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(71) Applicant: **UACJ Corporation**
Chiyoda-ku
Tokyo 100-0004 (JP)

(72) Inventors:
- **YAMAZAKI, Yuki**
  Tokyo 100-0004 (JP)
- **TAKEDA, Hiroki**
  Tokyo 100-0004 (JP)

(74) Representative: **Kramer Barske Schmidtchen Patentanwälte PartG mbB**
European Patent Attorneys
Landsberger Strasse 300
80687 München (DE)

(54) ALUMINUM ALLOY ROLLED SHEET AND METHOD FOR PRODUCING SAME

(57) An aluminum-alloy rolled sheet has a chemical composition containing Si: 0.80 mass% or more and 2.5 mass% or less, Mn: 0.40 mass% or more and 1.2 mass% or less, Mg: 0.25 mass% or more and 0.65 mass% or less, and Fe: 0.050 mass% or more and 0.45 mass% or less, the remainder being composed of Al and unavoidable impurities. The uniform elongation of the aluminum-alloy rolled sheet in the direction perpendicular to rolling is 19.5% or greater, and the value of the anisotropy of Lankford values Δr is -0.50 or greater and 0 or less. The aluminum-alloy rolled sheet has properties such that, after introducing a pre-strain of 2%, and thereafter performing aging treatment under conditions of a hold temperature of 170°C and a hold time of 20 minutes, the 0.2% yield strength is 175 MPa or greater.

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Description

TECHNICAL FIELD

[0001] The present invention relates to an aluminum-alloy rolled sheet and a production method thereof.

BACKGROUND ART

[0002] Although the specific gravity of Al-Mg-Si (aluminum-magnesium-silicon) alloys is approximately one third that of cold-rolled steel sheets, they have strengths equivalent to those of cold-rolled steel sheets. In addition, Al-Mg-Si alloys have bake hardenability, which is to say a property with which strength increases due to heating at the time of painting, baking, or the like, as compared to that before heating. Taking advantage of these properties, the replacement of cold-rolled steel sheets with aluminum-alloy sheets containing Mg continues to progress in fields in which there is strong demand for weight reduction, such as for automotive body sheets, body panels, and the like.

[0003] For example, Patent Document 1 describes an aluminum-alloy sheet having a chemical composition containing Si: 0.60 to 1.8% (mass%, same hereinafter) and Mg: 0.20 to 1.0%, the remainder being composed of Al and unavoidable impurities, in which: the arithmetic mean roughness Ra is 0.30 μm or less; when the r value (Lankford value) in the rolling direction is r_0, the r value in the direction perpendicular to rolling is r_{90}, and the r value in the 45° direction relative to the rolling direction is r_{45}, the average value of the r values r_{ave} (provided that $r_{ave} = (_{r0} + {}_{r90} + r_{45} \times 2)/4$) is 0.70 or greater, and the absolute value of the anisotropy of the r values Δr (provided that $\Delta r = (r_0 + r_{90} - r_{45} \times 2)/2$) is less than 0.10; when the tensile strength in the rolling direction is σ_0, the tensile strength in the direction perpendicular to rolling is σ_{90}, and the tensile strength in the 45° direction relative to the rolling direction is σ_{45}, the average value of the tensile strength σ_{ave} (provided that, $\sigma_{ave} = (\sigma_0 + \sigma_{90} + \sigma_{45} \times 2)/4$) is 230 MPa or greater; and when the elongation in the rolling direction is δ_0, the elongation in the direction perpendicular to rolling is δ_{90}, and the elongation in the 45° direction relative to the rolling direction is δ_{45}, the average value of the elongation δ_{ave} (provided that $\delta_{ave} = (\delta_0 + \delta_{90} + \delta_{45} \times 2)/4$) is 25% or greater.

PRIOR ART LITERATURE

Patent Documents

[0004] Patent Document 1: JP 2017-48452 A

SUMMARY OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0005] In recent years, from the viewpoint of reducing environmental load, there has been a demand for the use of aluminum scrap materials such as discarded automotive aluminum products and waste from automotive aluminum products as casting materials when preparing aluminum-alloy sheets. However, the chemical compositions of aluminum scrap materials are not uniform, and the types of elements included in aluminum scrap materials and the contents of each of the elements differ depending on the application of the aluminum scrap materials and the like. In addition, in some cases, aluminum scrap materials are accompanied by parts or the like having metals other than aluminum as primary components. Therefore, when aluminum scrap material is used as at least a portion of the casting materials, the content of elements other than aluminum in the aluminum-alloy sheet ultimately obtained tends to be great. There is a problem that an aluminum-alloy sheet having such a chemical composition tends to have decreased formability.

[0006] In particular, in applications such as automotive body sheets and body panels, it is required to excel in terms of various properties such as strength, formability, corrosion resistance, and the like. Therefore, the actual situation is that, in preparing aluminum-alloy sheets for use in such applications, aluminum virgin material having an aluminum purity of 99.9% or higher is used as the casting material.

[0007] The present invention was conceived considering this background and is directed to providing an aluminum-alloy rolled sheet having high strength that excels in formability, even when the ratio of aluminum virgin material in the casting material is reduced or when aluminum virgin material is not used as a casting material, and a production method thereof.

MEANS FOR SOLVING THE PROBLEMS

[0008] One aspect of the present invention is an aluminum-alloy rolled sheet containing Si (silicon): 0.80 mass% or more and 2.5 mass% or less, Mn (manganese): 0.40 mass% or more and 1.2 mass% or less, Mg (magnesium): 0.25 mass% or more and 0.65 mass% or less, and Fe (iron): 0.050 mass% or more and 0.45 mass% or less, the remainder being composed of Al (aluminum) and unavoidable impurities;

the uniform elongation in the direction perpendicular to rolling being 19.5% or greater;
having properties such that, after introducing a pre-strain of 2%, and thereafter performing aging treatment under conditions of a hold temperature of 170°C and a hold time of 20 minutes, the 0.2% yield strength is 175 Mpa or greater; and
the value of the anisotropy of the Lankford values Δr expressed by the following Equation (1) being -0.50 or greater and 0 or less.

$$\Delta r = (r_0 - 2 \times r_{45} + r_{90})/2 \ldots (1)$$

[0009] It is provided that, in Equation (1) above, r_0 represents the Lankford value in the rolling direction, r_{45} represents the Lankford value in the 45° direction relative to the rolling direction, and r_{90} represents the Lankford value in the direction perpendicular to rolling.

