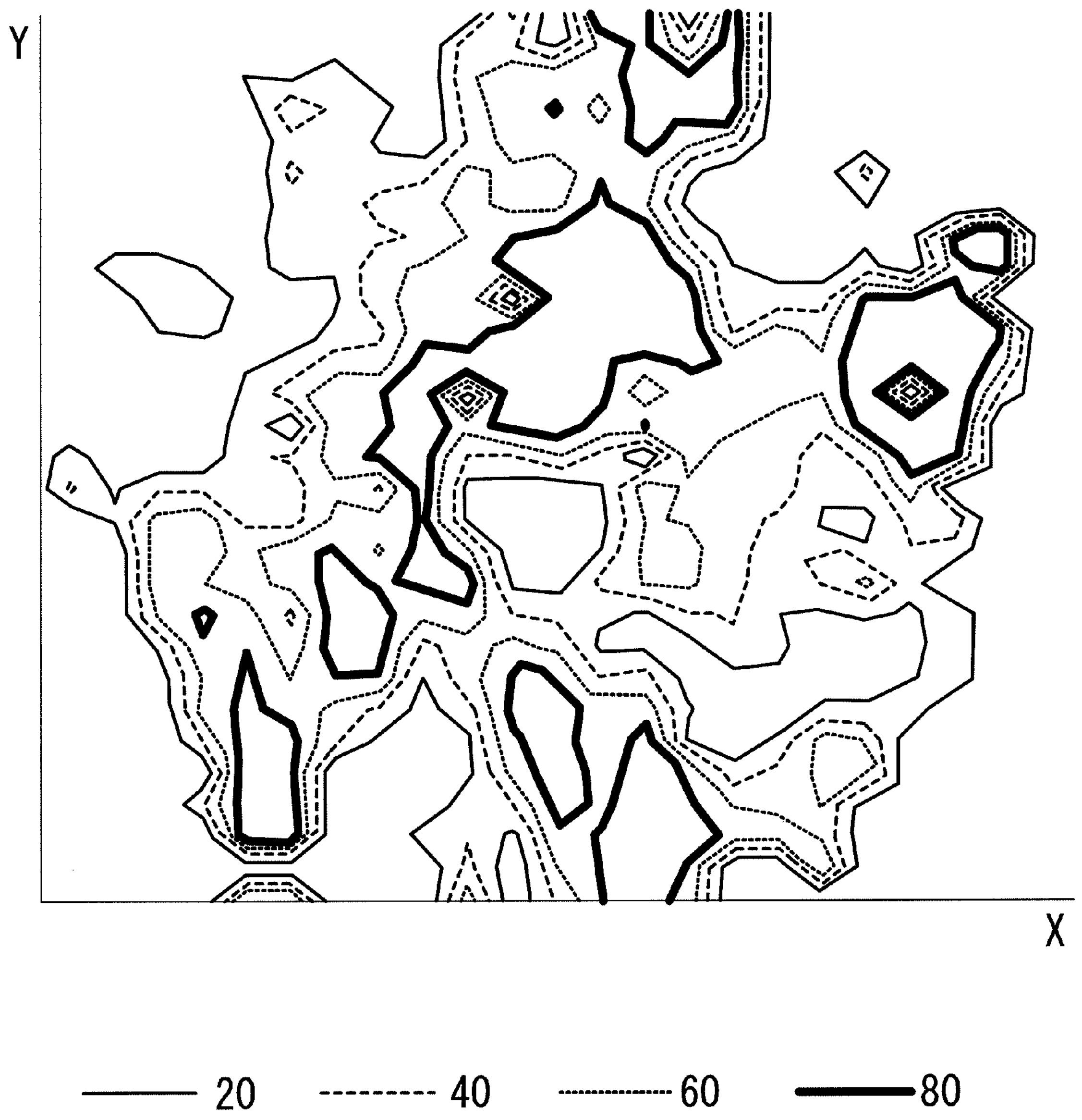
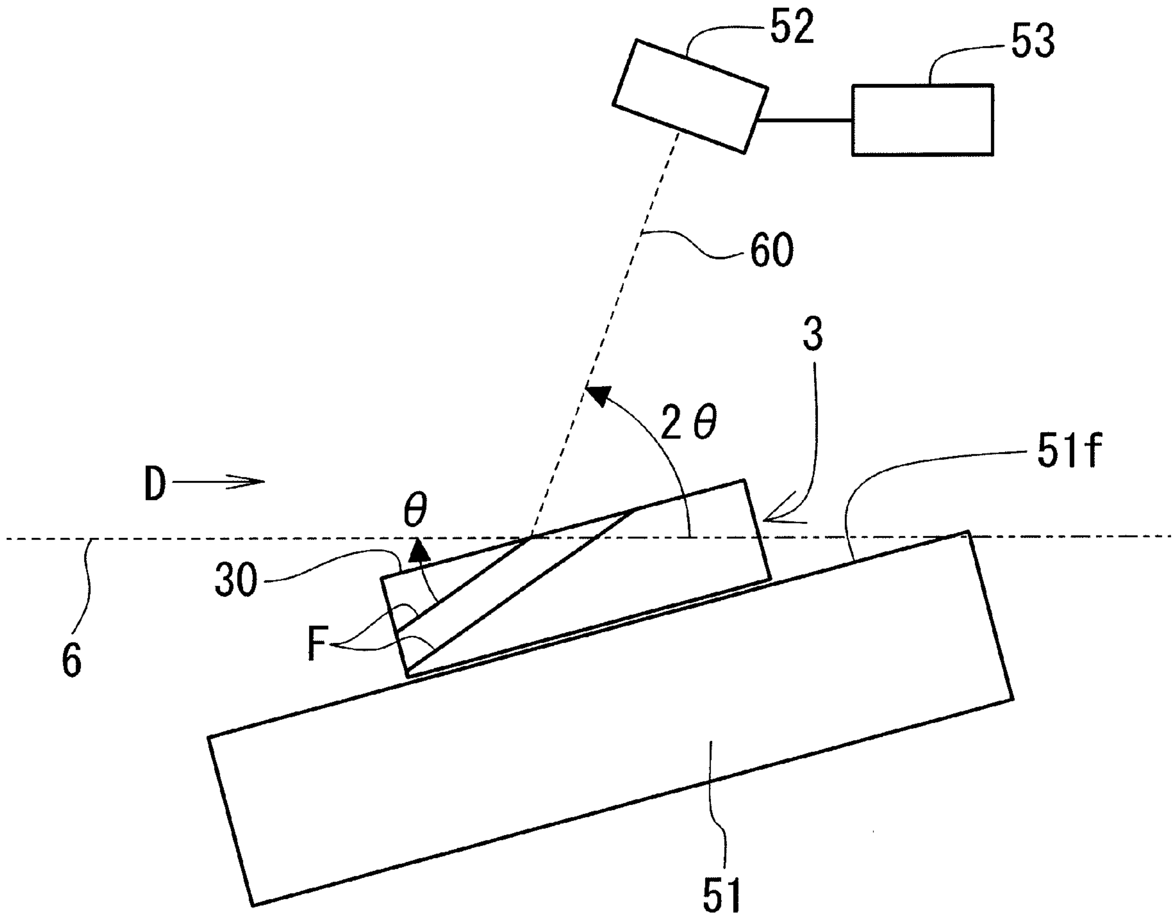


