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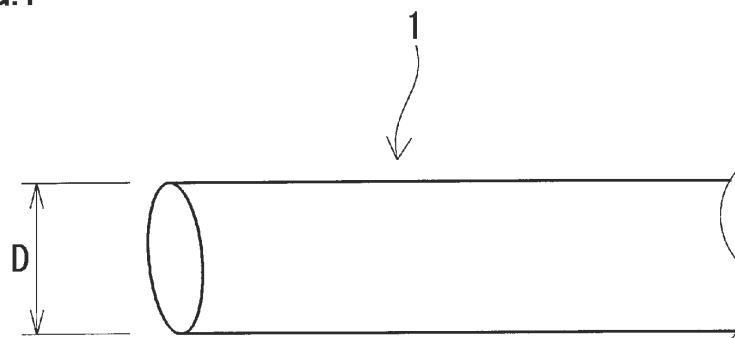
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(54) **ALUMINUM ALLOY WIRE AND METHOD FOR PRODUCING ALUMINUM ALLOY WIRE**

(57) An aluminum alloy wire composed of aluminum alloy, wherein the aluminum alloy includes 1.0 mass% or more and 1.3 mass% or less of silicon, 0.5 mass% or more and 1.2 mass% or less of magnesium, 0.3 mass% or more and 0.8 mass% or less of iron, 0.1 mass% or more and 0.4 mass% or less of copper, 0.2 mass% or more and 0.5 mass% or less of manganese, 0.001 mass% or more and 0.3 mass% or less of chromium, 0

mass% or more and 0.25 mass% or less of zinc, 0 mass% or more and 0.075 mass% or less of titanium, and 0 mass% or more and 0.17 mass% or less of zirconium, a remainder of the aluminum alloy consists of aluminum and an inevitable impurity, a 0.2% proof stress when compressed is 360 MPa or more, a crystal grain size of the aluminum alloy is 200 μm or less, and a degree of compressive deformation is 0.6 or more and 1.0 or less.

FIG.1



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Description

TECHNICAL FIELD

[0001] The present disclosure relates to an aluminum alloy wire and a method of producing the aluminum alloy wire.
[0002] The present application claims priority based on Japanese Patent Application No. 2023-138357 filed on August 28, 2023, the entire contents of which are incorporated herein by reference.

BACKGROUND ART

[0003] An aluminum alloy has been used as a material for various products each required to have a reduced weight. In particular, each of 6000 series aluminum alloys defined by the International Alloy Designation System has high strength and excellent corrosion resistance, and has been therefore used for a structural member, an automobile part, and the like. The 6000 series aluminum alloy is an Al-Mg-Si-based alloy in which silicon and magnesium are added to aluminum. Among the 6000 series aluminum alloys, A6061 can have strength improved by a T6 treatment. The T6 treatment is a heat treatment in which an artificial aging treatment is performed after a solution treatment.

[0004] Each of PTL 1 and PTL 2 discloses an aluminum alloy wire composed of an aluminum alloy having a specific composition. PTL 1 describes an aluminum alloy including, in terms of mass%, more than 1.0% and 1.5% or less of Si (silicon), 0.5% or more and 1.2% or less of Mg (magnesium), 0.3% or more and 0.8% or less of Fe (iron), 0% or more and 0.5% or less of Cu (copper), 0% or more and 0.5% or less of Mn (manganese), and 0% or more and 0.5% or less of Cr (chromium) with a remainder thereof being Al (aluminum) and an inevitable impurity. In the aluminum alloy of PTL 1, the content of the iron is equal to or more than the content of the copper. PTL 2 describes an aluminum alloy having a composition including 1.0 mass% or more and 1.3 mass% or less of silicon, 0.5 mass% or more and 1.2 mass% or less of magnesium, 0.3 mass% or more and 0.8 mass% or less of iron, 0.1 mass% or more and 0.4 mass% or less of copper, 0.2 mass% or more and 0.5 mass% or less of manganese, more than 0 mass% and 0.3 mass% or less of chromium, and 0.001 mass% or more and 0.1 mass% or less of titanium with a remainder thereof consisting of aluminum and an inevitable impurity. The aluminum alloy of PTL 2 may further include 0.001 mass% or more and 0.2 mass% or less of zirconium. The aluminum alloy wire is produced, for example, by performing rolling on a casted material of an aluminum alloy and then performing wire drawing on the rolled material.

CITATION LIST

PATENT LITERATURE

[0005]

PTL 1: Japanese Patent Laying-Open No. 2015-166480

PTL 2: WO 2022/249664

SUMMARY OF INVENTION

[0006] An aluminum alloy wire of the present disclosure is an aluminum alloy wire composed of an aluminum alloy. The aluminum alloy includes 1.0 mass% or more and 1.3 mass% or less of silicon, 0.5 mass% or more and 1.2 mass% or less of magnesium, 0.3 mass% or more and 0.8 mass% or less of iron, 0.1 mass% or more and 0.4 mass% or less of copper, 0.2 mass% or more and 0.5 mass% or less of manganese, 0.001 mass% or more and 0.3 mass% or less of chromium, 0 mass% or more and 0.25 mass% or less of zinc, 0 mass% or more and 0.075 mass% or less of titanium, and 0 mass% or more and 0.17 mass% or less of zirconium, and a remainder of the aluminum alloy consists of aluminum and an inevitable impurity. In a measurement result obtained after performing a solution treatment and an aging treatment on the aluminum alloy wire, a 0.2% proof stress when compressed is 360 MPa or more, a crystal grain size of the aluminum alloy is 200 μm or less, and a degree of compressive deformation C when compressed at a compression ratio of 50% is 0.6 or more and 1.0 or less. In the solution treatment, a heating temperature is 530°C or more and 580°C or less, a holding time is 15 minutes or more and 360 minutes or less, and a temperature increase rate is 120°C/min or less. In the aging treatment, a heating temperature is 160°C or more and 190°C or less, and a holding time is 2 hours or more and 40 hours or less.

BRIEF DESCRIPTION OF DRAWINGS

[0007]

[Fig. 1] Fig. 1 is a schematic perspective view showing an exemplary aluminum alloy wire according to an embodiment.

[Fig. 2] Fig. 2 is a schematic diagram illustrating a method of measuring a degree of compressive deformation of the aluminum alloy wire.

[Fig. 3] Fig. 3 is a diagram showing a K absorption edge spectrum of Cr of each of samples No. 2a and No. 10a of a test example 1.

DETAILED DESCRIPTION

[Problem to be Solved by the Present Disclosure]

[0008] There has been required an aluminum alloy wire having a strength equal to or more than that of A6061 and having excellent plastic workability.

[0009] An aluminum alloy member is produced by performing plastic working on an aluminum alloy wire. Examples of the aluminum alloy member includes a structural member and an automobile part. The plastic working is, for example, forging, rolling, and press working. Moreover, a high proof stress is required depending on a purpose of use of the aluminum alloy member. In particular, in the case of an aluminum alloy member to be subjected to a compressive load during use, a proof stress against compression is desirably high.

[0010] One object of the present disclosure is to provide an aluminum alloy wire having high strength and excellent workability.

[Advantageous Effect of the Present Disclosure]

[0011] The aluminum alloy wire of the present disclosure has high strength and excellent workability when a predetermined solution treatment and an aging treatment are performed.

[Description of Embodiments]

[0012] First, embodiments of the present disclosure will be listed and described.

(1) An aluminum alloy wire of the present disclosure is an aluminum alloy wire composed of an aluminum alloy. The aluminum alloy includes 1.0 mass% or more and 1.3 mass% or less of silicon, 0.5 mass% or more and 1.2 mass% or less of magnesium, 0.3 mass% or more and 0.8 mass% or less of iron, 0.1 mass% or more and 0.4 mass% or less of copper, 0.2 mass% or more and 0.5 mass% or less of manganese, 0.001 mass% or more and 0.3 mass% or less of chromium, 0 mass% or more and 0.25 mass% or less of zinc, 0 mass% or more and 0.075 mass% or less of titanium, and 0 mass% or more and 0.17 mass% or less of zirconium, and a remainder of the aluminum alloy consists of aluminum and an inevitable impurity. In a measurement result obtained after performing a solution treatment and an aging treatment on the aluminum alloy wire, a 0.2% proof stress when compressed is 360 MPa or more, a crystal grain size of the aluminum alloy is 200 μm or less, and a degree of compressive deformation C when compressed at a compression ratio of 50% is 0.6 or more and 1.0 or less. In the solution treatment, a heating temperature is 530°C or more and 580°C or less, a holding time is 15 minutes or more and 360 minutes or less, and a temperature increase rate is 120°C/min or less. In the aging treatment, a heating temperature is 160°C or more and 190°C or less, and a holding time is 2 hours or more and 40 hours or less.

[0013] The aluminum alloy wire according to (1) has the specific composition, and therefore has high strength and excellent workability when the predetermined solution treatment and aging treatment are performed. In the aluminum alloy wire according to (1), the 0.2% proof stress when compressed, the crystal grain size of the aluminum alloy, and the degree of compressive deformation C satisfy the respective specific ranges in a state in which the solution treatment and the aging treatment have been performed. Since the 0.2% proof stress when compressed is 360 MPa or more, a proof stress against compression is high. Since the crystal grain size of the aluminum alloy is 200 μm or less, the aluminum alloy has high strength and excellent workability. Further, since the degree of compressive deformation C is 0.6 or more and 1.0 or less, the workability is excellent. The aluminum alloy wire according to (1) has not been subjected to the solution treatment and the aging treatment, and corresponds to a "normal wire material" described later.

[0014] (2) In the aluminum alloy wire according to (1), in the measurement result obtained after performing the solution treatment and the aging treatment on the aluminum alloy wire, an apex of a main peak in a K absorption edge spectrum of the chromium as obtained by an XAFS analysis may be located in a range of 6012.75 eV or more and 6014.00 eV or less. The apex of the main peak is found by fitting the main peak with a Gaussian function in a range of 6009 eV to 6017 eV.