[0010] Another aspect of the present invention is, in a production method of an aluminum-alloy rolled sheet according to the aspect described above:

an ingot having the aforementioned chemical composition is prepared;
subsequently, a hot-rolled sheet is prepared by performing hot rolling on the ingot;
after the hot rolling, one or more cold rolling passes are performed on the hot-rolled sheet, without performing intermediate annealing, to prepare an aluminum-alloy rolled sheet; and
after the cold rolling, the aluminum-alloy rolled sheet is subjected to solution heat treatment by heating the aluminum-alloy rolled sheet and thereafter performing quenching on the aluminum-alloy rolled sheet.

EFFECTS OF THE INVENTION

[0011] The aluminum-alloy rolled sheet is provided with the chemical composition specified above and further has mechanical properties in the ranges specified above for each of the uniform elongation in the direction perpendicular to rolling, the 0.2% yield strength after the aforementioned specific treatment has been performed and the anisotropy Δr of the Lankford values (hereinafter referred to as "r values"). Such aluminum-alloy rolled sheets have high strength and excel in formability, even when the ratio of aluminum virgin material in the casting materials is reduced or when aluminum virgin material is not used as a casting material.

[0012] In addition, in the production method of the aluminum-alloy rolled sheet, after hot rolling is performed on an ingot having the chemical composition specified above, cold rolling is performed without subjecting the hot-rolled sheet after hot rolling to intermediate annealing. Consequently, even when the content of elements other than aluminum in the hot-rolled sheet is relatively great, the impact of these elements on formability can be reduced. As a result, with the production method described above, aluminum-alloy rolled sheets having high strength that excel in formability can be easily prepared, even when the ratio of aluminum virgin material in the casting materials is reduced or when aluminum virgin material is not used as a casting material.

[0013] Thus, with the aspect described above, aluminum-alloy rolled sheets having high strength that excel in formability, even when the ratio of aluminum virgin material in the casting material is reduced or when aluminum virgin material is not used as a casting material, and a production method thereof, can be provided.

MODES FOR CARRYING OUT THE INVENTION

(Aluminum-Alloy Rolled Sheet)

[0014] The chemical composition and properties of the aluminum-alloy rolled sheet will be described.

[Chemical Composition]

[0015] The aluminum-alloy rolled sheet includes Si, Mn, Mg, and Fe as essential components.

. Si: 0.80 mass% or more and 2.5 mass% or less

[0016] The Si content in the aluminum-alloy rolled sheet is 0.80 mass% or more and 2.5 mass% or less. A portion of the Si in the aluminum-alloy rolled sheet is in solid solution in the Al matrix. The Si that is in solid solution in the Al matrix has the function of enhancing the magnitude of the increase in strength due to work hardening, and also has the function of improving the uniform elongation of the aluminum-alloy rolled sheet.

[0017] In addition, Si that is not in solid solution in the Al matrix is present as second-phase particles dispersed in the Al matrix. Second-phase particles including Si are composed of, for example, elemental Si, Mg_2Si, Al-(Fe,Mn)-Si intermetallic compounds, Al-Mn-Si intermetallic compounds, Al-Fe-Si intermetallic compounds, and the like. These second-phase particles serve as sites for recrystallization nuclei formation during solution heat treatment in the aluminum-alloy rolled sheet production process, and have the function of inhibiting the development of cube orientation in the aluminum-alloy rolled sheet after the solution heat treatment.

[0018] By setting the Si content in the aluminum-alloy rolled sheet to 0.80 mass% or more, preferably 0.90 mass% or more, and more preferably 1.0 mass% or more, the uniform elongation of the aluminum-alloy rolled sheet can be enhanced, and the anisotropy of the r values Δr can also be set in the aforementioned specific ranges, such that the formability of the aluminum-alloy rolled sheet can be increased. Furthermore, by setting the Si content in the aluminum-alloy rolled sheet to 0.80 mass% or more, the strength of the aluminum-alloy rolled sheet can be increased. In addition, the ratio of aluminum virgin material in the casting material can easily be reduced.

[0019] On the other hand, if the Si content in the aluminum-alloy rolled sheet is excessively great, there is a risk of the quantity of second-phase particles formed in the aluminum-alloy rolled sheet being excessively great, leading to degradation of the formability of the aluminum-alloy rolled sheet. By setting the Si content in the aluminum-alloy rolled sheet to 2.5 mass% or less, preferably 2.3 mass% or less, and more preferably 2.1 mass% or less, degradation of the formability of the aluminum-alloy rolled sheet can easily be avoided.

. Mn: 0.40 mass% or more and 1.2 mass% or less

[0020] The Mn content in the aluminum-alloy rolled sheet is 0.40 mass% or more and 1.2 mass% or less. A portion of Mn in the aluminum-alloy rolled sheet is in solid solution in the Al matrix. The Mn that is in solid solution in the Al matrix has the function of enhancing the magnitude of the increase in strength due to work hardening, and also has the function of improving the uniform elongation of the aluminum-alloy rolled sheet.

[0021] In addition, Mn that is not in solid solution in the Al matrix is present as second-phase particles dispersed in the Al matrix. The second-phase particles including Mn are composed of, for example, Al-(Fe,Mn)-Si intermetallic compounds, Al-Mn-Si intermetallic compounds, and the like. As described above, these second-phase particles serve as sites for recrystallization nuclei formation during solution heat treatment in the aluminum-alloy rolled sheet production process, and have the function of inhibiting the development of cube orientation in the aluminum-alloy rolled sheet after the solution heat treatment.

