(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 516 952 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
05.03.2025 Bulletin 2025/10

(21) Application number: **22940090.8**

(22) Date of filing: **26.04.2022**

(51) International Patent Classification (IPC):
***C22C 21/00** (2006.01)* ***C22C 21/02** (2006.01)*
***C22C 21/06** (2006.01)*

(52) Cooperative Patent Classification (CPC):
C22C 21/00; C22C 21/02; C22C 21/06

(86) International application number:
PCT/JP2022/018901

(87) International publication number:
WO 2023/209810 (02.11.2023 Gazette 2023/44)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(71) Applicant: **Nippon Light Metal Company, Ltd.**
Tokyo 105-0004 (JP)

(72) Inventors:
- **XING Jie**
Shizuoka-shi, Shizuoka 421-3203 (JP)
- **HANDA Takeshi**
Shizuoka-shi, Shizuoka 421-3203 (JP)
- **OWADA Yasuyuki**
Shizuoka-shi, Shizuoka 421-3203 (JP)

(74) Representative: **Mewburn Ellis LLP**
Aurora Building
Counterslip
Bristol BS1 6BX (GB)

(54) **AL-MG-SI-NI ALLOY AND AL-MG-SI-NI ALLOY MATERIAL**

(57) Provided are a high-strength 6000 series aluminum alloy having exceptional plastic workability even when the Fe content is increased in association with recycling of scrap material, and an aluminum alloy material composed of said aluminum alloy. The present invention relates to an Al-Mg-Si-Ni alloy characterized by containing more than 0 to 2.0 wt% of Fe and containing Ni such that 0.7≤Ni (wt%)/Fe (wt%)≤3.5. The alloy preferably contains 0.5-1.4 wt% of Si, 0.6-1.7 wt% of Mg, 0.1-2.5 wt% of Ni, and 0.1-2.0 wt% of Fe, the balance being Al and inevitable impurities.

Description

TECHNICAL FIELD

[0001] The present invention relates to a high-strength aluminum alloy material having excellent plastic workability, and more particularly to an aluminum alloy and an aluminum alloy material suitable for recycling by using scrap materials.

PRIOR ARTS

[0002] The 6000 series aluminum alloys are one of the most widely used heat-treatable aluminum alloys. The 6000 series aluminum alloys are Al-Mg-Si-based aluminum alloys containing mainly Mg and Si, and, in addition to excellent moldability and corrosion resistance, exhibit moderate age hardening and have good strength, and are therefore widely used as structural members for transportation equipment such as vehicles.

[0003] However, in recent years, demand for weight reduction of transportation equipment has been increased in order to improve fuel efficiency and reduce CO_2 emission, and high strength and high toughness are strongly desired for 6000 series aluminum alloy materials. On the other hand, for example, in Patent Literature 1 (Japanese Patent Unexamined Publication No. 2017-155251), there is disclosed a forging aluminum alloy having excellent strength and ductility which is characterized by containing, by % by mass, Si: 0.7% to 1.5%, Mg: 0.6% to 1.2%, Fe: 0.01% to 0.5%, and one or more element selected from the group consisting of Mn: 0.05% to 1.0%, Cr: 0.01% to 0.5%, and Zr: 0.01% to 0.2%, with the remainder consisting of Al and inevitable impurities, and, as a structure in an observation plane at a center of the thickness in a thickest portion of the forging aluminum alloy, having a dislocation density of from 1.0×10^{14} to 5.0×10^{16} /m^2 on average as measured by X-ray diffractometry, including small angle grain boundaries with a tilt angle of 2° to 15° in an average proportion of 50% or more as measured by SEM-EBSD analysis, where the small angle grain boundaries are present around grains having a misorientation of 2° or more, and including precipitates measurable with a TEM at 300000-fold magnification in an average number density of 5.0×10^2 /μm^3 or more.

[0004] In the aluminum alloy forging material described in Patent Literature 1, it is said that since in the case that the 6000 series aluminum alloy forging material is subjected to solution treatment and quenching treatment, and is subjected to work strain due to warm working and then subjected to artificial aging treatment, both strength and ductility are improved (higher strength and higher ductility) than in the normal case where processing strain is not applied, in order to exhibit and guarantee the effects, the average dislocation density, the average ratio of low-angle grain boundaries, and the average number density of precipitates are defined as the structure at the center of the thickness of the thickest part of the forging material after the artificial aging treatment.

[0005] Among 6000 series aluminum alloys, Al-Mg-Si-Cu-based excess Si type alloys have high strength and low deformation resistance, and are therefore used for plastically workable materials such as extruded materials, rolled materials, and forged materials that require high strength.

[0006] In Patent Literature 2 (Japanese Patent Unexamined Publication No. 2020-164946), the present inventors have disclosed an Al-Mg-Si-based aluminum alloy cold-rolled sheet comprises: Si: 0.50 to 0.90% by mass, Fe: less than 0.70% by mass, Cu: 0.10 to 0.90% by mass, Mg: 0.80 to 1.7% by mass, Mn: 0.10 to 1.3% by mass, Cr: 0.20 to 0.90% by mass, and Ti: 0.005 to 0.10% by mass, with the balance comprising Al and inevitable impurities, the aluminum alloy cold-rolled sheet having a UTS_L of 340 MPa or more and an SL of 16.0 J/cm^2 or more measured after a solution treatment is performed at 550°C for 5 minutes and further an aging treatment is performed at 175°C for 14 hours when the tensile strength of a test piece with an L direction as the longitudinal direction is defined as the UTS_L, and the Charpy value of the test piece with the L direction as the longitudinal direction is defined as the SL.

[0007] In the aluminum alloy cold-rolled sheet described in Patent Literature 2, the Si/Mg ratio of the Al-Mg-Si-based aluminum alloy is limited to the range of 0.4 to 0.9 to reduce the amount of the excess Si and the amount of the excess Mg, thereby making it possible to narrow the width of the PFZ generated during artificial aging treatment and to suppress the growth of intermetallic compounds such as β" and β' that precipitate as intermediate phases at grain boundaries. As a result, it is possible to make the aluminum alloy after solution treatment and aging treatment excellent in impact resistance.

PRIOR LITERATURE

PATENT LITERATURE

[0008]

Patent Literature 1: Japanese Patent Unexamined Publication No. 2017-155251
Patent Literature 2: Japanese Patent Unexamined Publication No. 2020-164946

Summary of the Invention

Technical Problem

[0009] Aluminum consumes a large amount of electricity during refining, and therefore in recent years, against the background of environmental issues such as global warming, there has been an increasing demand for recycling aluminum by using scrap materials. However, aluminum is inevitably prone to being contaminated with Fe, and this tendency becomes more remarkable as the ratio of scrap material in the raw material increases.

[0010] Fe has the effect of increasing the strength of aluminum, but in an aluminum alloy containing Si, an Al-Fe-Si-based crystallized product is formed. Here, since Si, which is a constituent element of Mg_2Si that precipitates by aging treatment and contributes to improving the strength of the aluminum alloy, is consumed by the formation of Al-(Fe, M)Si-based crystallized product, there is a case where the precipitation strengthening is not sufficiently obtained.