[0015] In the aluminum alloy wire according to (2), it is considered that the chromium is dissolved to form solid solution and

precipitated in the aluminum alloy in a well-balanced manner when the solution treatment and the aging treatment are performed. In the aluminum alloy wire according to (2), the crystal structure of the aluminum alloy is fine, the strength is high, and the workability is excellent.

[0016] (3) An aluminum alloy wire of the present disclosure is an aluminum alloy wire composed of an aluminum alloy. The aluminum alloy includes 1.0 mass% or more and 1.3 mass% or less of silicon, 0.5 mass% or more and 1.2 mass% or less of magnesium, 0.3 mass% or more and 0.8 mass% or less of iron, 0.1 mass% or more and 0.4 mass% or less of copper, 0.2 mass% or more and 0.5 mass% or less of manganese, 0.001 mass% or more and 0.3 mass% or less of chromium, 0 mass% or more and 0.25 mass% or less of zinc, 0 mass% or more and 0.075 mass% or less of titanium, and 0 mass% or more and 0.17 mass% or less of zirconium, and a remainder of the aluminum alloy consists of aluminum and an inevitable impurity. In a measurement result obtained after performing an aging treatment on the aluminum alloy wire, a 0.2% proof stress when compressed is 360 MPa or more, a crystal grain size of the aluminum alloy is 200 μm or less, and a degree of compressive deformation C when compressed at a compression ratio of 50% is 0.6 or more and 1.0 or less. In the aging treatment, a heating temperature is 160°C or more and 190°C or less, and a holding time is 2 hours or more and 40 hours or less.

[0017] The aluminum alloy wire according to (3) has the specific composition, and therefore has high strength and excellent workability when the predetermined aging treatment is performed. In the aluminum alloy wire according to (3), the 0.2% proof stress when compressed, the crystal grain size of the aluminum alloy, and the degree of compressive deformation C satisfy the respective specific ranges in a state in which the aging treatment has been performed. Since the 0.2% proof stress when compressed is 360 MPa or more, a proof stress against compression is high. Since the crystal grain size of the aluminum alloy is 200 μm or less, the aluminum alloy has high strength and excellent workability. Further, since the degree of compressive deformation C is 0.6 or more and 1.0 or less, the workability is excellent. The aluminum alloy wire according to (3) has been subjected only to the solution treatment, and corresponds to a "solution-treated wire material" described later.

[0018] (4) In the aluminum alloy wire according to (3), in the measurement result obtained after performing the aging treatment on the aluminum alloy wire, an apex of a main peak in a K absorption edge spectrum of the chromium as obtained by an XAFS analysis may be located in a range of 6012.75 eV or more and 6014.00 eV or less. The apex of the main peak is found by fitting the main peak with a Gaussian function in a range of 6009 eV to 6017 eV.

[0019] In the aluminum alloy wire according to (4), it is considered that the chromium is dissolved to form solid solution and precipitated in the aluminum alloy in a well-balanced manner when the aging treatment is performed. In the aluminum alloy wire according to (4), the crystal structure of the aluminum alloy is fine, the strength is high, and the workability is excellent.

[0020] (5) An aluminum alloy wire of the present disclosure is an aluminum alloy wire composed of an aluminum alloy. The aluminum alloy includes 1.0 mass% or more and 1.3 mass% or less of silicon, 0.5 mass% or more and 1.2 mass% or less of magnesium, 0.3 mass% or more and 0.8 mass% or less of iron, 0.1 mass% or more and 0.4 mass% or less of copper, 0.2 mass% or more and 0.5 mass% or less of manganese, 0.001 mass% or more and 0.3 mass% or less of chromium, 0 mass% or more and 0.25 mass% or less of zinc, 0 mass% or more and 0.075 mass% or less of titanium, and 0 mass% or more and 0.17 mass% or less of zirconium, and a remainder of the aluminum alloy consists of aluminum and an inevitable impurity. In the aluminum alloy wire, a 0.2% proof stress when compressed is 360 MPa or more, a crystal grain size of the aluminum alloy is 200 μm or less, and a degree of compressive deformation C when compressed at a compression ratio of 50% is 0.6 or more and 1.0 or less.

[0021] The aluminum alloy wire according to (5) has the specific composition, and therefore has high strength and excellent workability. Since the 0.2% proof stress when compressed is 360 MPa or more in the aluminum alloy wire according to (5), a proof stress against compression is high. Since the crystal grain size of the aluminum alloy is 200 μm or less, the aluminum alloy has high strength and excellent workability. Further, since the degree of compressive deformation C is 0.6 or more and 1.0 or less, the workability is excellent. The aluminum alloy wire according to (5) has been subjected to the solution treatment and the aging treatment, and corresponds to an "aging-treated wire material" described later.

[0022] (6) In the aluminum alloy wire according to (5), an apex of a main peak in a K absorption edge spectrum of the chromium as obtained by an XAFS analysis may be located in a range of 6012.75 eV or more and 6014.00 eV or less. The apex of the main peak is found by fitting the main peak with a Gaussian function in a range of 6009 eV to 6017 eV.

[0023] In the aluminum alloy wire according to (6), it is considered that the chromium is dissolved to form solid solution and precipitated in the aluminum alloy in a well-balanced manner. In the aluminum alloy wire according to (6), the crystal structure of the aluminum alloy is fine, the strength is high, and the workability is excellent.

[0024] (7) In the aluminum alloy wire according to any one of (1) to (6), a wire diameter of the aluminum alloy wire may be 1 mm or more and 30 mm or less.

[0025] Since the wire diameter of the aluminum alloy wire according to (7) is 1 mm or more and 30 mm or less, it is possible to achieve necessary strength and reduced weight.

[0026] (8) A method of producing an aluminum alloy wire according to the present disclosure includes: producing a continuous casted and rolled material composed of an aluminum alloy; producing a first drawn wire material by performing

a first wire drawing process on the continuous casted and rolled material; producing an intermediate heat-treated material by performing an intermediate heat treatment on the first drawn wire material; and producing a second drawn wire material by performing a second wire drawing process on the intermediate heat-treated material. The aluminum alloy includes 1.0 mass% or more and 1.3 mass% or less of silicon, 0.5 mass% or more and 1.2 mass% or less of magnesium, 0.3 mass% or more and 0.8 mass% or less of iron, 0.1 mass% or more and 0.4 mass% or less of copper, 0.2 mass% or more and 0.5 mass% or less of manganese, 0.001 mass% or more and 0.3 mass% or less of chromium, 0 mass% or more and 0.25 mass% or less of zinc, 0 mass% or more and 0.075 mass% or less of titanium, and 0 mass% or more and 0.17 mass% or less of zirconium, and a remainder of the aluminum alloy consists of aluminum and an inevitable impurity. In the intermediate heat treatment, a heating temperature is 250°C or more and less than 350°C, and a holding time is 1 hour or more and less than 5 hours. A second processing degree in the second wire drawing process is 20% or less.

[0027] In the method of producing the aluminum alloy wire according to the present disclosure, since the conditions of the intermediate heat treatment and the second processing degree of the second wire drawing process satisfy the specific ranges in the aluminum alloy wire having the specific composition, it is possible to control a balance between the solid solution/precipitation states of the chromium in the aluminum alloy when the solution treatment and the aging treatment are performed. The crystal structure of the aluminum alloy is fine in the aluminum alloy wire in the state in which the chromium is dissolved to form solid solution and precipitated in the aluminum alloy in a well-balanced manner when the solution treatment and the aging treatment are performed. According to the method of producing the aluminum alloy wire in the present disclosure, an aluminum alloy wire having high strength and excellent workability can be produced when the solution treatment and the aging treatment are performed.

[0028] (9) The method of producing the aluminum alloy wire according to (8) may include producing a solution-treated wire material by performing a solution treatment on the second drawn wire material. In the solution treatment, a heating temperature is 530°C or more and 580°C or less, a holding time is 15 minutes or more and 360 minutes or less, and a temperature increase rate is 120°C/min or less.

[0029] In the method of producing the aluminum alloy wire according to (9), it is possible to produce the aluminum alloy wire in which the chromium is dissolved to form solid solution and precipitated in the aluminum alloy in a well-balanced manner when the aging treatment is performed.

[0030] (10) The method of producing the aluminum alloy wire according to (9) may include producing an aging-treated wire material by performing an aging treatment on the solution-treated wire material. In the aging treatment, a heating temperature is 160°C or more and 190°C or less, and a holding time is 2 hours or more and 40 hours or less.

[0031] In the method of producing the aluminum alloy wire according to (10), it is possible to produce the aluminum alloy wire in which the chromium is dissolved to form solid solution and precipitated in the aluminum alloy in a well-balanced manner.

[0032] (11) In the method of producing the aluminum alloy wire according to any one of (8) to (10), a wire diameter of the second drawn wire material may be 1 mm or more and 30 mm or less.

[0033] In the method of producing the aluminum alloy wire according to (11), it is possible to produce an aluminum alloy wire in which necessary strength and reduced weight can be achieved.

[Details of Embodiments of the Present Disclosure]

[0034] Hereinafter, specific examples of an embodiment of the present disclosure will be described with reference to figures. In the figures, the same reference characters denote the same or corresponding portions. In each of the figures, a part of a configuration may be shown in an exaggerated or simplified manner for the sake of convenience of description. A dimensional ratio of portions in the figure may be different from an actual dimensional ratio.

<Aluminum Alloy Wire>

(Overview)

[0035] An aluminum alloy wire 1 according to the present embodiment as shown in Fig. 1 is composed of an aluminum alloy having a specific composition. The aluminum alloy includes silicon (Si), magnesium (Mg), iron (Fe), copper (Cu), manganese (Mn), and chromium (Cr), and a remainder thereof consists of aluminum (Al) and an inevitable impurity. The aluminum alloy may further include one or more elements selected from a group consisting of zinc (Zn), titanium (Ti), and zirconium (Zr). The content of each element will be described later.

[0036] Aluminum alloy wire 1 according to the present embodiment has the following characteristics (a) to (c) when a solution treatment and an aging treatment are performed.

(a) A 0.2% proof stress when compressed is 360 MPa or more.

(b) A crystal grain size of the aluminum alloy is 200 μm or less.