[0022] By setting the Mn content in the aluminum-alloy rolled sheet to 0.40 mass% or more, the uniform elongation of the aluminum-alloy rolled sheet can be enhanced, and the anisotropy of the r values Δr can also be set in the aforementioned specific ranges, such that the formability of the aluminum-alloy rolled sheet can be increased. Furthermore, by setting the Mn content in the aluminum-alloy rolled sheet to 0.40 mass% or more, the strength of the aluminum-alloy rolled sheet can be increased. In addition, by setting the Mn content in the aluminum-alloy rolled sheet to 0.40 mass% or more, the ratio of aluminum virgin material in the casting materials can easily be reduced. From the viewpoint of further enhancing these functions and effects, the Mn content in the aluminum-alloy rolled sheet preferably is 0.45 mass% or more, more preferably is 0.50 mass% or more, further preferably is 0.55 mass% or more, particularly preferably is more than 0.65 mass%, and most preferably is 0.70 mass% or more.

[0023] On the other hand, if the Mn content in the aluminum-alloy rolled sheet is excessively great, there is a risk of the quantity of second-phase particles formed in the aluminum-alloy rolled sheet being excessively great, leading to degradation of the formability of the aluminum-alloy rolled sheet. By setting the Mn content in the aluminum-alloy rolled sheet to 1.2 mass% or less, preferably 1.1 mass% or less, and more preferably 1.0 mass% or less, degradation of the formability of the aluminum-alloy rolled sheet can easily be avoided.

·Fe: 0.050 mass% or more and 0.45 mass% or less

[0024] The Fe content in the aluminum-alloy rolled sheet is 0.050 mass% or more and 0.45 mass% or less. The Fe in the aluminum-alloy rolled sheet is present primarily as second-phase particles, such as Al-Fe-Si intermetallic compounds and Al-(Fe,Mn)-Si intermetallic compounds. As described above, these second-phase particles serve as sites for recrystallization nuclei formation during solution heat treatment in the aluminum-alloy rolled sheet production process, and have the function of inhibiting the development of cube orientation in the aluminum-alloy rolled sheet after the solution heat treatment.

[0025] By setting the Fe content in the aluminum-alloy rolled sheet to 0.050 mass% or more, and preferably 0.10 mass% or more, the anisotropy of the r values Δr can be set in the aforementioned specific range, and the formability of the aluminum-alloy rolled sheet can be increased.

[0026] On the other hand, if the Fe content in the aluminum-alloy rolled sheet is excessively great, Si and Mn will be consumed by the formation of Al-Fe-Si intermetallic compounds, Al-(Fe,Mn)-Si intermetallic compounds, and the like, and the amount of Si and Mn in solid solution in the aluminum-alloy rolled sheet will tend to be low. Furthermore, if the amount of Si and Mn in solid solution in the aluminum-alloy rolled sheet is low, there is a risk of this leading to a decrease in the strength and the uniform elongation of the aluminum-alloy rolled sheet. By setting the Fe content in the aluminum-alloy rolled sheet to 0.45 mass% or less, and preferably 0.40 mass% or less, such problems can easily be avoided.

·Mg: 0.25 mass% or more and 0.65 mass% or less

[0027] The Mg content in the aluminum-alloy rolled sheet is 0.25 mass% or more and 0.65 mass% or less. In the aluminum-alloy rolled sheet, the Mg is present primarily as second-phase particles, such as Mg_2Si, and has the function of increasing the strength of the aluminum-alloy rolled sheet by way of precipitation strengthening.

[0028] By setting the Mg content in the aluminum-alloy rolled sheet to 0.25 mass% or more, and preferably 0.30 mass% or more, the strength of the aluminum-alloy rolled sheet can be increased. If the Mg content is less than 0.25 mass%, the quantity of GP zones formed in the aluminum-alloy rolled sheet production process will be low, and the effect of increasing strength by precipitation strengthening will tend to decrease. Consequently, in this case, there is a risk of this leading to a decrease in the strength of the aluminum-alloy rolled sheet.

[0029] On the other hand, if the Mg content is excessively great, coarse Mg-Si-based intermetallic compounds tend to form in the aluminum-alloy rolled sheet, and there is a risk of this leading to a decrease in strength, a decrease in elongation, and degradation of formability. By setting the Mg content in the aluminum-alloy rolled sheet to 0.65 mass% or less, preferably 0.60 mass% or less, and more preferably 0.55 mass% or less, these problems can easily be avoided.

[0030] The aluminum-alloy rolled sheet may further include, in addition to Si, Mn, Fe, and Mg, as essential components, one or two or more elements selected from the group consisting of Cu (copper), Cr (chromium), Zn (zinc), Ti (titanium), Zr (zirconium), Bi (bismuth), and B (boron), as optional components.

[0031] For example, the aluminum-alloy rolled sheet may contain Si: 0.80 mass% or more and 2.5 mass% or less, Mn: 0.40 mass% or more and 1.2 mass% or less, Mg: 0.25 mass% or more and 0.65 mass% or less, and Fe: 0.050 mass% or more and 0.45 mass% or less, and have a chemical composition further containing one or two or more elements selected from the group consisting of Cu: 0.0010 mass% or more and 1.0 mass% or less, Cr: 0.0010 mass% or more and 0.10 mass% or less, Zn: 0.0010 mass% or more and 1.0 mass% or less, and Ti: 0.0050 mass% or more and 0.20 mass% or less, the remainder being composed of Al and unavoidable impurities.

[0032] In addition, the aluminum-alloy rolled sheet may contain Si: 0.80 mass% or more and 2.5 mass% or less, Mn: 0.40 mass% or more and 1.2 mass% or less, Mg: 0.25 mass% or more and 0.65 mass% or less, and Fe: 0.050 mass% or more and 0.45 mass% or less, and have a chemical composition further containing one or two or more elements selected from the group consisting of Cu: 0.0010 mass% or more and 1.0 mass% or less, Cr: 0.0010 mass% or more and 0.10 mass% or less, Zn: 0.0010 mass% or more and 1.0 mass% or less, Ti: 0.0050 mass% or more and 0.20 mass% or less, Zr: more than 0 mass% and less than 0.10 mass%, and Bi: more than 0 mass% and less than 0.20 mass%, the remainder being composed of Al and unavoidable impurities.