[0011] Furthermore, when the aluminum alloy contains a large amount of Fe, the Al-Fe-Si-based crystallized product tends to become coarse. Since the coarsened crystallized products become the starting points of fracture, it is not possible to impart excellent ductility and toughness to the aluminum alloy, and it is also not possible to obtain good plastic workability.

[0012] With respect to these facts, in the aluminum alloy forging material described in Patent Literature 1 and the aluminum alloy cold-rolled sheet described in Patent Literature 2, the influence of Fe that is inevitably mixed in is not taken into consideration, and it is not possible to sufficiently increase the ratio of scrap material in the raw material.

[0013] In view of the problems in the prior arts as described above, the object of the present invention is to provide a high-strength 600 series aluminum alloy having exceptional plastic workability even when the Fe content is increased in association with recycling of scrap material, and an aluminum alloy material composed of the aluminum alloy.

Solution to Problem

[0014] In order to achieve the above object, as the result of intensive study as to the relationship between the composition, structure and mechanical properties of the Fe-containing 6000 series aluminum alloy materials, the present inventors have found that in order to obtain high-strength 6000 series aluminum alloy materials having excellent plastic workability, it is extremely effective to crystallize the Al-Fe-Ni-based compounds by adding Ni preferentially over the Al-Fe-Si-based compounds, and the like, and have reached the present invention.

[0015] Namely, the present invention provides an Al-Mg-Si-Ni-based alloy characterized by containing:

more than 0 and not more than 2.0 wt % of Fe, and
Ni which satisfies the inequality of $0.7 \leqq$ Ni (wt %) / Fe (wt %) $\leqq 3.5$.

[0016] The Al-Mg-Si-Ni-based alloy of the present invention contains more than 0 and not more than 2.0 wt % of Fe, and by adding an appropriate amount of Ni, the Al-Fe-Ni-based compounds are preferentially crystallized, and the amount of Si crystallized as Al-Fe-Si-based compounds is reduced, and thus, making it possible to effectively suppress the reduction of the amount of Si in solid solution in the parent phase. As a result, a sufficient amount of Mg-Si-based compounds can be precipitated by the aging treatment, and thus it is possible to exhibit high strength for the aluminum alloy through the precipitation strengthening. This effect can be reliably obtained when the Ni (wt %) / Fe (wt %) is 0.7 or more, but no further improvement can be obtained when adding Ni such that the Ni (wt %) / Fe (wt %) is 3.5 or more.

[0017] Further, it is preferable that the Al-Mg-Si-Ni-based alloy of the present invention contains:

Si: 0.5 to 1.4 wt %,
Mg: 0.6 to 1.7 wt %,
Ni: 0.1 to 2.5 wt %,
Fe: 0.1 to 2.0 wt %, and
with the balance being Al and inevitable impurities.

[0018] By setting the Si content to 0.5 wt % or more, it is possible to fully exhibit the solid solution strengthening and the age hardening, and by setting to 1.4 wt % or less, it is possible to suppress the decrease in corrosion resistance and the decrease in ductility due to coarsening of the crystallized products and the precipitants. Moreover, by setting the Si content to 0.6 to 0.8 wt %, it is possible to obtain these effects more reliably.

[0019] Further, by setting the Mg content to 0.6 wt % or more, due to the formation of a sufficient amount of Mg-Si-based precipitates, it is possible to improve the strength and fatigue characteristics, and by setting the Mg content to 1.7 wt % or less, it is possible to suppress the formation of coarse compounds which serve as the starting point of fracture. By setting the Mg content to 1.0 to 1.4 wt %, it is possible to obtain these effects more reliably.

[0020] Further, it is preferable that the Al-Mg-Si-Ni-based alloy of the present invention contains one or more of:

Cu: 0.2 to 1.0 wt %,
Mn: 0.1 to 0.8 wt %, and
Cr: 0.1 to 0.8 wt %.

[0021] By adding 0.2 to 1.0 wt % of Cu, due to the formation of the precipitates (Q phase or Q' phase), it is possible to enhance the mechanical strength and fatigue strength. Further, by adding 0.1 to 0.8 wt % of Mn or 0.1 to 0.8 wt % of Cr, due to the formation of the Al-(Fe, Mn, Cr)-Si-based compounds, it is possible to make the strength of the aluminum alloy material high.

[0022] Further, it is preferable that the Al-Mg-Si-Ni-based alloy of the present invention contains one or more of:

Zr: 0.05 to 0.20 wt %,
V: 0.05 to 0.20 wt %,
Ti: 0.01 to 0.15 wt %, and
B: 0.001 to 0.05 wt %.

[0023] By containing an appropriate amount of at least one of Zr, V, Ti and B, it is possible to realize the fine structure and stabilize the processing structure.

[0024] Furthermore, in the Al-Mg-Si-Ni-based alloy of the present invention, it is preferable that Mg (wt %) / Si (wt %) is 1.73 or more. By setting the Mg (wt%) / Si (wt%) to 1.73 or more, it is possible to precipitate a sufficient amount of Mg-Si-based compounds by aging treatment, and it is possible to exhibit high strength of the aluminum alloy material by precipitation strengthening.

[0025] Further, the present invention also provides an Al-Mg-Si-Ni-based alloy material made of the Al-Mg-Si-Ni-based alloy of the present invention, in which an Al-Fe-Ni-based compound is dispersed.

[0026] In the Al-Mg-Si-Ni-based alloy material of the present invention, Fe is rendered harmless by the addition of an appropriate amount of Ni, and the aluminum alloy material has high strength as well as excellent plastic workability. Since Al-Fe-Ni-based compounds are less likely to coarsen than Al-Fe-Si-based compounds, the formation of coarse compounds that could become the starting point of fracture when stress is applied is suppressed. As a result, the fine Al-Fe-Ni-based compounds are dispersed and crystallized, which imparts excellent plastic workability and toughness to the aluminum alloy.

[0027] In the Al-Mg-Si-Ni-based alloy material of the present invention, it is preferable to have tensile properties such as a 0.2% yield strength of 300 MPa or more and an elongation at break of 12% or more. Since the Al-Mg-Si-Ni-based alloy material has a 0.2% yield strength of 300 MPa or more and an elongation of 12% or more, it is possible to suitably use for structural members that require high reliability. Further, since sufficient ductility is ensured and the alloy has excellent plastic workability, it is possible to be made into plastically worked materials such as extruded materials, rolled materials, and forged materials.

[0028] Further, in the Al-Mg-Si-Ni-based alloy material of the present invention, it is preferable that the limit bending angle in the VDA bending test specified in VDA238-100 is 50° or more. Since the limit bending angle in the VDA bending test of the Al-Mg-Si-Ni-based alloy material is 50° or more, it is possible to carry out a processing step that requires a large plastic deformation.