FIG. 6



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/011698

A. CLASSIFICATION OF SUBJECT MATTER

C22C 21/00(2006.01)i; ***C22C 21/02***(2006.01)i; ***C22C 21/06***(2006.01)i; ***C22C 21/12***(2006.01)i; ***C22F 1/00***(2006.01)i; ***C22F 1/02***(2006.01)i; ***C22F 1/04***(2006.01)i; ***C22F 1/05***(2006.01)i; ***C22F 1/057***(2006.01)i

FI: C22C21/02; C22C21/00 L; C22C21/06; C22C21/12; C22F1/04 B; C22F1/057; C22F1/05; C22F1/00 606; C22F1/00 623; C22F1/00 625; C22F1/00 626; C22F1/00 630A; C22F1/00 683; C22F1/00 684C; C22F1/00 685Z; C22F1/00 686B; C22F1/00 691B; C22F1/00 691C; C22F1/00 691Z; C22F1/00 694A; C22F1/02

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)

C22C21/00; C22C21/02; C22C21/06; C22C21/12; C22F1/00; C22F1/02; C22F1/04; C22F1/05; C22F1/057

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

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2012-97321 A (FURUKAWA-SKY ALUMINUM CORP) 24 May 2012 (2012-05-24) claims 1, 2, paragraphs [0012], [0021], [0028]-[0030], [0035]	1-8
A	JP 2013-104122 A (SUMITOMO ELECTRIC IND LTD) 30 May 2013 (2013-05-30) paragraphs [0026]-[0070]	1-8
A	JP 2007-177308 A (SUMITOMO LIGHT METAL IND LTD) 12 July 2007 (2007-07-12) paragraphs [0026]-[0046]	1-8

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

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

Date of the actual completion of the international search	Date of mailing of the international search report
13 May 2022	**24 May 2022**

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office (ISA/JP) **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/011698

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JP 2013-104122 A	30 May 2013	CN 103339276 A paragraphs [0044]-[0143] KR 10-2013-0121927 A	
JP 2007-177308 A	12 July 2007	(Family: none)	

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

REFERENCES CITED IN THE DESCRIPTION

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- JP 2015124409 A **[0003]**