Cu: 0.0010 mass% or more and 1.0 mass% or less

[0033] The aluminum-alloy rolled sheet may contain 0.0010 mass% or more and 1.0 mass% or less of Cu, as an optional component. A portion of the Cu in the aluminum-alloy rolled sheet is in solid solution in the Al matrix. In addition, the Cu that is not in solid solution in the Al matrix is present as second-phase particles including Cu, such as of the Al-Cu type. The Cu in solid solution in the Al matrix has the function of enhancing the magnitude of the increase in strength due to work hardening. By setting the content of Cu in the aluminum-alloy rolled sheet to preferably 0.0010 mass% or more, more preferably 0.010 mass% or more, and yet more preferably 0.050 mass% or more, the magnitude of the increase in strength of the aluminum-alloy rolled sheet due to work hardening can be enhanced.

[0034] On the other hand, if the Cu content is excessively great, the number of second-phase particles including Cu formed in the aluminum-alloy rolled sheet tends to be great. Because second-phase particles including Cu tend to serve as starting points for corrosion due to the natural potential difference with the Al matrix, if the Cu content is excessively great, there is a risk of this leading to degradation of the corrosion resistance of the aluminum-alloy rolled sheet. By setting the Cu content in the aluminum-alloy rolled sheet to preferably 1.0 mass% or less, more preferably 0.40 mass% or less, yet more preferably 0.19 mass% or less, and particularly preferably 0.14 mass% or less, degradation of the corrosion resistance of the aluminum-alloy rolled sheet can easily be avoided.

Cr: 0.0010 mass% or more and 0.10 mass% or less

[0035] The aluminum-alloy rolled sheet may contain 0.0010 mass% or more and 0.10 mass% or less of Cr, as an optional component. Cr has functions such as increasing the strength of the aluminum-alloy rolled sheet, increasing the fineness of the crystal grains, and increasing surface treatability. On the other hand, if the Cr content is excessively great, coarse second-phase particles consisting of intermetallic compounds including Cr tend to form in the aluminum-alloy rolled sheet. Such coarse second-phase particles are undesirable as there is a risk of this leading to degradation of formability. By setting the Cr content in the aluminum-alloy rolled sheet in the aforementioned specific range, the effects described above can be obtained while avoiding the formation of coarse second-phase particles.

·Zn: 0.0010 mass% or more and 1.0 mass% or less

[0036] The aluminum-alloy rolled sheet may contain 0.0010 mass% or more and 1.0 mass% or less of Zn, as an optional component. Zn has functions such as increasing the strength of the aluminum-alloy rolled sheet, increasing the fineness of the crystal grains, and increasing surface treatability. On the other hand, if the Zn content is excessively great, there is a risk of this leading to degradation of the corrosion resistance of the aluminum-alloy rolled sheet. By setting the Zn content in the aluminum-alloy rolled sheet in the aforementioned specific range, the effects described above can be obtained while avoiding degradation of corrosion resistance.

·Ti: 0.0050 mass% or more and 0.20 mass% or less

[0037] The aluminum-alloy rolled sheet may contain 0.0050 mass% or more and 0.20 mass% or less of Ti as an optional component. Ti has the function of increasing the fineness of the ingot structure, inhibiting cracking of the ingot during casting, and also increasing the rollability during hot rolling. On the other hand, if the Ti content is excessively great, coarse crystallized products composed of intermetallic compounds including Ti tend to form in the ingot. Such coarse crystallized products are undesirable as there is a risk of this leading to degradation of rollability and formability.

[0038] By setting the Ti content in the aluminum-alloy rolled sheet in the aforementioned specific range, the effects described above can be obtained while avoiding degradation of rollability and formability. From the viewpoint of more reliably avoiding the formation of coarse crystallized products, the Ti content is more preferably 0.15 mass% or less.

·B: more than 0 ppm by mass and 500 ppm by mass or less

[0039] If Ti is included in the aluminum-alloy rolled sheet, it is preferable that the aluminum-alloy rolled sheet further includes more than 0 ppm by mass and 500 ppm by mass or less of B. In this case, the effect of increasing the fineness of the ingot structure can be further enhanced, and the formation of abnormal crystal grains, such as columnar crystals, in the casting process, can also be inhibited.

. Other Elements

[0040] The aluminum-rolled sheet may further include one or two elements selected from the group consisting of Zr: more than 0 mass% and less than 0.10 mass% and Bi: more than 0 mass% and less than 0.20 mass%. The Bi content in the aluminum-rolled sheet is preferably 0.060 mass% or less. In this case, the corrosion resistance of the aluminum-alloy rolled sheet can be further increased.

[Properties]

·Uniform Elongation

[0041] The uniform elongation of the aluminum-alloy rolled sheet in the direction perpendicular to rolling is 19.5% or greater. Here, uniform elongation refers to the maximum value of permanent elongation at which the aluminum-alloy rolled sheet uniformly deforms when a tensile test of the aluminum-alloy rolled sheet is performed. More specifically, the uniform elongation value is the value of the nominal strain corresponding to the maximum test force when a tensile test was performed using the method stipulated in JIS Z 2241:2011.

[0042] With regard to an aluminum-alloy rolled sheet having a uniform elongation value of 19.5% or greater, the aluminum-alloy rolled sheet tends to deform uniformly even if the amount of deformation is made great. Therefore, such aluminum-alloy rolled sheets excel in formability and can be easily formed into desired shapes when performing forming work such as, for example, stretch forming or deep drawing. From the viewpoint of further enhancing the formability of the aluminum-alloy rolled sheet, the uniform elongation value is preferably 20.0% or greater.