Effects of the invention

[0029] According to the present invention, it is possible to provide the high-strength 600 series aluminum alloy having exceptional plastic workability even when the Fe content is increased in association with recycling of scrap material, and the aluminum alloy material composed of the aluminum alloy.

Brief Explanation of the Drawings

[0030]

FIG. 1 is an X-ray diffraction pattern of the present aluminum alloy material having the composition of Example 4.
FIG. 2 is an X-ray diffraction pattern of the present aluminum alloy material having the composition of Example 8.
FIG. 3 is an optical microscope photograph of the present aluminum alloy material having the composition of Example 4.
FIG. 4 is an optical microscope photograph of the present aluminum alloy material having the composition of Example 8.

FIG. 5 is an optical microscope photograph of the present aluminum alloy material having the composition of Example 9.
FIG. 6 is an X-ray diffraction pattern of the comparative aluminum alloy material having the composition of Comparative Example 4.
FIG. 7 is an optical microscope photograph of the comparative aluminum alloy material having the composition of Comparative Example 4.
FIG. 8 is an optical microscope photograph of the comparative aluminum alloy material having the composition of Comparative Example 8.
FIG. 9 is a photograph showing the appearance of the comparative aluminum alloy material having the composition of Comparative Example 11.
FIG. 10 is an optical microscope photograph of the comparative aluminum alloy material having the composition of Comparative Example 9.
FIG. 11 is an optical microscope photograph of the comparative aluminum alloy material having the composition of Comparative Example 10.
FIG. 12 is an optical microscope photograph of the comparative aluminum alloy material having the composition of Comparative Example 11.

Embodiments for achieving the invention

[0031] Representative embodiments of the Al-Mg-Si-Ni-based alloy and the Al-Mg-Si-Ni-based alloy material of the present invention will be described in detail below with reference to the drawings, but the present invention is not limited to these.

1. Al-Mg-Si-Ni-based alloy

[0032] The Al-Mg-Si-Ni-based alloy of the present invention is characterized in that the Al-Fe-Ni-based compounds are crystallized preferentially over the Al-Fe-Si-based compounds to render Fe harmless, and, at the same time, Ni is added to a 6000 series aluminum alloy in order to utilize the dispersion strengthening due to the Al-Fe-Ni-based compounds. Each component will be described in detail below.

(1) Essential Added Elements

Si: 0.5 to 1.4 wt %

[0033] It is preferable that the Si content is set to 0.5 to 1.4 wt %.
By setting the Si content to 0.5 wt % or more, it is possible to fully exhibit the solid solution strengthening and the age hardening, and by setting to 1.4 wt % or less, it is possible to suppress the decrease in corrosion resistance and the decrease in ductility due to coarsening of the crystallized products and the precipitants. More preferable Si content is 0.6 to 0.8 wt %. By setting the Si content to 0.6 to 0.8 wt %, it is possible to obtain these effects more reliably.

Mg: 0.6 to 1.7 wt %

[0034] It is preferable that the Mg content is set to 0.6 to 1.7 wt %.
By setting the Mg content to 0.6 wt % or more, due to the formation of a sufficient amount of Mg-Si-based precipitates, it is possible to improve the strength and fatigue characteristics, and by setting the Mg content to 1.7 wt % or less, it is possible to suppress the formation of coarse compounds which serve as the starting point of fracture. More preferable Mg content is 1.0 to 1.4 wt %. By setting the Mg content to 1.0 to 1.4 wt %, it is possible to obtain these effects more reliably.

Ni: 0.1 to 2.5 wt %

[0035] It is preferable that the Ni content is set to 0.1 to 2.5 wt %, assuming that the Ni (wt %) / Fe (wt %) value is set to 0.7 to 3.5. By setting the Ni content to 0.1 wt % or more, it is possible to crystallize the Al-Fe-Ni-based compound. Further, by setting the Ni content to 2.5 wt % or less, it is possible to suppress the increase in raw material costs due to the addition of excessive Ni. The Ni content is more preferably 0.2 to 1.1 wt %, and most preferably 0.3 to 1.0 wt %.

Fe: 0.1 to 2.0 wt %

[0036] It is preferable that the Fe content is set to 0.1 to 2.0 wt %. By allowing the Fe content of 0.1 to 2.0 wt %, the scrap material can be suitably used as the raw material. Further, when the Fe content is 0.1 to 2.0 wt %, the effect of the Fe can be reliably rendered harmless by adding Ni. It is more preferable that the Fe content is set to 0.15 to 1.1 wt %.

[0037] In the Al-Mg-Si-Ni-based alloy of the present invention, the value of Ni (wt %) / Fe (wt %) is 0.7 to 3.5. By setting the value of Ni (wt %) / Fe (wt %) to 0.7 to 3.5, the Al-Fe-Ni-based compounds are preferentially crystallized without adding excessive Ni, and the amount of Si crystallized as Al-Fe-Si-based compounds is reduced, and thus, making it possible to effectively suppress the reduction of the amount of Si in solid solution in the parent phase. As a result, a sufficient amount of Mg-Si-based compounds can be precipitated by the aging treatment, and thus it is possible to exhibit high strength for the aluminum alloy through the precipitation strengthening. The Ni (wt %) / Fe (wt %) ratio is more preferably in the range of 1.0 to 3.0, and most preferably in the range of 1.1 to 2.0.

[0038] Furthermore, it is preferable that Mg (wt %) / Si (wt %) is 1.73 or more. By setting the Mg (wt%) / Si (wt%) to 1.73 or more, it is possible to precipitate a sufficient amount of Mg-Si-based compounds by aging treatment, and it is possible to exhibit high strength of the aluminum alloy material by precipitation strengthening. The Mg (wt %) / Si (wt %) ratio is more preferably in the range of 1.73 to 2.00, and most preferably in the range of 1.75 to 1.95.

(2) Optional Added Elements

Cu: 0.2 to 1.0 wt %

[0039] It is preferable that the Cu content is set to 0.2 to 1.0 wt %. Cu has the effect of increasing mechanical strength and fatigue strength by forming the Al, Mg, Si, and Cu-based quaternary precipitate (Q phase or Q' phase). When the Cu content is less than 0.2 wt%, these effects cannot be sufficiently obtained. On the other hand, when the Cu content exceeds 1.0 wt%, there is a possibility that the corrosion resistance is lowered.

Mn: 0.1 to 0.8 wt%

[0040] It is preferable that the content of Mn is set to 0.1 to 0.8 wt %. When the content of Mn is set to 0.1 wt % or more, the strength of the aluminum alloy can be increased by forming the Al-(Fe, Mn, Cr)-Si-based compound. Further, when setting the content of Mn to 0.8 wt % or less, it is possible to suppress the formation of coarse Al-(Fe, Mn, Cr)-Si-based compound that reduce toughness and ductility.