(c) A degree of compressive deformation C is 0.6 or more and 1.0 or less.

(Aluminum Alloy)

[0037] Among the above-described elements included in the aluminum alloy, the Si, the Mg, the Fe, the Cu, the Mn, and the Cr are essential elements, and the Zn, the Ti, and the Zr are optional elements. The aluminum alloy may not include the Zn, the Ti and the Zr. Each of these elements is dissolved to form solid solution or is precipitated in the aluminum alloy. The precipitated element may be precipitated solely or may be precipitated with the element forming a compound with another element. Since each of the elements is dissolved to form solid solution or precipitated in the aluminum alloy, the characteristics of aluminum alloy wire 1 are improved.

[0038] Hereinafter, the effect and content of each of the elements will be described. The content of each of the elements is represented by a mass ratio when the whole of the aluminum alloy is regarded as 100 mass%.

- Si

[0039] The Si forms a Mg-Si-based compound together with the Mg, and is precipitated, thereby strengthening the aluminum alloy. Remaining Si that does not form the compound is dissolved to form solid solution or precipitated in the aluminum alloy, thereby strengthening the aluminum alloy. However, when an excess of Si is contained, segregation of Si at a crystal grain boundary is likely to be increased, or a coarse compound is likely to be formed.

[0040] The content of the Si is 1.0 mass% or more and 1.3 mass% or less. Since the content of the Si is 1.0 mass% or more, the Si is precipitated to improve the strength of the aluminum alloy. Since the content of the Si is 1.3 mass% or less, embrittlement due to the segregation of the Si can be reduced, and the formation of the coarse compound can be reduced. As a result, the strength and workability of the aluminum alloy are less likely to be decreased. The content of the Si may be 1.1 mass% or more and 1.3 mass% or less.

- Mg

[0041] The Mg is dissolved to form solid solution in the aluminum alloy, or the Mg forms a Mg-Si-based compound and is precipitated, thereby strengthening the aluminum alloy. However, when an excess of Mg is contained, the strength may be decreased, segregation of Mg may occur, the workability may be decreased, or heat resistance may be decreased.

[0042] The content of the Mg is 0.5 mass% or more and 1.2 mass% or less. Since the content of the Mg is 0.5 mass% or more, the Mg is precipitated to improve the strength of the aluminum alloy. Since the content of the Mg is 1.2 mass% or less, not only the strength and workability of the aluminum alloy are less likely to be decreased, but also the heat resistance is less likely to be decreased. The content of the Mg may be 0.6 mass% or more and 1.1 mass% or less, or 0.7 mass% or more and 1.0 mass% or less.

- Fe

[0043] The Fe is dissolved to form solid solution in the aluminum alloy, or the Fe forms an Al-Fe-based compound and is precipitated, thereby strengthening the aluminum alloy. Moreover, the Fe promotes to cause fine crystal grains of the aluminum alloy and to cause work hardening. Since the fine crystal grains lead to increased crystal grain boundaries, the embrittlement due to the segregation of the Si can be relatively reduced. As a result, the strength and workability of the aluminum alloy are improved. However, when an excess of Fe is contained, the compound is excessively generated or becomes coarse, which leads to decreased workability.

[0044] The content of the Fe is 0.3 mass% or more and 0.8 mass% or less. When the content of the Fe falls within this range, the Fe is dissolved to form solid solution and precipitated and the crystal grains become fine, thereby improving the strength and workability of the aluminum alloy. The content of the Fe may be 0.3 mass% or more and 0.7 mass% or less, or 0.3 mass% or more and 0.6 mass% or less. The content of the Fe is preferably equal to or more than the content of the Cu described below. When the content of the Fe is as large as the content of the Cu, preferably, the content of the Fe is more than the content of the Cu, the strength of the aluminum alloy can be further increased.

- Cu

[0045] The Cu forms an Al-Cu-based compound and is precipitated, thereby strengthening the aluminum alloy. Further, the Cu also has an effect of reducing the embrittlement due to the segregation of the Si. However, when an excess of Cu is contained, corrosion resistance and heat resistance are decreased.

[0046] The content of the Cu is 0.1 mass% or more and 0.4 mass% or less. Since the content of the Cu is 0.1 mass% or more, the Cu is precipitated to improve the strength of the aluminum alloy. Since the content of the Cu is 0.4 mass% or less,

the corrosion resistance and heat resistance of the aluminum alloy are less likely to be decreased.

- Mn

[0047] The Mn is dissolved to form solid solution in the aluminum alloy, or the Mn forms an Al-Mn-based compound and is precipitated, thereby strengthening the aluminum alloy. Further, the Mn is finely dispersed and precipitated in the aluminum alloy, thereby reducing coarse crystal grains of the aluminum alloy and contributing to attaining fine crystal grains. The Mn also has an effect of improving the heat resistance of the aluminum alloy. However, when an excess of Mn is contained, a coarse compound is likely to be formed, which leads to decreased workability.

[0048] The content of the Mn is 0.2 mass% or more and 0.5 mass% or less. When the content of the Mn falls within this range, the Mn is dissolved to form solid solution and precipitated and the crystal grains become fine, with the result that not only the strength and workability of the aluminum alloy are improved, but also the heat resistance is improved. The content of the Mn may be 0.2 mass% or more and 0.4 mass% or less, or 0.2 mass% or more and 0.3 mass% or less.

- Cr

[0049] The Cr is dissolved to form solid solution in the aluminum alloy, or the Cr forms an Al-Cr-based compound and is precipitated, thereby strengthening the aluminum alloy. Further, the Cr is finely dispersed and precipitated in the aluminum alloy, thereby reducing coarse crystal grains of the aluminum alloy and contributing to attaining fine crystal grains. The Cr also has an effect of improving the heat resistance and corrosion resistance of the aluminum alloy. However, when an excess of Cr is contained, a coarse compound is likely to be formed, which leads to decreased workability.

[0050] The content of the Cr is 0.001 mass% or more and 0.3 mass% or less. When the content of the Cr falls within this range, the Cr is dissolved to form solid solution and precipitated and the crystal grains become fine, with the result that not only the strength and workability of the aluminum alloy are improved, but also the heat resistance and corrosion resistance are improved. The content of the Cr may be 0.005 mass% or more and 0.2 mass% or less, or 0.01 mass% or more and 0.1 mass% or less.

- Zn

[0051] The Zn forms an Al-Zn-based compound and is precipitated, thereby strengthening the aluminum alloy. However, when an excess of Zn is contained, the workability is decreased and the corrosion resistance and the heat resistance are decreased.

[0052] The content of the Zn is 0 mass% or more and 0.25 mass% or less. In the case where the Zn is included, since the content of the Zn is 0.005 mass% or more and 0.25 mass% or less, not only the strength of the aluminum alloy is improved, but also the corrosion resistance and heat resistance are less likely to be decreased. The content of the Zn may be 0.05 mass% or more and 0.2 mass% or less.

- Ti

[0053] The Ti has an effect of attaining fine crystal grains of the aluminum alloy. However, when an excess of Ti is contained, the workability is decreased.

[0054] The content of the Ti is 0 mass% or more and 0.075 mass% or less. In the case where the Ti is included, since the content of the Ti is 0.001 mass% or more and 0.075 mass% or less, the strength and workability of the aluminum alloy are improved. The content of the Ti may be 0.005 mass% or more and 0.05 mass% or less, or 0.01 mass% or more and 0.05 mass% or less.

- Zr

[0055] The Zr is finely dispersed and precipitated in the aluminum alloy, thereby reducing coarse crystal grains of the aluminum alloy and contributing to attaining fine crystal grains. The Zr also has an effect of improving the heat resistance of the aluminum alloy. However, when an excess of Zr is contained, a coarse compound is likely to be formed, which leads to decreased workability.

[0056] The content of the Zr is 0 mass% or more and 0.17 mass% or less. In the case where the Zr is included, since the content of the Zr is 0.001 mass% or more and 0.17 mass% or less, the strength and workability of the aluminum alloy are improved. The content of the Zr may be 0.001 mass% or more and 0.15 mass% or less, or 0.005 mass% or more and 0.1 mass% or less. The total content of the Ti and the Zr is, for example, 0.001 mass% or more and 0.2 mass% or less, or 0.005 mass% or more and 0.1 mass% or less.

- Sr

[0057] Moreover, the aluminum alloy may include strontium (Sr). The Sr has an effect of finely precipitating the Si. As a result, the workability of the aluminum alloy is improved. The content of the Sr is, for example, 0.005 mass% or more and 0.05 mass% or less, or 0.005 mass% or more and 0.03 mass% or less.

[0058] The composition of the aluminum alloy can be measured by a known method. For example, an energy dispersive X-ray spectrometer can be used to analyze the composition of the aluminum alloy.

(Implementations of Aluminum Alloy Wire)

[0059] Aluminum alloy wire 1 is produced through a wire drawing process. Aluminum alloy wire 1 may be subjected to a solution treatment, or may be subjected to an aging treatment after the solution treatment. Aluminum alloy wire 1 of the present embodiment may be implemented in any of the following states: a state in which both the solution treatment and the aging treatment have not been performed; a state in which the aging treatment has not been performed after the solution treatment; or a state in which the aging treatment has been performed after the solution treatment. Hereinafter, aluminum alloy wire 1 not having been subjected to the solution treatment and the aging treatment may be referred to as a "normal wire material", aluminum alloy wire 1 having been subjected only to the solution treatment may be referred to as a "solution-treated wire material", and aluminum alloy wire 1 having been subjected to the solution treatment and the aging treatment may be referred to as an "aging-treated wire material".

[0060] In the case where aluminum alloy wire 1 is the normal wire material, the characteristics of aluminum alloy wire 1 are improved by performing the solution treatment and the aging treatment. When aluminum alloy wire 1 is the solution-treated wire material, the characteristics of aluminum alloy wire 1 are improved by performing the aging treatment. In comparison among the normal wire material, the solution-treated wire material, and the aging-treated wire material, a relation between tensile strength and elongation in each wire material generally has the following tendency. The normal wire material has low tensile strength and low elongation. The solution-treated wire material has low tensile strength but high elongation. The aging-treated wire material has high tensile strength and high elongation.