[0043] If the value of the uniform elongation of the aluminum-alloy rolled sheet is less than 19.5%, plastic instability phenomena such as necking occur when the amount of deformation has become great, and the deformation of the aluminum-alloy rolled sheet tends to become uneven. Consequently, in this case, the formability of the aluminum-alloy rolled sheet is degraded, forming defects are likely to occur, and there is a risk of this leading to a degradation of the appearance after forming work.

·r values

[0044] The value of the anisotropy of the r values Δr of the aluminum-alloy rolled sheet is -0.50 or greater and 0 or less. Here, the anisotropy of the r values Δr is expressed by the following Equation (1) using the r value r_0 in the rolling direction, the r value r_{45} in the 45° direction relative to the rolling direction, and the r value r_{90} in the direction perpendicular to rolling.

$$\Delta r = (r_0 - 2 \times r_{45} + r_{90})/2 \ldots (1)$$

[0045] In addition, the r value r_0 in the rolling direction, the r value r_{45} in the 45° direction relative to the rolling direction, and the r value r_{90} in the direction perpendicular to rolling are values obtained by dividing the logarithmic strain in the width direction of the tensile test piece by the logarithmic strain in the thickness direction of the tensile test piece, when the tensile test piece is subjected to tensile deformation, with the respective direction as the longitudinal direction, and with a strain of, for example, 15% having been applied.

[0046] The main crystal orientation in aluminum alloys is an orientation known as cube orientation, and if cube orientation develops, there is a tendency for the value of the r value r_{45} in the 45° direction relative to the rolling direction to be lower than the values of the r value r_0 in the rolling direction and the r value r_{90} in the direction perpendicular to rolling. In conventional Al-Mg-Si-based alloys, cube orientation tends to develop, and the value of the r value r_{45} in the 45° direction relative to the rolling direction tends to decrease. Therefore, the value of the anisotropy of r values Δr in conventional Al-Mg-Si-based alloys is usually a positive value.

[0047] In contrast, with the aluminum-alloy rolled sheet described above, by performing hot rolling, cold rolling, and solution heat treatment, in accordance with the aspect described above, on an ingot having a chemical composition in the aforementioned specific ranges, the development of the cube orientation can be inhibited, and the value of the r value r_{45} in the 45° direction relative to the rolling direction can be increased. Furthermore, as a result of increasing the value of the r value r_{45} in the 45° direction relative to the rolling direction, the value of the anisotropy of the r values Δr can be set in the aforementioned specific range.

[0048] Aluminum-alloy rolled sheets in which the value of the anisotropy or the r values Δr is in the aforementioned specific range excel in formability and can be easily formed into desired shapes even when forming work such as, for example, rectangular cup drawing is performed. From the viewpoint of further enhancing such functions and effects, from the viewpoint of further enhancing the formability of the aluminum-alloy rolled sheet, the value of the anisotropy of the r values Δr is preferably -0.50 or greater and -0.01 or less, more preferably -0.45 or greater and -0.05 or less, and even more preferably -0.40 or greater and -0.08 or less.

[0049] If the value of the anisotropy of r values Δr of the aluminum-alloy rolled sheet is outside the aforementioned specific range, this leads to degradation of the formability of the aluminum-alloy rolled sheet, and forming defects tend to occur, and there is a risk of this leading to degradation of the appearance after forming work.

[0050] From the viewpoint of further enhancing the formability of the aluminum-alloy rolled sheet, the r value r_{45} in the 45° direction relative to the rolling direction is preferably 0.45 or greater, more preferably 0.55 or greater, further preferably 0.65 or greater, and particularly preferably 0.75 or greater.

[0051] From the same viewpoint, the average value of the r values expressed by the following Equation (2) is preferably 0.65 or greater and more preferably 0.70 or greater.

$$r_{ave} = (r_0 + 2 \times r_{45} + r_{90})/4 \ldots (2)$$

·Tensile Strength, 0.2% Yield Strength, and Elongation at Break

[0052] The tensile strength TS in the direction perpendicular to the rolling of the aluminum-alloy rolled sheet is preferably 190 MPa or greater and more preferably 230 MPa or greater. In this case, the strength of aluminum products prepared using the aluminum-alloy rolled sheet can be further increased.

[0053] In addition, the 0.2% yield strength YS in the direction perpendicular to the rolling of the aluminum-alloy rolled sheet is preferably 100 MPa or greater. In this case, the stiffness of aluminum products prepared using the aluminum-alloy rolled sheet can be further increased.

[0054] On the other hand, from the viewpoint of further increasing the formability of the aluminum-alloy rolled sheet, the 0.2% yield strength YS in the direction perpendicular to the rolling of the aluminum-alloy rolled sheet is preferably 160 MPa or less.

[0055] In addition, the difference between the tensile strength TS and the 0.2% yield strength YS, TS - YS, is preferably 110 MPa or greater, and more preferably 125 MPa or greater. In this case, the formability of the aluminum-alloy rolled sheet can be further increased and the aluminum-alloy rolled sheet can be formed into desired shapes more easily when performing forming work, such as deep drawing, for example.

[0056] In addition, the elongation at break in the direction perpendicular to rolling of the aluminum-alloy rolled sheet is preferably 22% or greater and more preferably 23% or greater. In this case, the formability of the aluminum-alloy rolled sheet can be further increased.

[0057] Note that elongation at break refers to the value of the permanent elongation after the aluminum-alloy rolled sheet broke, when a tensile test of the aluminum-alloy rolled sheet was performed. More specifically, the value of the elongation at break is the value of the nominal strain at the time at which the test piece broke when a tensile test was performed using the method stipulated in JIS Z 2241:2011.

. 0.2% Yield Strength Following Application of Pre-Strain and Aging Treatment

[0058] The aluminum-alloy rolled sheet has properties such that, after introducing a pre-strain of 2%, and then performing aging treatment under conditions of a hold temperature of 170°C and a hold time of 20 minutes, the 0.2% yield strength in the direction perpendicular to rolling (hereinafter referred to as "BHYS") is 175 MPa or greater. The BHYS value is an indicator of the strength after the aluminum-alloy rolled sheet has been subjected to press-forming and then painting and baking.