Cr: 0.1 to 0.8 wt%

[0041] It is preferable that the content of Cr is set to 0.1 to 0.8 wt %. When the content of Cr is set to 0.1 wt % or more, the strength of the aluminum alloy can be increased by forming the Al-(Fe, Mn, Cr)-Si-based compound. Further, when setting the content of Cr to 0.8 wt % or less, it is possible to suppress the formation of coarse Al-(Fe, Mn, Cr)-Si-based compound that reduce toughness and ductility.

Zr: 0.05 to 0.20 wt %

[0042] Zr has the effect of suppressing recrystallization structure through the pinning effect of the compound, and can stabilize the processing structure. By setting the content to 0.05 wt % or more, the effect can be sufficiently exhibited, and by setting the content to 0.20 wt % or less, the decrease in ductility due to the coarsening of the compounds can be suppressed.

V: 0.05 to 0.20 wt %

[0043] By adding 0.05 wt % or more of V, the Al-V-based dispersed particles are formed, which suppress the movement of crystal grain boundaries and the recrystallization, thereby exhibiting a so-called pinning effect, and thus, it is possible to contribute to strength. Further, by setting the added amount of V to 0.20 wt % or less, it is possible to suppress the decrease in ductility due to the coarsening of the Al-V-based dispersed particles.

Ti: 0.01 to 0.15 wt %

[0044] By adding in combination with B, Ti forms the Al-Ti-based and the Ti-B-based compounds, which refine the casting structure, prevent casting cracks, and at the same time, promote the homogenization of the added elements. These effects are insufficient when added in an amount of less than 0.01 wt %, and when added in an amount more than 0.15 wt %, not only does the effect saturate, but also the coarse Al-Ti crystallized products are formed, which results in lowering toughness. Further, by solid-dissolving Ti in Al, the growth of Al_2Cu and Al_2CuMg precipitates, which are strengthening phases, at a high temperature can be suppressed, making it possible to stably obtain high strength.

B: 0.001 to 0.05 wt %

[0045] The addition of B can refine the casting structure. The refinement effect can be sufficiently exhibited by setting the B content to 0.001 wt % or more, and by setting to 0.05 wt % or less, the decrease in ductility due to the formation of coarse compounds can be suppressed. Note, in order to obtain the refinement effect of the casting structure, it is preferable to add B to the molten alloy immediately before the casting.

2. Al-Mg-Si-Ni-based alloy material

[0046] The Al-Mg-Si-Ni-based alloy material of the present invention is an aluminum alloy material made of the Al-Mg-Si-Ni-based alloy of the present invention. The structure and mechanical properties of the Al-Mg-Si-Ni-based alloy material will be described in detail below.

(1) Structure

[0047] The Al-Mg-Si-Ni-based alloy material of the present invention is characterized in that the fine Al-Fe-Ni-based compounds are dispersed.

[0048] Since the formation energy of the Al-Fe-Ni-based compounds is lower than that of the Al-Fe-Si-based compounds, by adding a small amount of Ni to the Al-Mg-Si-based alloy, it is possible to finely crystallize the Al-Fe-Ni based compounds before the Al-Fe-Si-based compounds are crystallized. Here, the formation energy of Al_2FeNi is -0.52 eV, whereas the formation energy of $Al_2(FeSi)_3$ is -0.481 eV, the formation energy of $AlFe_2Si$ is -0.46 eV, and the formation energy of $Al_2Fe_3Si_4$ is -0.431 eV.

[0049] Further, the Al-Fe-Ni-based compounds can be crystallized more finely than the Al-Fe-Si-based compounds. Since the dispersion strengthening can be exhibited remarkably effectively by uniform dispersion of the fine Al-Fe-Ni-based compounds, when the Fe and Ni contents are large, it is possible to make the aluminum alloy highly strong by utilizing the dispersion strengthening. Here, even when the Fe and Ni contents are large, the Al-Fe-Ni-based compounds do not become coarse, and the number of the compounds can be increased.

[0050] By crystallizing finely the Al-Fe-Ni-based compounds before the crystallization of the Al-Fe-Si-based compounds, since the amount of solid-dissolved Si after the solution treatment can be sufficiently secured, it is possible to increase the strength while maintaining high toughness by the subsequent heat treatment. That is, even when the aluminum alloy is made of scrap materials and contains a relatively large amount of Fe, it is possible to impart excellent toughness and high strength at the same time.

[0051] The average particle size of the Al-Fe-Ni-based compounds dispersed in the Al-Mg-Si-Ni-based alloy material is preferably 15 μm or less, more preferably 10 μm or less, and most preferably 5 μm or less. By setting the average particle size of the Al-Fe-Ni-based compounds to these values, it is possible to suppress the decrease in toughness and ductility caused by the Al-Fe-Ni-based compounds, and to utilize the dispersion strengthening. The method for determining the average particle size of the Al-Fe-Ni-based compound is not particularly limited, and, for example, the average particle size of the Ni-containing compounds can be determined from an optical microscope photograph, SEM-EDS mapping, or EPMA mapping of the cross section of the Al-Mg-Si-Ni-based alloy material.

[0052] Further, it is also preferable that 80% or more of the crystallized products dispersed in the Al-Mg-Si-Ni-based alloy material are the Al-Fe-Ni-based compounds. More preferable proportion of the Al-Fe-Ni-based compounds is 85% or more, and most preferable proportion of the Al-Fe-Ni-based compounds is 90% or more. The method for determining the proportion of Al-Fe-Ni-based compounds is not particularly limited, and, for example, the proportion of compounds containing Ni can be determined from SEM-EDS mapping or EPMA mapping of a cross section of the Al-Mg-Si-Ni-based alloy material. Further, quantitative values obtained by various elemental analyses may be used, or the proportion may be calculated from peak intensities in a diffraction pattern obtained by XRD measurement.

(2) Mechanical Properties

[0053] The 0.2% yield strength of the Al-Mg-Si-Ni-based alloy material is preferably 300 MPa or more, more preferably 330 MPa or more, and most preferably 360 MPa or more. The elongation at break of the Al-Mg-Si-Ni-based alloy material is preferably 12% or more, more preferably 13% or more, and most preferably 14% or more. Since the Al-Mg-Si-Ni-based alloy material has these tensile properties, it is possible to suitably use for structural members that require high reliability. Further, since sufficient ductility is ensured and the alloy has excellent plastic workability, it is possible to be made into plastically worked materials such as extruded materials, rolled materials, and forged materials.

[0054] Further, in the Al-Mg-Si-Ni-based alloy material of the present invention, it is preferable that the limit bending angle in the VDA bending test specified in VDA238-100 is 50° or more. The limit bending angle is more preferably 60° or more, and most preferably 70° or more. When the value of the limit bending angle in the VDA bending test of the Al-Mg-Si-Ni based alloy material is equal to or greater than these values, it is possible to carry out a processing step that requires a large plastic deformation.

[0055] The VDA is the German Association of the Automotive Industry Standard (Verband der Automobilindustrie), and VDA238-100 is specified as a plate bending test aimed at evaluating the cracking behavior when a component is crushed.