<Solution Treatment>

[0061] For the conditions of the solution treatment, the heating temperature is 530°C or more and 580°C or less, the holding time is 15 minutes or more and 360 minutes or less, and the temperature increase rate is 120°C/min or less. Since the heating temperature is 530°C or more and the holding time is 15 minutes or more, the elements included in the aluminum alloy can be sufficiently dissolved to form solid solution in the aluminum alloy. As the heating temperature is higher, an element such as the Fe can be promoted to be dissolved to form solid solution. The heating temperature may be 550°C or more. When the heating temperature is too high, the segregation of the Si is likely to occur or a void is likely to be generated in the aluminum alloy. When the heating temperature is 580°C or less, the segregation of the Si can be sufficiently reduced and the generation of the void can be reduced. As the holding time is longer, the dissolving of the element to form solid solution proceeds, but when the holding time is too long, the segregation of the Si proceeds. Therefore, the holding time may be 30 minutes or more and 120 minutes or less, or 50 minutes or more and 100 minutes or less.

[0062] When the temperature increase rate is too large, the void tends to be generated in the aluminum alloy. When the temperature increase rate is 120°C/min or less, the generation of the void can be reduced. Moreover, the temperature increase rate is preferably 2°C/min or more. As the temperature increase rate is larger, the segregation of the Si is more likely to be reduced. The temperature increase rate may be 2°C/min or more and 120°C/min or less, 10°C/min or more and 120°C/min or less, or 25°C/min or more and 120°C/min or less.

[0063] In the solution treatment, aluminum alloy wire 1 is held at the heating temperature for the certain period of time and is then cooled to the ordinary temperature. As a temperature decrease rate at the time of the cooling is larger, the state in which the above-described elements are dissolved to form solid solution in the aluminum alloy can be maintained. The temperature decrease rate is, for example, 50°C/sec or more. The temperature decrease rate may be 100°C/sec or more, 200°C/sec or more, or 500°C/sec or more. The cooling in the solution treatment can be performed, for example, by water cooling.

<Aging Treatment>

[0064] The aging treatment is performed after the solution treatment. For the conditions of the aging treatment, the heating temperature is 160°C or more and 190°C or less and the holding time is 2 hours or more and 40 hours or less. Since the heating temperature is 160°C or more and the holding time is 2 hours or more, each of the elements dissolved to form solid solution by the solution treatment can be sufficiently precipitated in the aluminum alloy. Since the heating temperature

is 190°C or less, coarse crystal grains of the aluminum alloy can be reduced or coarse precipitates can be reduced. As the heating temperature is higher, the precipitation of the element proceeds, with the result that the holding time can be short. The heating temperature may be 170°C or more. The holding time may be 4 hours or more and 20 hours or less, or 6 hours or more and 10 hours or less.

(Shape of Aluminum Alloy Wire 1)

[0065] Aluminum alloy wire 1 may have any shape. The shape of a cross section of aluminum alloy wire 1 shown in Fig. 1 is a circular shape. The cross section of aluminum alloy wire 1 is a cross section orthogonal to the length of aluminum alloy wire 1. The shape of the cross section of aluminum alloy wire 1 may be a non-circular shape. Examples of the non-circular shape include a polygonal shape and an oval shape. Examples of the polygonal shape includes a quadrangle and a hexagon. The quadrangle includes a rectangle and a square. The oval shape include an elliptical shape.

(Wire Diameter of Aluminum Alloy Wire 1)

[0066] Wire diameter D of aluminum alloy wire 1 is, for example, 1 mm or more and 30 mm or less. When the shape of the cross section of aluminum alloy wire 1 is the circular shape, wire diameter D of aluminum alloy wire 1 is the diameter of the cross section. When the shape of the cross section of aluminum alloy wire 1 is the non-circular shape, wire diameter D of aluminum alloy wire 1 is regarded as the diameter of a circle having an area equal to the area of the cross section. Wire diameter D may be 4 mm or more or 10 mm or less.

(Characteristics of Aluminum Alloy Wire)

[0067] In aluminum alloy wire 1 of the present embodiment, the 0.2% proof stress when compressed is 360 MPa or more, the crystal grain size of the aluminum alloy is 200 μm or less, and the degree of compressive deformation C is 0.6 or more and 1.0 or less in the state in which the solution treatment and the aging treatment have been performed, i.e., in the aging-treated wire material. Further, the apex of the main peak in the K absorption edge spectrum of the Cr as obtained by the XAFS analysis may be located in the range of 6012.75 eV or more and 6014.00 eV or less. These characteristics are measured under different conditions depending on the implementations of aluminum alloy wire 1. When aluminum alloy wire 1 is the normal wire material, the measurement is performed after the solution treatment and the aging treatment are performed on aluminum alloy wire 1. When aluminum alloy wire 1 is the solution-treated wire material, the measurement is performed after only the aging treatment is performed on aluminum alloy wire 1 without performing the solution treatment. When aluminum alloy wire 1 is the aging-treated wire material, the measurement is performed as it is.

<0.2% Proof Stress When Compressed>

[0068] As the 0.2% proof stress when compressed is higher, the proof stress against compression is higher. Since the 0.2% proof stress when compressed is 360 MPa or more, aluminum alloy wire 1 has a high proof stress against compression and is excellent in compression characteristic. The 0.2% proof stress when compressed may be 380 MPa or more or may be 400 MPa or more. The upper limit of the 0.2% proof stress when compressed is, for example, 500 MPa. The 0.2% proof stress when compressed may be, for example, 360 MPa or more and 500 MPa or less, 380 MPa or more and 480 MPa or less, or 400 MPa or more and 450 MPa or less.

[0069] The 0.2% proof stress when compressed can be found from a stress-strain curve (SS curve) obtained by a compression test. Specifically, for the 0.2% proof stress when compressed, stress to cause 0.2% permanent strain is read from the stress-strain curve. The compression test is performed in accordance with JIS K 7181:2011.

<Crystal Grain Size of Aluminum Alloy>

[0070] As the crystal grain size of the aluminum alloy is smaller, the aluminum alloy has a finer crystal structure, with the result that the strength and workability of aluminum alloy wire 1 are improved. Since the crystal grain size is 200 μm or less, aluminum alloy wire 1 has high strength and excellent workability. The crystal grain size may be 150 μm or less or may be 100 μm or less. The lower limit of the crystal grain size is, for example, 5 μm . The crystal grain size may be, for example, 5 μm or more and 200 μm or less, 10 μm or more and 150 μm or less, or 20 μm or more and 100 μm or less.

[0071] The crystal grain size of the aluminum alloy can be found by an intercept method. The crystal grain size is measured by the intercept method as follows. The cross section of the aluminum alloy wire is observed with a microscope. The cross section is a cross section orthogonal to the length of the aluminum alloy wire. The microscope may be an optical microscope or a scanning electron microscope (SEM). The magnification of the microscope is appropriately adjusted in accordance with the crystal grain size. The magnification of the microscope is, for example, 50 times or more and 1000

times or less. A straight line is drawn on the photograph of the observed cross section. The number n of crystal grains crossed by this straight line is found. In the case where the end of the straight line is located inside a crystal grain, i.e., in the case of a crystal grain not crossed completely by the straight line, the crystal grain is counted as $1/2$. A value obtained by multiplying, by 1.5, a value obtained by dividing length L of the straight line by the number n of the crystal grains is regarded as the crystal grain size. A plurality of straight lines may be drawn. The number of the straight lines is, for example, 4 or more and 10 or less. When the plurality of straight lines are drawn, the crystal grain size is obtained from each of the straight lines, and the average value thereof is regarded as the crystal grain size.

<Degree of Compressive Deformation>

[0072] The degree of compressive deformation C represents uniformity of deformation when aluminum alloy wire 1 is compressed at the compression ratio of 50%. A method of measuring the degree of compressive deformation C will be described with reference to Fig. 2. A test piece 1s of the aluminum alloy wire is prepared. Test piece 1s is cut out from aluminum alloy wire 1. Test piece 1s has a cylindrical shape. The shape of an end surface of test piece 1s is a circular shape, and diameter d thereof is 1 mm or more and 30 mm or less. A length h of test piece 1s is 10 mm. The shape of the end surface of test piece 1s may not be an exactly circular shape. When a degree of circularity of the end surface of test piece 1s before compression is 0.9 or more and 1 or less, the shape of the end surface is regarded as the circular shape. The degree of circularity is calculated by $4 \times \pi \times S_s / L_s^2$ using an area S_s of the end surface of test piece 1s and a peripheral length L_s thereof. As the degree of circularity is closer to 1, it is indicated that the shape of the end surface is closer to an exact circle. When the shape of the cross section of aluminum alloy wire 1 is a non-circular shape, test piece 1s cut out from aluminum alloy wire 1 is cut into a cylindrical shape.

[0073] As shown in Fig. 2, test piece 1s is sandwiched between two plates 21, 22, and a compressive load F is applied to test piece 1s. Two plates 21, 22 are disposed in parallel. End surfaces 11, 12 of test piece 1s are in contact with plates 21, 22, respectively. When plates 21, 22 are moved to come close to each other along the axis of test piece 1s, test piece 1s is compressed. Test piece 1s having length h before the compression is compressed at the compression ratio of 50%, thereby obtaining a compressed test piece 1a. The compression ratio of 50% means that the length of compressed test piece 1a becomes the half of length h of test piece 1s before the compression. That is, the length of compressed test piece 1a is $h/2$. The degree of compressive deformation C is calculated by $C = 4 \times \pi \times S_a / L_a^2$ using cross sectional area S_a and peripheral length L_a of compressed test piece 1a. Cross sectional area S_a is a value obtained by squaring the cross sectional area of test piece 1s before the compression. That is, cross sectional area S_a is equal to a value obtained by squaring the above-described area S_s . That is, $S_a = S_s^2$. For peripheral length L_a , it is assumed that a peripheral length at the center position of the length of compressed test piece 1a, i.e., at the position of $h/4$ is measured.