[0059] When aluminum-alloy rolled sheets are used as automotive body panels or body sheets, the aluminum-alloy rolled sheet is usually subjected to press-forming, and then subjected to paint baking. Therefore, by enhancing the strength of the aluminum-alloy rolled sheet after paint baking, the degree of freedom in product design is enhanced, such that the aluminum-alloy rolled sheet can be used for various parts. Aluminum-alloy rolled sheets having properties such that the BHYS value is 175 MPa or greater excel in strength after paint baking and are suitable as automotive exterior materials such as automotive body panels and body sheets. From the viewpoint of further enhancing the degree of freedom in product design, the BHYS value is more preferably 180 MPa or greater and yet more preferably 190 MPa or greater.

[Thickness of the Aluminum-Alloy Rolled Sheet]

[0060] The thickness of the aluminum-alloy rolled sheet is not particularly limited and can be set, as appropriate, in accordance with the application. For example, if the aluminum-alloy rolled sheet is used as an automotive exterior material such as an automotive body panel or a body sheet, the thickness of the aluminum-alloy rolled sheet can be set, as appropriate, in the range of 0.5 to 2.5 mm.

(Production Method of the Aluminum-Alloy Rolled Sheet)

[0061] In preparing the aluminum-alloy rolled sheet, it suffices that:

an ingot having the aforementioned chemical composition is prepared;
subsequently, a hot-rolled sheet is prepared by performing hot rolling on the ingot;
after the hot rolling, one or more cold rolling passes are performed on the hot-rolled sheet, without performing intermediate annealing, to prepare an aluminum-alloy rolled sheet; and
after the cold rolling, the aluminum-alloy rolled sheet is subjected to solution heat treatment by heating the aluminum-alloy rolled sheet and thereafter performing quenching on the aluminum-alloy rolled sheet. Hereafter, each step in the production method of the aluminum-alloy rolled sheet will be described in detail.

. Preparation of the Ingot

[0062] In the production method described above, the method of preparing the ingot is not particularly limited. For example, in the production method described above, the ingot may be prepared by DC casting.

[0063] In the production method described above, aluminum scrap material is preferably used as at least a portion of the casting materials when preparing the ingot. By using aluminum scrap material as at least a portion of the casting materials, the ratio of aluminum virgin material in the casting materials can be reduced, or the ingot can be prepared without using aluminum virgin material. As a result, the environmental load when preparing the aluminum-alloy rolled sheet can be reduced. From the viewpoint of further enhancing such functions and effects, the ratio of aluminum scrap material in the casting materials is preferably 50 mass% or more, more preferably 75 mass% or more, and most preferably 100 mass%, which is to say, all of the casting materials are aluminum scrap materials.

[0064] Aluminum scrap materials that can be used as casting materials in the production method described above include, for example, discarded automotive aluminum products, ends and chips produced in automotive aluminum product production processes, and the like. In addition, parts having metals other than aluminum as the main components, for example, rivets used for joining with other parts and the like, may be mixed into the aluminum scrap material. Examples of the automotive aluminum products described above include body panels, heat exchangers, fins for heat exchangers, tubes for heat exchangers, engine blocks, and the like.

. Homogenizing Treatment

[0065] In the production method described above, after the ingot has been prepared and before hot rolling is performed, homogenizing treatment may be performed by heating the ingot, as needed. If homogenizing treatment is performed, the ingot is preferably held at a temperature of 480°C or higher and 560°C or lower for 0.5 h or more and 24 h or less. By setting the hold temperature and the hold time in the homogenizing treatment in the aforementioned specific ranges, elements such as Si, Mn, and Mg can sufficiently form a solid solution in the Al matrix. As a result, the strength and formability of the aluminum-alloy rolled sheet can be further increased.

[0066] In addition, if homogenizing treatment is performed, the ingot after homogenizing treatment has been completed is preferably cooled so that the average cooling rate is 55°C/h or faster, and is more preferably cooled so that this is 60°C/h or faster, and particularly preferably cooled so that this is 100°C/h or faster, until the temperature of the ingot reaches 300°C. By cooling the ingot after the homogenizing treatment at an average cooling rate in the aforementioned specific range, coarsening of second-phase particles, such as of Mg_2Si and elemental Si, formed in the ingots, can be inhibited, thus inhibiting decreases in the amounts of elements such as Si, Mg, and Mn in solid solution, such that the strength and formability of the finally obtained aluminum-alloy rolled sheet can be further increased. The cooling method after the homogenizing treatment is not particularly limited and can be selected, as appropriate, from cooling methods such as, for example, fan air-cooling, mist cooling, shower cooling, and water cooling.

[0067] From the viewpoint of enhancing productivity for the aluminum-alloy rolled sheet and also reducing energy consumption during the production process, it is preferable to perform hot rolling on the ingot after preparing the ingot, without performing homogenizing treatment.

. Hot Rolling

[0068] In the production method described above, a hot-rolled sheet is prepared by performing hot rolling on an ingot. When hot rolling is performed, the ingot is preferably heated to a temperature of 300°C or higher and 560°C or lower, before the start of rolling. By setting the heating temperature of the ingot before hot rolling in the aforementioned specific range, the deformation resistance of the ingot can be reduced, the rollability and productivity can be increased, and the occurrence of cracks in the ingot during hot rolling can also be inhibited. From the viewpoint of obtaining such functions and effects more reliably, it is more preferable to perform hot rolling after heating the ingot to a temperature of 300°C or higher and 560°C or lower and holding for 0.5 h or more and 24 h or less, before the start of rolling.