[0056] The method for producing the Al-Mg-Si-Ni-based alloy material is not particularly limited as long as the effects of the present invention are not impaired, and various conventionally known methods for producing the aluminum alloy materials can be used by using the Al-Mg-Si-Ni-based alloy of the present invention.

[0057] Although representative embodiments of the present invention have been described above, the present invention is not limited to these, and various design changes are possible, and all such design changes are included in the technical scope of the present invention.

EXAMPLE

<<Examples>>

[0058] Aluminum alloy slabs with a thickness of 70 mm having the compositions shown in Table 1 as Examples were obtained by DC continuous casting. The components in Table 1 are shown in wt %. Table 1 also shows the values of Ni (wt %) / Fe (wt %) and Mg (wt %) / Si (wt %). For all compositions shown as Examples, the values of Ni (wt %) / Fe (wt %) are within the range of 0.7 to 3.5.

[0059] Next, the obtained slab was subjected to the homogenization treatment under the conditions of 540°C for 6 hours, and then hot-rolled to a thickness of 6 mm. Next, the sheet was cold-rolled to a thickness of 2 mm, and then subjected to the T6 heat treatment to obtain the present aluminum alloy material according to the present invention. The T6 heat treatment was a treatment which consisted of holding at 557°C for 2 hours, followed by water cooling and aging at 175°C.

[Table 1]

	Si	Fe	Mg	Cu	Ni	Mn	Cr	Al	Ni/Fe	Mg/Si
EX.1	0.68	0.16	1.20	-	0.30	-	-	bal.	1.9	1.76
EX.2	0.68	0.16	1.19	0.29	0.30	-	-	bal.	1.9	1.75
EX.3	0.70	0.16	1.20	0.43	0.29	-	-	bal.	1.8	1.71
EX.4	0.71	0.17	1.21	0.30	0.53	-	-	bal.	3.1	1.70
EX.5	0.72	0.17	1.39	0.30	0.31	-	-	bal.	1.8	1.93
EX.6	0.71	0.17	1.20	0.29	0.30	0.30	-	bal.	1.8	1.69
EX.7	0.68	0.18	1.18	0.29	0.30	-	0.19	bal.	1.7	1.74
EX.8	0.69	0.17	1.18	0.29	0.30	0.30	0.20	bal.	1.8	1.71
EX.9	0.60	1.01	1.00	0.31	1.06	-	-	bal.	1.0	1.67
Com. Ex.1	0.69	0.16	1.19	-	-	-	-	bal.	-	1.72
Com. Ex.2	0.71	0.18	1.21	0.30	-	-	-	bal.	-	1.70
Com. Ex.3	0.69	0.17	1.23	0.45	-	-	-	bal.	-	1.78
Com. Ex.4	0.77	0.17	1.22	0.43	-	0.30	0.20	bal.	-	1.58
Com. Ex.5	0.72	0.17	1.21	0.45	-	-	0.19	bal.	-	1.68
Com. Ex.6	1.10	0.16	1.19	0.29	0.29	-	-	bal.	1.8	1.08
Com. Ex.7	1.06	0.18	0.86	0.45	-	0.38	0.27	bal.	-	0.81
Com. Ex.8	0.61	1.01	0.99	0.30	-	-	-	bal.	-	1.62
Com. Ex.9	0.62	1.76	1.02	0.29	-	-	-	bal.	-	1.65
Com. Ex.10	0.60	2.66	0.98	0.30	-	-	-	bal.	-	1.63
Com. Ex.11	0.60	2.66	0.98	0.30	2.76	-	-	bal.	1.0	1.63

[0060] The obtained present aluminum alloy material was cut and subjected to the mirror-polishing to prepare a cross-sectional sample. Next, an X-ray diffraction pattern from the cross section was obtained by using an X-ray diffraction method, and the compound was identified. The X-ray diffraction patterns of the present aluminum alloy materials having the compositions of Example 4 and Example 8 are shown in FIG. 1 and FIG. 2, respectively. In the present aluminum alloy material having the composition of Example 4, only clearly observed peaks were due to Al, $Al_9(FeNi)_2$ and Mg_2Si. Further, in the present aluminum alloy material having the composition of Example 8, peaks due to Al, $Al_9(FeNi)_2$ and Mg_2Si were clearly observed, and a small peak due to α-Al(Fe·M)Si was also confirmed. From these results, it can be seen that almost of the compounds formed are Al-Fe-Ni-based compounds.

[0061] Further, the obtained present aluminum alloy material was cut and mirror-polished to prepare a cross-sectional observation sample, and the structure was observed by an optical microscope. Optical microscope photographs of the present aluminum alloy materials having the compositions of Example 4, Example 8 and Example 9 are shown in FIG. 3, FIG. 4 and FIG. 5, respectively.

[0062] The fine Al-Fe-Ni-based compounds are dispersed in a large amount, and no Al-Fe-Ni-based compound with a particle size of 10 μm or more is observed. Further, even when the amounts of Fe and Ni added are large (Example 9), the Al-Fe-Ni-based compounds do not become coarse, and it can be seen that the number of dispersed Al-Fe-Ni-based compounds increases significantly.

[0063] The tensile properties of the obtained aluminum alloy materials are shown in Table 2. As the tensile test pieces, No. 14A test pieces as specified in JIS Z 2241 were used, and the tensile speeds according to JIS Z 2241 were 2 mm/min up to 0.2% yield strength and 5 mm/min after 0.2% yield strength. As shown in Table 2, the present aluminum alloy material according to the present invention has both a 0.2% yield strength of 300 MPa and an elongation of 12% or more.

[Table 2]

	Tensile strength (MPa)	0.2% yield strength (MPa)	Elongation (%)	VDA bending angle (°)	
				L Direction	LT Direction
EX.1	335	309	14.5	78	79
EX.2	389	360	13.5	58	59
EX.3	395	365	14.9	54	57
EX.4	394	362	14.5	56	62
EX.5	388	363	12.8	60	66
EX.6	393	361	14.4	57	69
EX.7	389	360	14.9	64	69
EX.8	397	356	15.1	52	67
EX.9	389	341	15.4	52	62
Com. Ex.1	309	273	15.5	72	70
Com. Ex.2	340	297	16.3	60	63
Com. Ex.3	373	342	13.3	42	39
Com. Ex.4	382	346	14.0	47	57
Com. Ex.5	379	346	14.4	47	46
Com. Ex.6	397	375	11.2	30	24
Com. Ex.7	419	398	15.2	46	48
Com. Ex.8	350	295	16.5	72	79
Com. Ex.9	319	262	12.7	59	76
Com. Ex.10	270	211	11.6	58	74
Com. Ex.11	-	-	-	-	-

[0064] Further, the VDA bending test specified in VDA238-100 was carried out on each of the obtained present aluminum alloy materials to evaluate the limit bending angle. The obtained limit bending angles are shown in Table 2. The limit bending angle was evaluated in the L direction (rolling direction) and the LT direction (direction perpendicular to the rolling direction), and all of the obtained present aluminum alloy materials had a value of 50° or more.