[0074] When the degree of compressive deformation C is 0.6 or more and 1.0 or less, the shape of the end surface of compressed test piece 1a is substantially maintained to be the circular shape as compared with the shape of the end surface of test piece 1s before the compression, but is uniformly deformed. Since such an aluminum alloy wire is uniformly deformed during working, the workability thereof is excellent. That is, the degree of compressive deformation C can be used as one index indicating the workability. When the degree of compressive deformation C is less than 0.6, the shape of the end surface is not sufficiently maintained before and after the compression and the end surface is deformed non-uniformly. Such an aluminum alloy wire is inferior in workability because the aluminum alloy wire is deformed non-uniformly during working. It can be said that as the degree of compressive deformation C is closer to 1, the workability is more excellent. The degree of compressive deformation C may be 0.7 or more, or may be 0.8 or more.

<Position of Main Peak in K Absorption Edge Spectrum of Cr>

[0075] The XAFS refers to X-ray absorption fine structure (X-ray Absorption Fine Structure), and is a method of analyzing an absorption spectrum obtained by applying X-ray to a substance. By the XAFS analysis, it is possible to evaluate a state of an element in the aluminum alloy.

[0076] A reason why aluminum alloy wire 1 of the present embodiment has the above-described characteristics in the state in which the solution treatment and the aging treatment have been performed is unclear; however, it is presumably because the balance is optimized between the solid solution and precipitation of the above-described elements included in the aluminum alloy. The K absorption edge spectrum of the Cr represents a solid solution/precipitation state of the Cr. When the apex of the main peak in the K absorption edge spectrum of the Cr is located in the range of 6012.75 eV or more and 6014.00 eV or less, the Cr is dissolved to form solid solution and precipitated in the aluminum alloy in a well-balanced manner. In such an aluminum alloy wire 1, the crystal structure of the aluminum alloy is fine, the strength is high, and the workability is excellent. The apex of the main peak was found by fitting the main peak with the Gaussian function in the range of 6009 eV to 6017 eV in the K absorption edge spectrum of the Cr.

(Purpose of Use of Aluminum Alloy Wire)

[0077] Aluminum alloy wire 1 of the present embodiment can be suitably used as a material for aluminum alloy members such as a structural member and an automobile part. Since aluminum alloy wire 1 has the high proof strength against compression, aluminum alloy wire 1 is particularly suitable as a material for an aluminum alloy member to which a compression load is applied during use.

<Method of Producing Aluminum Alloy Wire>

[0078] The present inventors have studied a method of producing the aluminum alloy wire having the above-described specific composition and having high strength and excellent workability in the state in which the solution treatment and the aging treatment have been performed. As a result, the present inventors have found that the conditions of an intermediate heat treatment performed during the wire drawing process and the conditions of the wire drawing process performed immediately before the solution treatment are preferably adjusted to fall specific ranges.

[0079] Aluminum alloy wire 1 of the present embodiment can be produced by the method of producing the aluminum alloy wire according to the embodiment. The method of producing the aluminum alloy wire according to the present embodiment includes a first step, a second step, a third step, and a fourth step in this order. Each of the steps is as follows.

[0080] The first step is a step of producing a continuous casted and rolled material composed of an aluminum alloy. This aluminum alloy has the specific composition described above.

[0081] The second step is a step of producing a first drawn wire material by performing a first wire drawing process on the continuous casted and rolled material.

[0082] The third step is a step of producing an intermediate heat-treated material by performing an intermediate heat treatment on the first drawn wire material. For the conditions of the intermediate heat treatment, a heating temperature is 250°C or more and less than 350°C and a holding time is 1 hour or more and less than 5 hours.

[0083] The fourth step is a step of producing a second drawn wire material by performing a second wire drawing process on the intermediate heat-treated material. A second processing degree in the second wire drawing process is 20% or less.

[0084] In the method of producing the aluminum alloy wire according to the present embodiment, the aluminum alloy wire is produced by performing the wire drawing process on the continuous casted and rolled material. In the method of producing the aluminum alloy wire according to the present embodiment, the intermediate heat treatment is performed during the wire drawing process. One of features of the method of producing the aluminum alloy wire according to the present embodiment is that the heating temperature of the intermediate heat treatment is relatively low, the holding time is short, and the second processing degree in the second wire drawing process after the intermediate heat treatment is 20% or less. In the method of producing the aluminum alloy wire according to the present embodiment, the conditions of the intermediate heat treatment and the second processing degree in the second wire drawing process satisfy the specific ranges, thereby controlling the balance of the solid solution/precipitation state of the Cr in the aluminum alloy when the solution treatment and the aging treatment are performed. By the method of producing the aluminum alloy wire according to the present embodiment, aluminum alloy wire 1 of the present embodiment can be produced.

[0085] Hereinafter, each of the steps will be described in detail.

(First Step)

[0086] The continuous casted and rolled material can be produced by a continuous casting and rolling method. The continuous casting and rolling method is a method of casting a molten aluminum alloy and then performing rolling continuously. The continuous casted and rolled material is used as a material for the aluminum alloy wire. When the material is the continuous casted and rolled material, a continuous long aluminum alloy wire can be produced. In particular, since a solidification rate is fast in a Properzi continuous casting and rolling method, each of the elements included in the aluminum alloy is likely to be dissolved to form solid solution and crystallized precipitates generated during the casting are likely to be finely dispersed. Therefore, the continuous casted and rolled material produced by the Properzi continuous casting and rolling method is excellent in plastic workability and the wire drawing process is readily performed thereon.

[0087] The shape of the continuous casted and rolled material may be any shape. The shape of a cross section of the continuous casted and rolled material may be a circular shape or a rectangular shape. The cross section of the continuous casted and rolled material is a cross section orthogonal to the length of the continuous casted and rolled material. The wire diameter of the continuous casted and rolled material is, for example, 5 mm or more and 40 mm or less. The wire diameter of the continuous casted and rolled material may be 10 mm or more and 30 mm or less. When the the shape of the cross section of the continuous casted and rolled material is the circular shape, the wire diameter of the continuous casted and rolled material is the diameter of the cross section. When the shape of the cross section of the continuous casted and rolled material is the rectangular shape, the wire diameter of the continuous casted and rolled material is regarded as the diameter of a circle having an area equal to the area of the cross section.

(Second Step)

[0088] The first wire drawing process is performed in a cold manner. A first processing degree in the first wire drawing process is not particularly limited. The first processing degree is selected such that the final wire diameter of the second drawn wire material in the fourth step falls within a predetermined range. The first processing degree is, for example, 1% or more and 99.9% or less. The first processing degree may be 5% or more and 80% or less, or 5% or more and 50% or less. The first processing degree is a ratio expressed in percentage (%) and obtained by dividing, by the cross sectional area before the first wire drawing process, a difference between the cross sectional area before the first wire drawing process and the cross sectional area after the first wire drawing process. The cross sectional area before the first wire drawing process corresponds to the cross sectional area of the continuous casted and rolled material. The cross sectional area after the first wire drawing corresponds to the cross sectional area of the first drawn wire material. The wire diameter of the first drawn wire material is, for example, 1.01 mm or more and 33.5 mm or less. The wire diameter of the first drawn wire material may be 4.5 mm or more or 11.2 mm or less.

(Third Step)

[0089] The first drawn wire material in the second step is work-hardened by the first wire drawing process. In the intermediate heat treatment, the first drawn wire material is softened, thereby improving workability of the intermediate heat-treated material. Therefore, the second wire drawing process is readily performed on the intermediate heat-treated material in the fourth step. The wire diameter of the first drawn wire material is not substantially changed by the intermediate heat treatment. That is, the wire diameter of the intermediate heat-treated material is substantially equal to the wire diameter of the first drawn wire material.

[0090] Since the heating temperature of the intermediate heat treatment is 250°C or more and the holding time is 1 hour or more, the first drawn wire material can be sufficiently softened. As the heating temperature becomes higher or the holding time becomes longer, the softening of the intermediate heat-treated material proceeds. On the other hand, when the heating temperature is too high or the holding time is too long, the crystal grains of the aluminum alloy become coarse, which leads to decreased workability. Since the heating temperature is less than 350°C and the holding time is less than 5 hours, the coarse crystal grains of the aluminum alloy can be reduced and the workability is less likely to be decreased. The heating temperature of the intermediate heat treatment may be 280°C or more and 330°C or less. The holding time may be 2 hours or more and 4 hours or less.

(Fourth Step)

[0091] The second wire drawing process is performed in a cold manner. The second processing degree in the second wire drawing process is 20% or less. The second processing degree is selected from the range of 20% or less such that the wire diameter of the second drawn wire material falls within a predetermined range. The second processing degree may be 15% or less, or 10% or less. The second processing degree may be, for example, 1% or more and 20% or less, 2% or more and 15% or less, or 5% or more and 10% or less. The second processing degree is a ratio expressed in percentage (%) and obtained by dividing, by the cross sectional area before the second wire drawing process, a difference between the cross sectional area before the second wire drawing process and the cross sectional area after the second wire drawing process. The cross sectional area before the second wire drawing process corresponds to the cross sectional area of the intermediate heat-treated material. The cross sectional area after the second wire drawing corresponds to the cross sectional area of the second drawn wire material. The wire diameter of the second drawn wire material is, for example, 1 mm or more and 30 mm or less. The wire diameter of the second drawn wire material may be 4 mm or more or 10 mm or less. The wire diameter of the second drawn wire material is substantially equal to the wire diameter of aluminum alloy wire 1 to be produced.

[0092] In the method of producing the aluminum alloy wire according to the present embodiment, it is possible to produce aluminum alloy wire 1 of the present embodiment having high strength and excellent workability in the state in which the solution treatment and the aging treatment have been performed. The second drawn wire material in the fourth step is an aluminum alloy wire not having been subjected to the solution treatment and the aging treatment. That is, the second drawn wire material corresponds to the normal wire material described above. When the measurement is performed after the solution treatment and the aging treatment are performed on the aluminum alloy wire, i.e., the normal wire material, the aluminum alloy wire having been subjected to the solution treatment and the aging treatment, i.e., the aging-treated wire material has the characteristics described above. Specifically, the 0.2% proof stress when compressed is 360 MPa or more, the crystal grain size of the aluminum alloy is 200 μm or less, and the degree of compressive deformation C is 0.6 or more and 1.0 or less. Further, in the aluminum alloy wire having been subjected to the solution treatment and the aging treatment, the apex of the main peak in the K absorption edge spectrum of the Cr as obtained by the XAFS analysis is located in the specific range.