[0069] In addition, the ingot heating temperature before hot rolling is more preferably 500°C or higher and 560°C or lower, and further preferably 510°C or higher and 560°C or lower. In this case, by heating before hot rolling, elements, such as Si, Mn, and Mg, can form a solid solution in the Al matrix, similar to the homogenizing treatment described above. As a result, the formability of the aluminum-alloy rolled sheet can be increased even when a homogenizing treatment is omitted. From the viewpoint of obtaining such a function and effect more reliably, it is more preferable to perform hot rolling after holding the ingot at a temperature of 500°C or higher and 560°C or lower for 0.5 h or more and 24 h or less, and it is further preferable to perform hot rolling after holding the ingot at a temperature of 500°C or higher and 560°C or lower for 2 h or more and 12 h or less.

[0070] The temperature of the hot-rolled sheet when hot rolling is completed is not particularly limited, but from the viewpoint of productivity, this may be within the range of, for example, 200°C or higher and 350°C or lower.

. Cold Rolling

[0071] In the production method described above, the aluminum-alloy rolled sheet is prepared by performing cold rolling on the hot-rolled sheet in one or more passes, without performing intermediate annealing after performing hot rolling. Here, intermediate annealing refers to annealing performed in the interval following hot rolling and before the completion of cold rolling. In the production method described above, by performing cold rolling, without performing intermediate annealing, on the hot-rolled sheet, the precipitation of second-phase particles and the growth of second-phase particles in the hot-rolled sheet due to annealing can be inhibited, and cold rolling can be performed while maintaining the amounts of Si and the like in solid solution in the Al matrix. Furthermore, by performing solution heat treatment, which is described below, on the aluminum-alloy rolled sheet obtained in this manner, the amounts of Si and the like in solid solution can be further increased, and the strength and formability of the aluminum-alloy rolled sheet that is finally obtained can be improved.

[0072] The total rolling reduction in the cold rolling, which is to say, the ratio of the amount by which the thickness is reduced in the cold rolling, relative to the thickness of the hot-rolled sheet, is preferably 50% or more and more preferably 66% or more. By setting the total rolling reduction in cold rolling in the aforementioned specific range, second-phase particles present in the hot-rolled sheet can be crushed in the cold rolling. As a result, coarse second-phase particles remaining in the aluminum-alloy rolled sheet can easily be avoided, and decreases in uniform elongation and degradation of formability, owing to coarse second-phase particles, can be more easily avoided.

. Solution Heat Treatment

[0073] In the production method described above, the aluminum-alloy rolled sheet is subjected to solution heat treatment by heating the aluminum-alloy rolled sheet after cold rolling to temperature at the solution heat treatment temperature or higher, and thereafter performing quenching on the aluminum-alloy rolled sheet. By performing the solution heat treatment on the aluminum-alloy rolled sheet, the aluminum-alloy rolled sheet can be made into a supersaturated solid solution of Si, Mg, and the like, the amount of Si, Mn, Mg, and the like in solid solution can be increased, and the quantity of second-phase particles present in the aluminum-alloy rolled sheet can also be reduced. As a result, the strength and formability of the aluminum-alloy rolled sheet can be increased. From the viewpoint of obtaining such functions and effects more reliably, the treatment temperature of the aluminum-alloy rolled sheet in the solution heat treatment is preferably 450°C or higher and 560°C or lower, more preferably 500°C or higher and 560°C or lower, and yet more preferably 520°C or higher and 560°C or lower.

[0074] In the solution heat treatment, heating may be terminated when the temperature of the aluminum-alloy rolled sheet has reached a desired temperature, or heating may be terminated after holding the desired temperature for a certain amount of time. However, if the time for which the temperature of the aluminum-alloy rolled sheet is held in the solution heat treatment is excessively long, this leads to degradation of productivity and there is a risk of this leading to an excessive increase in the strength of the aluminum-alloy rolled sheet and degradation of formability. From the viewpoint of avoiding such problems, the time for which the temperature of the aluminum-alloy rolled sheet is held in the solution heat treatment is preferably 1 minute or less, more preferably 5 seconds or less, and yet more preferably 1 second or less.

[0075] In addition, in the solution heat treatment, quenching is performed immediately after heating of the aluminum-alloy rolled sheet has been terminated. Thereby, precipitation of second-phase particles and growth of second-phase particles in the aluminum-alloy rolled sheet can be inhibited and decreases in the amount of Si and the like in solid solution can be avoided. As a result, an aluminum-alloy rolled sheet that excels in formability can be easily obtained. From the viewpoint of obtaining such a function and effect more reliably, cooling of the aluminum-alloy rolled sheet is preferably performed so that the average cooling rate is 100°C/min or faster, and cooling is more preferably performed so that the average cooling rate is 300°C/min or faster, from the temperature when heating was terminated until 150°C is reached. The cooling method for quenching is not particularly limited and can be selected as appropriate from cooling methods such as, for example, fan air-cooling, mist cooling, shower cooling, and water cooling.

. Pre-Aging Treatment

[0076] In the production method described above, pre-aging treatment may be performed on the aluminum-alloy rolled sheet after the solution heat treatment has been performed, if necessary. By further performing pre-aging treatment on the aluminum-alloy rolled sheet, the bake hardenability of the aluminum-alloy rolled sheet can be further enhanced, and the magnitude of the increase in the strength of the aluminum-alloy rolled sheet due to painting and baking can be further enhanced. From the viewpoint of obtaining such a function and effect more reliably, the pre-aging treatment is preferably performed immediately after the solution heat treatment.

[0077] In addition, in the pre-aging treatment, the aluminum-alloy rolled sheet is preferably held at a temperature of 40°C or higher and 150°C or lower for 1 h or more and 100 h or less. In this case, the bake hardenability of the aluminum-alloy rolled sheet can be further enhanced, and excessive increases in the strength and decreases in the elongation of the aluminum-alloy rolled sheet after the pre-aging treatment can also be avoided. As a result, bake hardenability can be further enhanced while ensuring that formability excels. From the viewpoint of further enhancing such functions and effects, the hold temperature in the pre-aging treatment is more preferably 40°C or higher and 100°C or lower, and yet more preferably 60°C or higher and 90°C or lower.