<<Comparative Examples>>

[0065] Comparative aluminum alloy materials were obtained in the same manner as in the Example, except that slabs of the aluminum alloys having the compositions shown in Table 1 as Comparative Examples were used. Further, the obtained comparative aluminum alloy materials were evaluated in the same manner as in the Examples.

[0066] The X-ray diffraction pattern of the comparative aluminum alloy material having the composition of Comparative Example 4 is shown in FIG. 6. When the compound formed in the comparative aluminum alloy material having the composition of Comparative Example 4 was identified by the X-ray diffraction, the peaks due to Al and α-Al(Fe·M)Si were clearly observed.

[0067] Optical microscope photographs of the comparative aluminum alloy materials having the compositions of Comparative Example 4 and Comparative Example 8 are shown in FIG. 7 and FIG. 8, respectively. Comparing the structures of Comparative Example 4 and Example 8, in which the main difference is the presence or absence of Ni addition, it can be seen that the compounds in Comparative Example 4 are coarsened. This result shows that the addition of Ni refines the compound.

[0068] When the Fe content is large (about 1 wt %), comparing the structures of Comparative Example 8 and Example 9, in which the main difference is the presence or absence of Ni addition, it can be seen that the compounds in Comparative Example 8 are coarsened. This result shows that even when the Fe content is large, the addition of Ni refines the compound.

[0069] Table 2 shows the tensile properties and the limit bending angle in the VDA bending test of each of the obtained comparative aluminum alloy materials. Among the comparative aluminum alloy materials, there is no material that satisfies all of the 0.2% yield strength of 300 MPa or more, the elongation of 12% or more, and the limit bending angle of 50° or more.

[0070] For example, when comparing the mechanical properties of Comparative Example 4 and Example 8, in which the main difference is the presence or absence of Ni addition, the limit bending angle in the L direction in Comparative Example 4 does not reach 50°, and sufficient plastic workability cannot be exhibited. Further, when comparing Comparative Example 8, which has a large Fe content, with Example 9, the 0.2% yield strength of Comparative Example 8 does not reach 300 MPa, and the alloy cannot be used as a high-strength member.

[0071] In addition, in Comparative Example 9 and Comparative Example 10, which contain a large amount of Fe and do not contain Ni, the precipitation strengthening due to Mg_2Si cannot be sufficiently exhibited, and the 0.2% yield strength is a low value. In particular, in Comparative Example 10, which has a larger Fe content, the 0.2% yield strength is an extremely low value of 211 MPa.

[0072] Here, Comparative Example 11 is the example where Ni was added to the composition of Comparative Example 10, and, when the Fe content was too large, coarse Fe-based primary crystals were formed, and good sheet material could not be obtained. FIG. 9 is a photograph showing the appearance of the aluminum alloy material in Comparative Example 11, and it can be seen that many cracks were generated and a smooth surface was not obtained.

[0073] Optical microscope photographs of the comparative aluminum alloy materials having the compositions of Comparative Example 9, Comparative Example 10 and Comparative Example 11 are shown in FIG. 10, FIG. 11 and FIG. 12, respectively. In Comparative Example 10, which has a large Fe content, the formation of coarse Fe-based primary crystals is confirmed. In Comparative Example 11 in which Ni was added, the width of the iron-based primary crystals become thin, but when the Fe content was too large, coarsening could not be completely suppressed.

[0074] From the above results, it can be seen that by using the Al-Mg-Si-Ni-based alloy of the present invention, even when the Fe content is increased, a high-strength aluminum alloy material having excellent plastic workability can be obtained so long as the Fe content is 2.0 wt % or less.

Claims

1. An Al-Mg-Si-Ni-based alloy, which comprises:

more than 0 and not more than 2.0 wt % of Fe, and
Ni which satisfies the inequality of $0.7 \leqq$ Ni (wt %) / Fe (wt %) $\leqq 3.5$.

2. The Al-Mg-Si-Ni-based alloy according to claim 1, which comprises:

Si: 0.5 to 1.4 wt %,
Mg: 0.6 to 1.7 wt %,
Ni: 0.1 to 2.5 wt %, and

Fe: 0.1 to 2.0 wt %,
with the balance being Al and inevitable impurities.

3. The Al-Mg-Si-Ni-based alloy according to claim 1 or 2, which comprises one or more of:

Cu: 0.2 to 1.0 wt %,
Mn: 0.1 to 0.8 wt %, and
Cr: 0.1 to 0.8 wt %.

4. The Al-Mg-Si-Ni-based alloy according to claim 1 or 2, which comprises one or more of:

Zr: 0.05 to 0.20 wt %,
V: 0.05 to 0.20 wt %,
Ti: 0.01 to 0.15 wt %, and
B: 0.001 to 0.05 wt %.

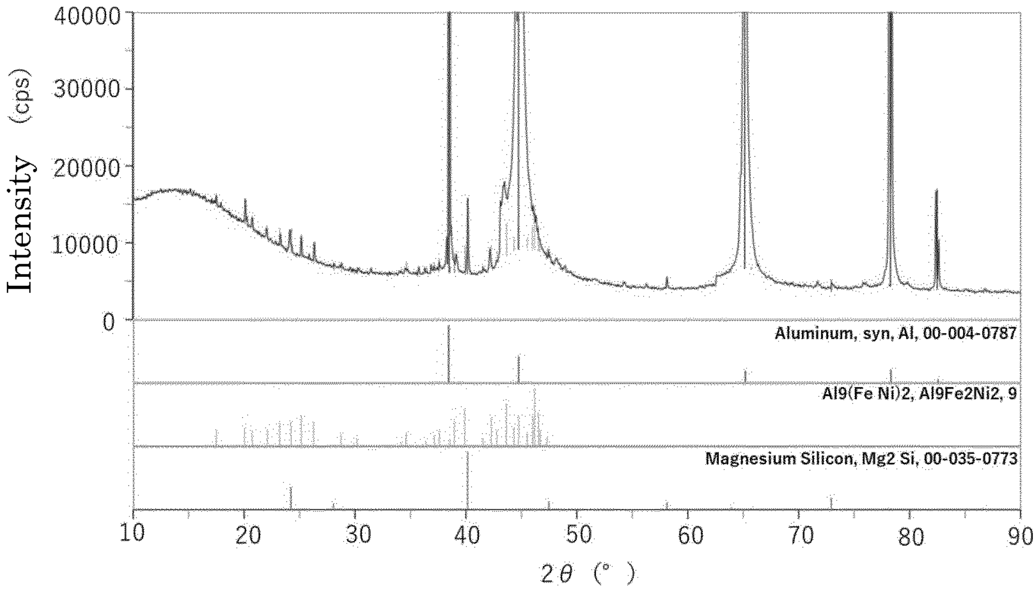
5. The Al-Mg-Si-Ni-based alloy according to claim 1 or 2, wherein Mg (wt %) / Si (wt %) is 1.73 or more.