(Fifth Step)

[0093] The method of producing the aluminum alloy wire according to the present embodiment may further include a fifth step after the fourth step.

[0094] The fifth step is a step of produce a solution-treated wire material by performing the solution treatment on the second drawn wire material. The conditions of the solution treatment are as described above.

[0095] In the solution-treated wire material, the elements included in the aluminum alloy are dissolved to form solid solution due to the solution treatment. The solution-treated wire material is an aluminum alloy wire having been subjected only to the solution treatment. When this aluminum alloy wire, i.e., the solution-treated wire material, is subjected to the aging treatment and the measurement is then performed thereon, the aluminum alloy wire having been subjected to the aging treatment, i.e., the aging-treated wire material, has the characteristics described above.

(Sixth Step)

[0096] The method of producing the aluminum alloy wire according to the present embodiment may further include a sixth step after the fifth step.

[0097] The sixth step is a step of producing the aging-treated wire material by performing the aging treatment on the solution-treated wire material. The conditions of the aging treatment are as described above.

[0098] In the aging-treated wire material, the elements dissolved to form solid solution in the aluminum alloy are precipitated due to the aging treatment. The aging-treated wire material is an aluminum alloy wire having been subjected to the solution treatment and the aging treatment. This aluminum alloy wire, i.e., the aging-treated wire material, has the characteristics described above as it is.

[Test Example 1]

[0099] Samples of aluminum alloy wires having compositions shown in Table 1 were produced. A composition I shown in Table 1 falls within the range of the composition of the aluminum alloy in the present embodiment. A composition II shown in Table 1 falls out of the range of the composition of the aluminum alloy in the present embodiment. Composition II corresponds to the composition of the aluminum alloy defined in International Alloy Number A6061.

[Table 1]

	Elements (mass%)								
	Si	Mg	Fe	Cu	Mn	Cr	Zn	Zr+Ti	Bal.
Composition I	1.20	0.80	0.50	0.30	0.27	0.01	-	0.02	Al
Composition II	0.70	1.00	0.30	0.30	0.02	0.15	0.02	0.06	Al

(Production of Samples)

[0100] Each of the samples of the aluminum alloy wires was produced by performing a wire drawing process on a continuous casted and rolled material in a cold manner. Table 2 shows production conditions for the aluminum alloy wire. The continuous casted and rolled material was produced by a known Properzi continuous casting and rolling machine. The continuous casted and rolled material was produced using a molten metal adjusted in its components to have composition I or composition II shown in Table 1. When the item of the composition in Table 2 is "I", it means that the composition is composition I shown in Table 1. When the item of the composition in Table 2 is "II", it means that the composition is composition II shown in Table 1.

[0101] When performing the wire drawing process on the continuous casted and rolled material, an intermediate heat treatment was performed during the wire drawing process. That is, a first wire drawing process, the intermediate heat treatment, and a second wire drawing process were performed in this order. A first processing degree in the first wire drawing process, conditions of the intermediate heat treatment, and a second processing degree in the second wire drawing process are shown in Table 2. The items of the intermediate heat treatment in Table 2 show a heating temperature and a holding time. For example, "300°C × 3 h" means that the heating temperature is 300°C and the holding time is 3 hours.

[0102] After the second wire drawing process, the aluminum alloy wire, which was the normal wire material, was subjected to the solution treatment and the aging treatment, thereby producing an aluminum alloy wire, which is the aging-treated wire material. The conditions of the solution treatment and the conditions of the aging treatment are shown in Table 2. For the conditions of the solution treatment, a heating temperature is 550°C and a holding time is 60 minutes. For the

conditions of the aging treatment, a heating temperature is 175°C and a holding time is 8 hours. The temperature increase rate in the solution treatment is 2.3°C/min or 110°C/min. In the solution treatment, the aluminum alloy wire was held at the heating temperature for the certain period of time and was then cooled by water to the ordinary temperature. The temperature decrease rate in the solution treatment is 1000°C/sec. The shape of a cross section of the produced aluminum alloy wire is a circular shape. The wire diameter of the aluminum alloy wire is in a range of 1 mm or more and 30 mm or less.

[0103] As shown in Table 2, a sample No. 1a and a sample No. 1b are the same in terms of composition and production conditions except that the temperature increase rate in the solution treatment is different therebetween. In the following description, sample No. 1a and sample No. 1b may be collectively referred to as "sample No. 1". Similarly, a sample No. 2a and a sample No. 2b may be collectively referred to as "sample No. 2", and a sample No. 10a and a sample No. 10b may be collectively referred to as "sample No. 10".

[Table 2]

Sample No.	Composition	Production Conditions					
		First Wire Drawing Process	Intermediate Heat Treatment	Second Wire Drawing Process	Solution Treatment		Aging Treatment
		First Processing Degree (%)	Temperature × Time	Second Processing Degree (%)	Temperature × Time	Temperature Increase Rate (°C/min)	Temperature × Time
1a	I	5	300°C × 3h	5	550°C × 60min	2.3	175°C × 8h
1b						110	
2a		50	300°C × 3h	10		2.3	
2b						110	
10a	II	10	380°C × 3h	10		2.3	
10b						110	
11	I	30	380°C × 10h	5			

(Characteristics of Samples)

[0104] The characteristics of each of the samples of the aluminum alloy wires each having been subjected to the solution treatment and the aging treatment were examined. The examined characteristics are a 0.2% proof stress when compressed, a crystal grain size of the aluminum alloy, a degree of compressive deformation, and the position of a main peak in a K absorption edge spectrum of the Cr. A method of measuring each characteristic will be described below. The results of the examined characteristics are shown in Table 3.

<0.2% Proof Stress When Compressed>

[0105] The 0.2% proof stress when compressed is found from a stress-strain curve (SS curve) obtained by a compression test. The compression test is performed in accordance with JIS K 7181:2011. A test piece used in the compression test was cut from the aluminum alloy wire of each sample. The length of the test piece is 10 mm. The compression test is performed at the ordinary temperature.

<Crystal Grain Size of Aluminum Alloy>

[0106] The crystal grain size of the aluminum alloy is found by observing a cross section of the aluminum alloy wire with a microscope and employing the intercept method. In the measurement of the crystal grain size by the intercept method, five straight lines were drawn on the photograph of the observed cross section, and the average value of the crystal grain sizes obtained from the straight lines was found.

<Degree of Compressive Deformation>

[0107] The degree of compressive deformation is found from the shape of compressed test piece 1a after compressing

test piece 1s at a compression ratio of 50% as shown in Fig. 2. Test piece 1s was cut from the aluminum alloy wire of each sample. Length h of test piece 1s before the compression is 10 mm. As described above, the degree of compressive deformation C is calculated by $4 \times \pi \times S_a / L_a^2$ using cross sectional area S_a and peripheral length L_a of compressed test piece 1a. Cross sectional area S_a is a value obtained by squaring the cross sectional area of test piece 1s before the compression. Peripheral length L_a was found by measuring the peripheral length at the center position of the length of compressed test piece 1a. When the degree of compressive deformation C is 0.6 or more and 1.0 or less, it can be said that it is uniformly deformed. In this case, the degree of compressive deformation in Table 3 is evaluated as "A". When the degree of compressive deformation C is less than 0.6, it can be said that it is deformed non-uniformly. In this case, the degree of compressive deformation in Table 3 is evaluated as "B".

<Position of Main Peak in K Absorption Edge Spectrum of Cr>

[0108] The K absorption edge spectrum of the Cr is measured by an XAFS analysis apparatus installed in beamline (BL) 16 of SAGA Light Source. The XAFS analysis may use a BL by which an XAFS analysis equivalent thereto can be performed, such as BLO1B1 or BL14B2 of SPring-8, which is a large-scale synchrotron radiation facility, or BL5S1 or BL11S2 of Aichi Synchrotron Radiation Center. The sample for the analysis was cut from the aluminum alloy wire of each sample, and the surface of the aluminum alloy wire was polished. The position of the apex of the main peak in the K absorption edge spectrum of the Cr as obtained is found. The apex of the main peak is found by fitting the main peak with a Gaussian function in a range of 6009 eV to 6017 eV. When the position of the apex of the main peak is in the range of 6012.75 eV or more and 6014.00 eV or less, the position of the main peak in Table 3 is determined as "A". When the position of the apex of the main peak falls out of the range of 6012.75 eV or more and 6014.00 eV or less, the position of the main peak in Table 3 is determined as "B".

[Table 3]

Sample No.	Characteristics			
	0.2% Proof Stress When Compressed (MPa)	Crystal Grain Size (μm)	Evaluation of Degree of Compressive Deformation	Determination of Position of Main Peak
1a	403	114	A	A
1b	403	98	A	A
2a	411	80	A	A
2b	404	68	A	A
10a	347	2477	B	B
10b	353	1573	B	B
11	380	811	B	A

[0109] As shown in Table 3, in each of sample No. 1 and sample No. 2, the 0.2% proof stress when compressed is 360 MPa or more and the proof stress against compression is high. The 0.2% proof stress of each of sample No. 1 and sample No. 2 when compressed is 400 MPa or more. In each of sample No. 1 and sample No. 2, the crystal grain size of the aluminum alloy is 200 μm or less, and the evaluation of the degree of compressive deformation is also "A". Therefore, it is understandable that each of sample No. 1 and sample No. 2 has high strength and excellent workability. In each of sample No. 1 and sample No. 2, the position of the main peak in the K absorption edge spectrum of the Cr is determined as "A", and the position of the apex of the main peak is in the range of 6012.75 eV or more and 6014.00 eV or less. The degree of compressive deformation C of sample No. 1a was 0.63, the degree of compressive deformation C of sample No. 1b was 0.65, the degree of compressive deformation C of sample No. 2a was 0.69, and the degree of compressive deformation C of sample No. 2b was 0.90. In view of these results, it is understandable that as the crystal grain size of the aluminum alloy is smaller, the degree of compressive deformation C is closer to 1. It is considered that the crystal grain size of the aluminum alloy is preferably 75 μm or less, particularly 70 μm or less.

[0110] On the other hand, in sample No. 10, the 0.2% proof stress when compressed is low, and the crystal grain size of the aluminum alloy is large. In sample No. 10, the evaluation of the degree of compressive deformation is "B", and the workability is low. In sample No. 10, the determination of the position of the main peak in the K absorption edge spectrum of the Cr is "B", and the position of the apex of the main peak falls out of the range of 6012.75 eV or more and 6014.00 eV or less. The 0.2% proof stress when compressed is high in sample No. 11, but the crystal grain size of the aluminum alloy is large. In sample No. 11, the evaluation of the degree of compressive deformation is "B", and the workability is low. It should be noted that in sample No. 11, the determination of the position of the main peak in the K absorption edge spectrum of the

Cr was "A".

[0111] Fig. 3 shows the respective K absorption edge spectra of the Cr in sample No. 2a and sample No. 10a together. In Fig. 3, the K absorption edge spectrum of the Cr in sample No. 2a is indicated by a thick solid line, and the K absorption edge spectrum of the Cr in sample No. 10a is indicated by a thin solid line. In each of the K absorption edge spectra of the Cr as shown in Fig. 3, the horizontal axis represents X-ray energy (eV), and the vertical axis represents X-ray absorption (any unit; a.u.). In Fig. 3, a thick broken line indicates the position of the main peak in the K absorption edge spectrum of the Cr in sample No. 2a, and a thin broken line indicates the position of the main peak in the K absorption edge spectrum of the Cr in sample No. 10a. The position of the main peak in the K absorption edge spectrum of the Cr in sample No. 2a is 6013.1 eV. The position of the main peak in the K absorption edge spectrum of the Cr in sample No. 10a is 6011.9 eV.

[Test Example 2]

[0112] Samples of aluminum alloy wires different in terms of temperature increase rate in the solution treatment were produced, and the characteristics of each sample were examined. The temperature increase rate in the solution treatment and the results of the examined characteristics are shown in Table 4.

[0113] Each of aluminum alloy wires of samples No. 2-1 to No. 2-5 shown in Table 4 is the same in terms of composition and production conditions as that of sample No. 2 of test example 1 except that the temperature increase rate in the solution treatment was as shown in Table 4. Sample No. 2-1 corresponds to sample No. 2a of test example 1, and sample No. 2-5 corresponds to sample No. 2b of test example 1. Moreover, each of aluminum alloy wires of samples No. 2-11 to 2-15 are the same in terms of composition and production conditions as that of sample No. 10 of test example 1 except that the temperature increase rate in the solution treatment was as shown in Table 4. Sample No. 2-11 corresponds to sample No. 10a of test example 1, and sample No. 2-15 corresponds to sample No. 10b of test example 1.

[0114] The characteristics of each sample were measured in the same manner as in test example 1.

[Table 4]

Sample No.	Solution Treatment	Characteristics			
	Temperature Increase Rate (°C/min)	0.2% Proof Stress When Compressed (MPa)	Crystal Grain Size (μm)	Evaluation of Degree of Compressive Deformation	Determination of Position of Main Peak
2-1	2.3	411	80	A	A
2-2	12.2	415	71	A	A
2-3	27.5	408	65	A	A
2-4	55.0	410	73	A	A
2-5	110	404	68	A	A
2-11	2.3	347	2477	B	B
2-12	12.2	351	2517	B	B
2-13	27.5	356	1477	B	B
2-14	55.0	351	2041	B	B
2-15	110	353	1573	B	B

[0115] As shown in Table 4, in each of samples No. 2-1 to 2-5, the 0.2% proof stress when compressed is 360 MPa or more, and the crystal grain size of the aluminum alloy is 200 μm or less. In each of samples No. 2-1 to 2-5, the evaluation of the degree of compressive deformation is also "A". Therefore, it is understandable that each of samples No. 2-1 to 2-5 has high strength and excellent workability. In each of samples No. 2-1 to 2-5, the determination of the position of the main peak in the K absorption edge spectrum of the Cr is "A", and the position of the apex of the main peak is in the range of 6012.75 eV or more and 6014.00 eV or less.

[0116] On the other hand, in each of samples No. 2-11 to 2-15, the 0.2% proof stress when compressed is low and the crystal grain size of the aluminum alloy is large. In each of samples No. 2-11 to 2-15, the evaluation of the degree of compressive deformation is "B", and the workability is low. In each of samples No. 2-11 to 2-15, the determination of the position of the main peak in the K absorption edge spectrum of the Cr is "B", and the position of the apex of the main peak is out of the range of 6012.75 eV or more and 6014.00 eV or less.

[0117] The present invention is not limited to these examples, is defined by the terms of the claims, and is intended to include any modifications within the scope and meaning equivalent to the terms of the claims.

REFERENCE SIGNS LIST

[0118]

1 aluminum alloy wire
 1s test piece
 1a compressed test piece
 11, 12 end surface
 21, 22 plates
 D wire diameter
 h length
 d diameter

Claims

1. An aluminum alloy wire composed of an aluminum alloy, wherein

the aluminum alloy includes

1.0 mass% or more and 1.3 mass% or less of silicon,
 0.5 mass% or more and 1.2 mass% or less of magnesium,
 0.3 mass% or more and 0.8 mass% or less of iron,
 0.1 mass% or more and 0.4 mass% or less of copper,
 0.2 mass% or more and 0.5 mass% or less of manganese,
 0.001 mass% or more and 0.3 mass% or less of chromium,
 0 mass% or more and 0.25 mass% or less of zinc,
 0 mass% or more and 0.075 mass% or less of titanium, and
 0 mass% or more and 0.17 mass% or less of zirconium,

a remainder of the aluminum alloy consists of aluminum and an inevitable impurity,
 in a measurement result obtained after performing a solution treatment and an aging treatment on the aluminum alloy wire,

a 0.2% proof stress when compressed is 360 MPa or more,
 a crystal grain size of the aluminum alloy is 200 μm or less, and
 a degree of compressive deformation C when compressed at a compression ratio of 50% is 0.6 or more and 1.0 or less,

in the solution treatment,

a heating temperature is 530°C or more and 580°C or less,
 a holding time is 15 minutes or more and 360 minutes or less, and
 a temperature increase rate is 120°C/min or less, and

in the aging treatment,

a heating temperature is 160°C or more and 190°C or less, and
 a holding time is 2 hours or more and 40 hours or less.

2. The aluminum alloy wire according to claim 1, wherein

in the measurement result obtained after performing the solution treatment and the aging treatment on the aluminum alloy wire,

an apex of a main peak in a K absorption edge spectrum of the chromium as obtained by an XAFS analysis is

located in a range of 6012.75 eV or more and 6014.00 eV or less, and the apex of the main peak is found by fitting the main peak with a Gaussian function in a range of 6009 eV to 6017 eV.

3. An aluminum alloy wire composed of an aluminum alloy, wherein

the aluminum alloy includes

1.0 mass% or more and 1.3 mass% or less of silicon,
0.5 mass% or more and 1.2 mass% or less of magnesium,
0.3 mass% or more and 0.8 mass% or less of iron,
0.1 mass% or more and 0.4 mass% or less of copper,
0.2 mass% or more and 0.5 mass% or less of manganese,
0.001 mass% or more and 0.3 mass% or less of chromium,
0 mass% or more and 0.25 mass% or less of zinc,
0 mass% or more and 0.075 mass% or less of titanium, and
0 mass% or more and 0.17 mass% or less of zirconium,

a remainder of the aluminum alloy consists of aluminum and an inevitable impurity, in a measurement result obtained after performing an aging treatment on the aluminum alloy wire,

a 0.2% proof stress when compressed is 360 MPa or more,
a crystal grain size of the aluminum alloy is 200 μm or less, and
a degree of compressive deformation C when compressed at a compression ratio of 50% is 0.6 or more and 1.0 or less, and

in the aging treatment,

a heating temperature is 160°C or more and 190°C or less, and
a holding time is 2 hours or more and 40 hours or less.

4. The aluminum alloy wire according to claim 3, wherein

in the measurement result obtained after performing the aging treatment on the aluminum alloy wire,

an apex of a main peak in a K absorption edge spectrum of the chromium as obtained by an XAFS analysis is located in a range of 6012.75 eV or more and 6014.00 eV or less, and the apex of the main peak is found by fitting the main peak with a Gaussian function in a range of 6009 eV to 6017 eV.

5. An aluminum alloy wire composed of an aluminum alloy, wherein

the aluminum alloy includes

1.0 mass% or more and 1.3 mass% or less of silicon,
0.5 mass% or more and 1.2 mass% or less of magnesium,
0.3 mass% or more and 0.8 mass% or less of iron,
0.1 mass% or more and 0.4 mass% or less of copper,
0.2 mass% or more and 0.5 mass% or less of manganese,
0.001 mass% or more and 0.3 mass% or less of chromium,
0 mass% or more and 0.25 mass% or less of zinc,
0 mass% or more and 0.075 mass% or less of titanium, and
0 mass% or more and 0.17 mass% or less of zirconium,

a remainder of the aluminum alloy consists of aluminum and an inevitable impurity, and in the aluminum alloy wire,

a 0.2% proof stress when compressed is 360 MPa or more,
a crystal grain size of the aluminum alloy is 200 μm or less, and

a degree of compressive deformation C when compressed at a compression ratio of 50% is 0.6 or more and 1.0 or less.

6. The aluminum alloy wire according to claim 5, wherein

an apex of a main peak in a K absorption edge spectrum of the chromium as obtained by an XAFS analysis is located in a range of 6012.75 eV or more and 6014.00 eV or less, and the apex of the main peak is found by fitting the main peak with a Gaussian function in a range of 6009 eV to 6017 eV.