6. An Al-Mg-Si-Ni-based alloy material comprising the Al-Mg-Si-Ni-based alloy according to any one of claims 1 to 5, wherein Al-Fe-Ni-based compounds are dispersed.

7. The Al-Mg-Si-Ni-based alloy material according to claim 6, which has tensile properties of a 0.2% yield strength of 300 MPa or more and an elongation at break of 12% or more.

8. The Al-Mg-Si-Ni-based alloy material according to claim 6, wherein a limit bending angle in the VDA bending test specified in VDA238-100 is 50° or more.

[FIG. 1]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10000
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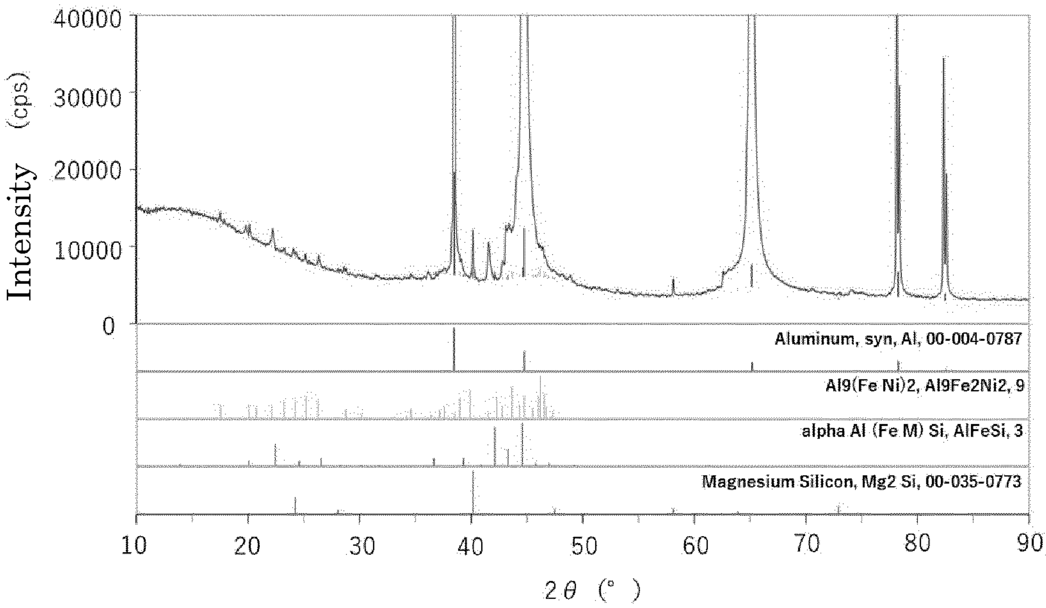
Magnesium Silicon, Mg2 Si, 00-035-0773
10
20
30
40
50
60
70
80
90
2θ (°)

[FIG. 2]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30000
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alpha Al (Fe M) Si, AlFeSi, 3
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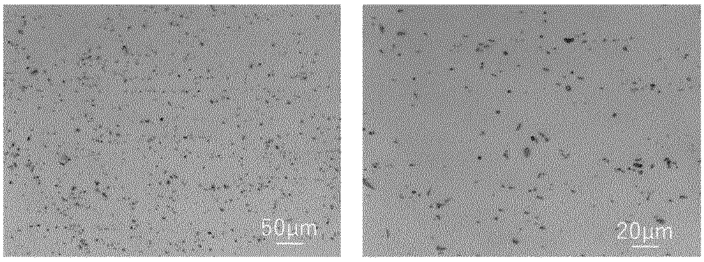
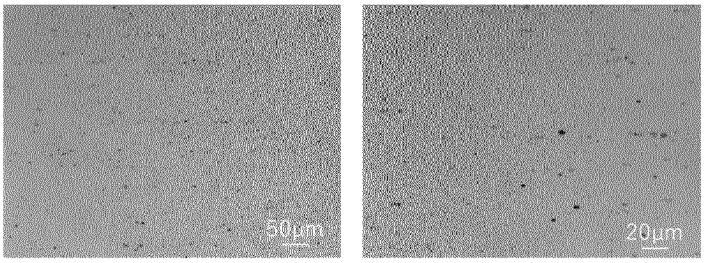
20
30
40
50
60
70
80
90
2θ (°)

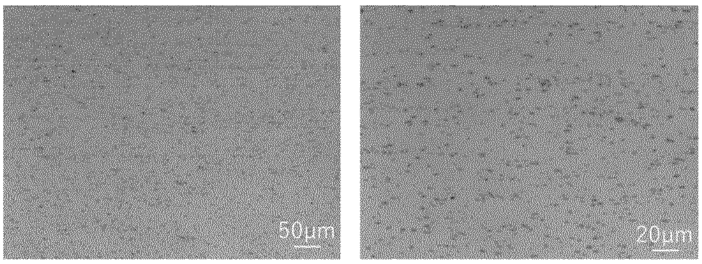
[FIG. 3]



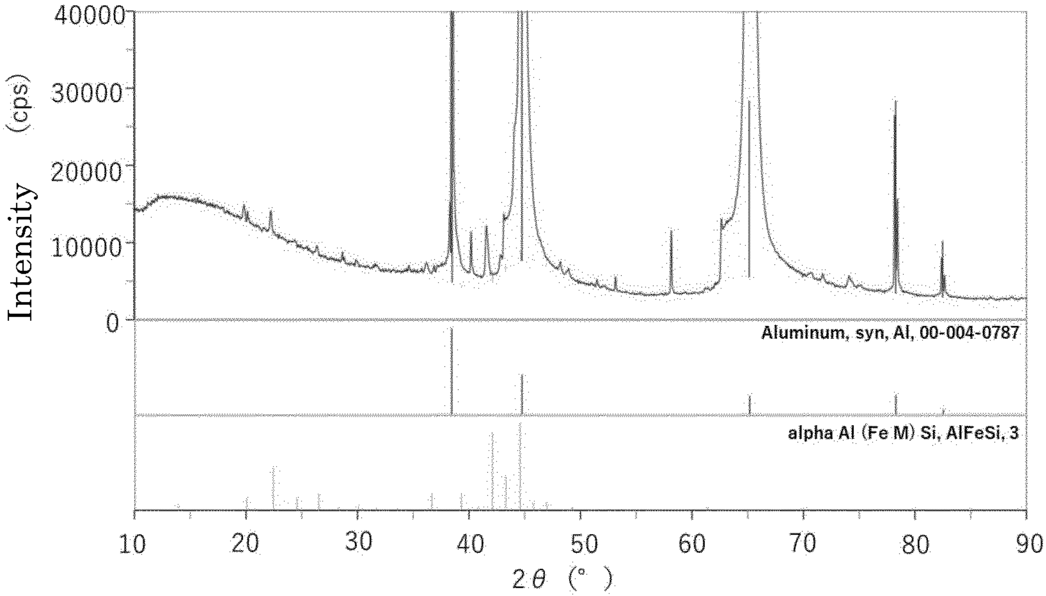
[FIG. 4]