7. The aluminum alloy wire according to any one of claims 1 to 6, wherein a wire diameter of the aluminum alloy wire is 1 mm or more and 30 mm or less.

8. A method of producing an aluminum alloy wire, the method comprising:

producing a continuous casted and rolled material composed of an aluminum alloy;
producing a first drawn wire material by performing a first wire drawing process on the continuous casted and rolled material;
producing an intermediate heat-treated material by performing an intermediate heat treatment on the first drawn wire material; and
producing a second drawn wire material by performing a second wire drawing process on the intermediate heat-treated material, wherein the aluminum alloy includes

1.0 mass% or more and 1.3 mass% or less of silicon,
0.5 mass% or more and 1.2 mass% or less of magnesium,
0.3 mass% or more and 0.8 mass% or less of iron,
0.1 mass% or more and 0.4 mass% or less of copper,
0.2 mass% or more and 0.5 mass% or less of manganese,
0.001 mass% or more and 0.3 mass% or less of chromium,
0 mass% or more and 0.25 mass% or less of zinc,
0 mass% or more and 0.075 mass% or less of titanium, and
0 mass% or more and 0.17 mass% or less of zirconium,

a remainder of the aluminum alloy consists of aluminum and an inevitable impurity, and in the intermediate heat treatment,

a heating temperature is 250°C or more and less than 350°C,
a holding time is 1 hour or more and less than 5 hours, and
a second processing degree in the second wire drawing process is 20% or less.

9. The method of producing the aluminum alloy wire according to claim 8, comprising producing a solution-treated wire material by performing a solution treatment on the second drawn wire material, wherein in the solution treatment,

a heating temperature is 530°C or more and 580°C or less,
a holding time is 15 minutes or more and 360 minutes or less, and
a temperature increase rate is 120°C/min or less.

10. The method of producing the aluminum alloy wire according to claim 9, comprising producing an aging-treated wire material by performing an aging treatment on the solution-treated wire material, wherein in the aging treatment,

a heating temperature is 160°C or more and 190°C or less, and
a holding time is 2 hours or more and 40 hours or less.

11. The method of producing the aluminum alloy wire according to any one of claims 8 to 10, wherein a wire diameter of the second drawn wire material is 1 mm or more and 30 mm or less.

FIG.1

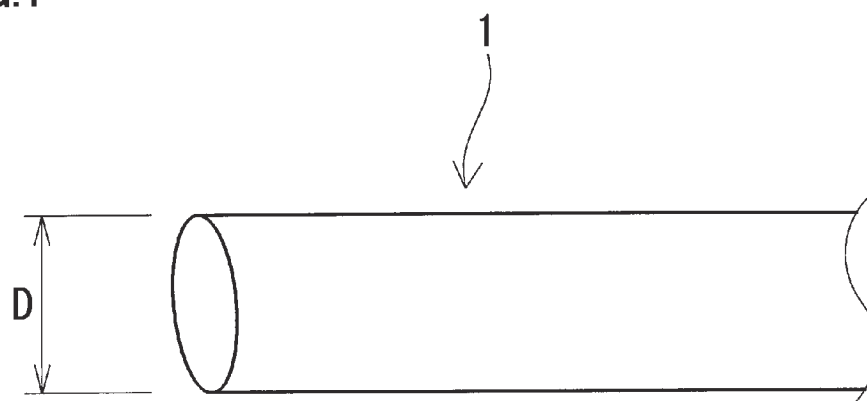


FIG.2

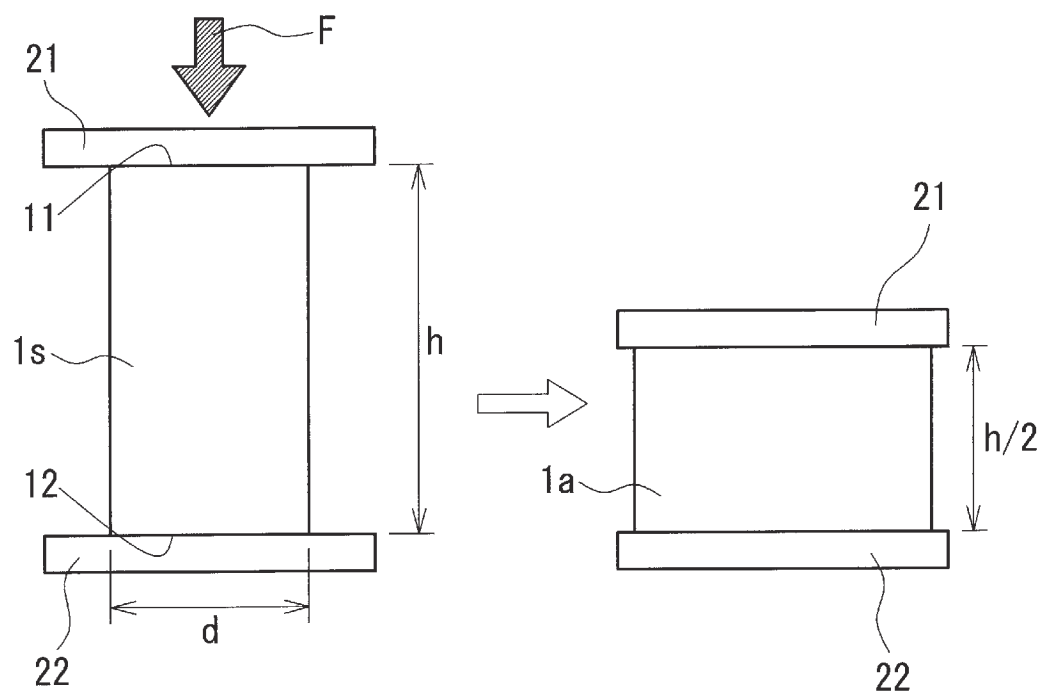
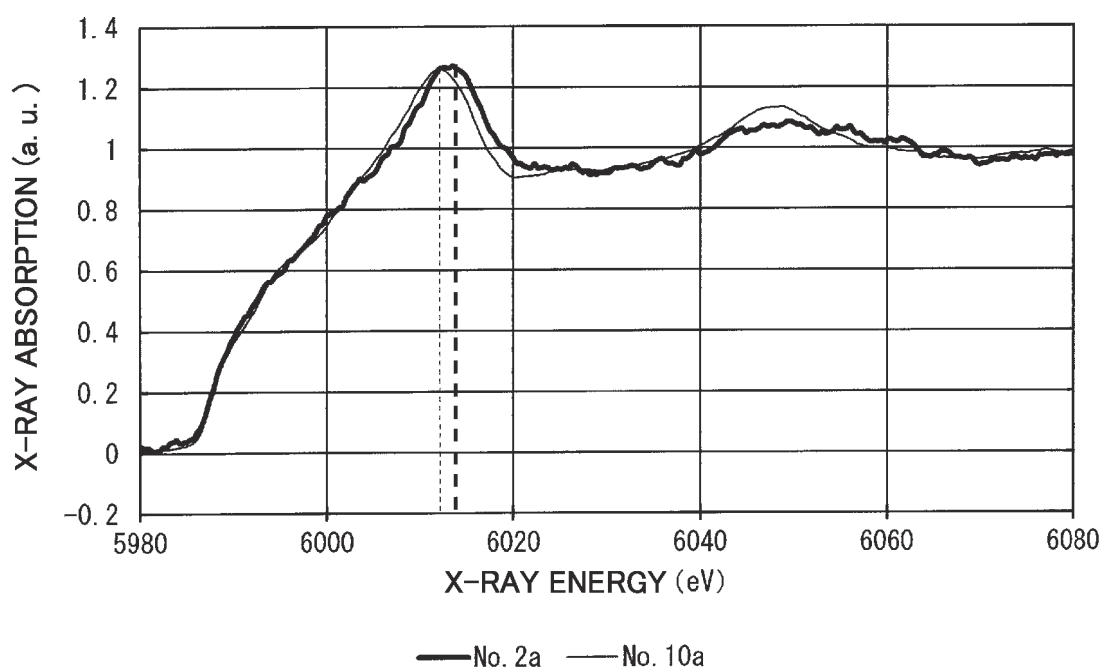


FIG.3



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2024/021324

A. CLASSIFICATION OF SUBJECT MATTER

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

FI: C22C21/02; C22C21/06; C22F1/05; C22F1/00 625; C22F1/00 624; C22F1/00 602; C22F1/00 630A; C22F1/00 630K; C22F1/00 694A; C22F1/00 691B; C22F1/00 691C; C22F1/00 686B; C22F1/00 692A; C22F1/00 691A; C22F1/00 686A; C22F1/00 631A; C22F1/00 685Z

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)

C22C21/00-21/18; C22F1/00; C22F1/04-1/057

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 1971-2024
Registered utility model specifications of Japan 1996-2024
Published registered utility model applications of Japan 1994-2024

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2021/153412 A1 (SUMITOMO ELECTRIC INDUSTRIES, LTD.) 05 August 2021 (2021-08-05) entire text, all drawings	1-11
A	WO 2022/249665 A1 (SUMITOMO ELECTRIC INDUSTRIES, LTD.) 01 December 2022 (2022-12-01) entire text, all drawings	1-11
A	WO 2022/249664 A1 (SUMITOMO ELECTRIC INDUSTRIES, LTD.) 01 December 2022 (2022-12-01) entire text, all drawings	1-11
A	JP 2015-166480 A (SUMITOMO ELECTRIC INDUSTRIES, LTD.) 24 September 2015 (2015-09-24) entire text, all drawings	1-11

☐ 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

17 September 2024

Date of mailing of the international search report

01 October 2024

Name and mailing address of the ISA/JP

Japan Patent Office (ISA/JP)
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2024/021324

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WO	2022/249665	A1	01 December 2022	(Family: none)	

WO	2022/249664	A1	01 December 2022	EP 4350020 A1 entire text, all drawings CN 117321232 A KR 10-2024-0013741 A	

JP	2015-166480	A	24 September 2015	(Family: none)	

REFERENCES CITED IN THE DESCRIPTION

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- JP 2015166480 A [0005]
- WO 2022249664 A [0005]