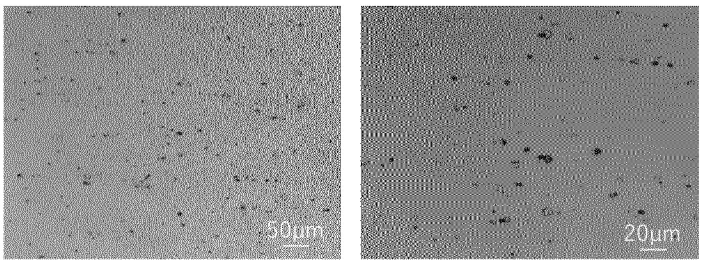
[FIG. 5]



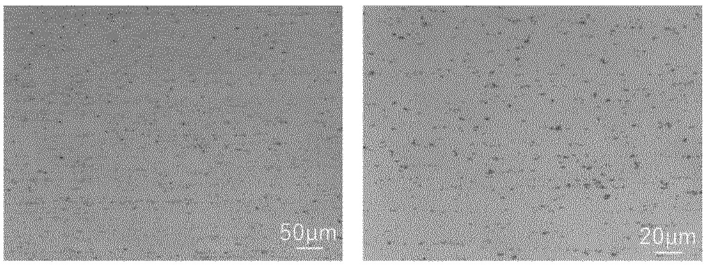
[FIG. 6]



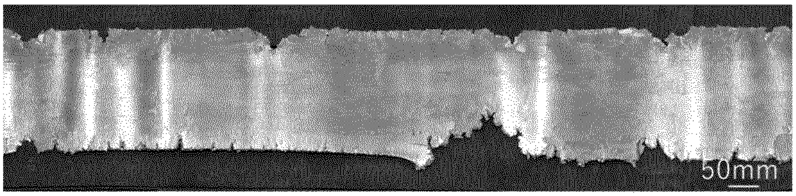
[FIG. 7]



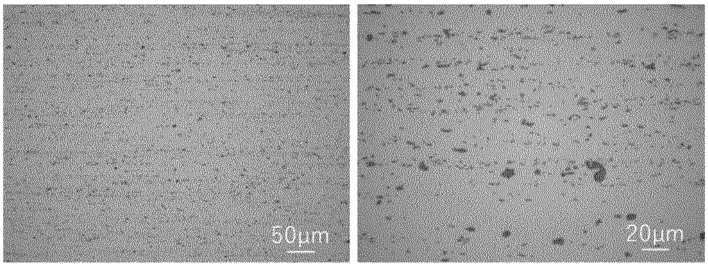
[FIG. 8]



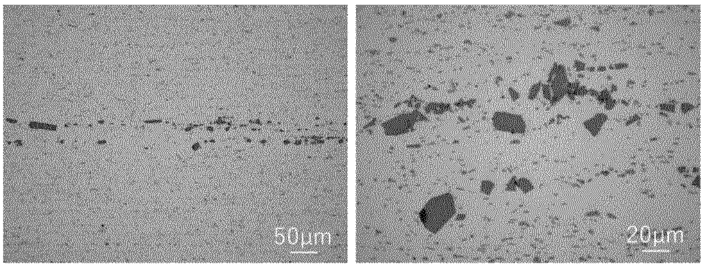
[FIG. 9]



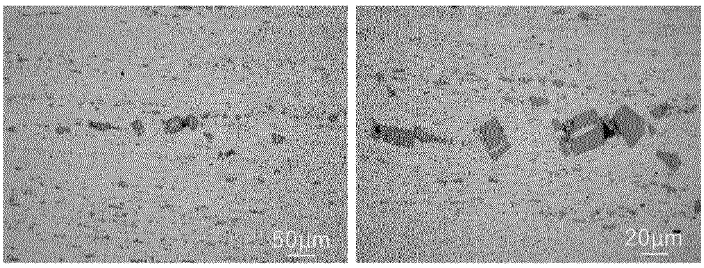
[FIG. 10]



[FIG. 11]



[FIG. 12]



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/018901

A. CLASSIFICATION OF SUBJECT MATTER

C22C 21/00(2006.01)i; ***C22C 21/02***(2006.01)i; ***C22C 21/06***(2006.01)i
FI: C22C21/00 N; C22C21/02; C22C21/06

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

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.
X A	JP 4-311545 A (SHOWA ALUM CORP) 04 November 1992 (1992-11-04) paragraphs [0006]-[0013], table 1	1-6 7-8
X A	JP 2016-37632 A (NAT UNIV YOKOHAMA) 22 March 2016 (2016-03-22) paragraphs [0017], [0020]-[0038], table 1	1-2, 6 3-5, 7-8
X	JP 60-125356 A (FURUKAWA DENKI KOGYO KK) 04 July 1985 (1985-07-04) table 1	1-2
X	JP 2006-316321 A (NIPPON LIGHT METAL CO LTD) 24 November 2006 (2006-11-24) table 1	1, 3
X	JP 2014-189844 A (UACJ CORP) 06 October 2014 (2014-10-06) paragraphs [0017]-[0027], [0046]-[0049], table 1	1, 4-6
X	JP 2019-218612 A (UACJ CORP) 26 December 2019 (2019-12-26) paragraphs [0026]-[0031], [0043], table 1	1, 4-6

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

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Date of the actual completion of the international search	Date of mailing of the international search report
06 July 2022	**19 July 2022**
Name and mailing address of the ISA/JP **Japan Patent Office (ISA/JP)** **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/018901

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 5-1348 A (SUMITOMO LIGHT METAL IND LTD) 08 January 1993 (1993-01-08) paragraphs [0021]-[0031], table 4	1, 5-6
X	WO 2019/167469 A1 (HONDA MOTOR CO., LTD.) 06 September 2019 (2019-09-06) paragraphs [0012]-[0027], table 1	1, 3-4
A	JP 2020-519772 A (NOVELIS INC) 02 July 2020 (2020-07-02)	1-8
A	US 2021/0388468 A1 (APPLE INC.) 16 December 2021 (2021-12-16)	1-8

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

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/018901

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 4-311545 A	04 November 1992	(Family: none)	
JP 2016-37632 A	22 March 2016	(Family: none)	
JP 60-125356 A	04 July 1985	(Family: none)	
JP 2006-316321 A	24 November 2006	(Family: none)	
JP 2014-189844 A	06 October 2014	(Family: none)	
JP 2019-218612 A	26 December 2019	(Family: none)	
JP 5-1348 A	08 January 1993	(Family: none)	
WO 2019/167469 A1	06 September 2019	(Family: none)	
JP 2020-519772 A	02 July 2020	US 2018/0340244 A1	
		WO 2018/218108 A1	
		EP 3631030 A1	
		CN 110662852 A	
		CA 3064022 A1	
		KR 10-2020-0010438 A	
		MX 2019013899 A	
US 2021/0388468 A1	16 December 2021	CN 113802031 A	

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

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2017155251 A **[0003] [0008]**
- JP 2020164946 A **[0006] [0008]**