Working Examples

[0078] Working examples of the aluminum-alloy rolled sheet and the production method thereof are described below. The aluminum-alloy rolled sheet of the present example has a chemical composition containing Si: 0.80 mass% or more and 2.5 mass% or less, Mn: 0.40 mass% or more and 1.2 mass% or less, Mg: 0.25 mass% or more and 0.65 mass% or less, and Fe: 0.050 mass% or more and 0.45 mass% or less, the remainder being composed of Al and unavoidable impurities. The uniform elongation of the aluminum-alloy rolled sheet in the direction perpendicular to rolling is 19.5% or greater, and the value of the anisotropy of the Lankford values Δr represented by the following Equation (1) is -0.50 or greater and 0 or less. In addition, the aluminum-alloy rolled sheet has properties such that, after introducing a pre-strain of 2%, and thereafter performing aging treatment under conditions of a hold temperature of 170°C and a hold time of 20 minutes, the 0.2% yield strength in the direction perpendicular to rolling is 175 MPa or greater.

$$\Delta r = (r_0 - 2 \times r_{45} + r_{90})/2 \ldots (1)$$

[0079] It is provided that, in Equation (1) above, r_0 represents the Lankford value in the rolling direction, r_{45} represents the Lankford value in the 45° direction relative to the rolling direction, and r_{90} represents the Lankford value in the direction perpendicular to rolling.

[0080] The aluminum-alloy rolled sheets of the present examples are prepared, for example, as follows. First, ingots having the chemical compositions shown in Table 1 (alloy symbols A1 to A7) are prepared by way of DC casting. Note that "Bal." in Table 1 indicates that the element in question is the remainder. In preparing the ingots, both aluminum virgin material and aluminum scrap materials can be used as casting materials, but from the viewpoint of reducing the environmental load, it is preferable to increase the ratio of aluminum scrap materials in the casting materials.

[0081] Next, without subjecting the resulting ingots to homogenizing treatment, heating is performed to the temperature indicated for any of production conditions symbols C1 to C3 in Table 2, and after holding said temperature for the time indicated in Table 2, hot rolling is performed on the ingot. The temperature of the hot-rolled sheet when hot rolling is completed is as shown in Table 2. Subsequently, without performing intermediate annealing, cold rolling is performed on the hot-rolled sheet obtained by the hot rolling. The total rolling reduction in the cold rolling and the thickness of the aluminum-alloy rolled sheet after cold rolling are as shown in Table 2.

[0082] After cold rolling has been completed, solution heat treatment is performed on the aluminum-alloy rolled sheet. In the solution heat treatment, the aluminum-alloy rolled sheet is heated to the treatment temperature indicated for any of production conditions symbols C1-C3 in Table 2, and heating is terminated when the temperature of the aluminum-alloy rolled sheet has reached said treatment temperature. Immediately after heating has been terminated, quenching is performed on the aluminum-alloy rolled sheet. In the quenching, the aluminum-alloy rolled sheet is cooled so that the average cooling rate is 600°C/min or faster and 1,000°C/min or slower, from the temperature when heating is terminated until 150°C is reached.

[0083] Immediately after the solution heat treatment has been completed, pre-aging treatment is performed by holding the aluminum-alloy rolled sheet at a temperature of 70°C or higher and 80°C or lower for 5 h. The Test Materials S1 to S7 shown in Table 3 can thereby be obtained.

[0084] Note that Test Materials R1 to R5 shown in Table 3 are test materials for comparison with Test Materials S1 to S7. The production method of Test Materials R1 to R3 is the same as the production method of Test Materials S1 to S7, other than in that the chemical compositions and production conditions are changed as shown in Table 3.

[0085] The production method of Test Material R4 is as follows. First, an ingot having the chemical composition indicated for alloy symbol A11 in Table 1 is prepared by DC casting. Next, the ingot is subjected to homogenizing treatment. The hold temperature and hold time in the homogenizing treatment are as indicated for production conditions symbol C6 in Table 2. After performing the homogenizing treatment, the ingot is cooled to room temperature at an average cooling rate of 300°C/h. Subsequently, the ingot is once again heated to the temperature indicated in Table 2, said temperature is held for the time indicated in Table 2, and then hot rolling is performed on the ingot. The temperature of the hot-rolled sheet when hot rolling is completed is as shown in Table 2.

[0086] After hot rolling has been completed, the hot-rolled sheet is heated to 350°C, and intermediate annealing is performed. Cold rolling is performed on the hot-rolled sheet after intermediate annealing has been completed, under the conditions indicated for production conditions symbol C6 in Table 2. After cold rolling has been completed, solution heat treatment and pre-aging treatment are performed on the aluminum-alloy rolled sheet, in the same manner as for Test Materials S 1 to S7, whereby the Test Material R4 can be obtained.

[0087] The production method of Test Material R5 is as follows. First, an ingot having the chemical composition indicated for alloy symbol A12 in Table 1 is prepared by DC casting. Next, the ingot is subjected to homogenizing treatment. The hold temperature and hold time in the homogenizing treatment are as indicated for production conditions symbol C7 in Table 2. After performing the homogenizing treatment, the ingot is cooled to room temperature at an average cooling rate of 50°C/h. Subsequently, the ingot is once again heated to the temperature indicated in Table 2, said temperature is held for the time indicated in Table 2, and then hot rolling is performed on the ingot. The temperature of the hot-rolled sheet when hot rolling is completed is as shown in Table 2.

[0088] After hot rolling has been completed, cold rolling is performed on the hot-rolled sheet, without performing intermediate annealing. The total rolling reduction in the cold rolling and the thickness of the aluminum-alloy rolled sheet after cold rolling are as shown in Table 2. After cold rolling has been completed, solution heat treatment and pre-aging treatment are performed on the aluminum-alloy rolled sheet, in the same manner as for Test Materials S 1 to S7, whereby Test Material R5 can be obtained.

[0089] The evaluation methods for tensile strength, 0.2% yield strength, elongation at break, uniform elongation, BHYS, r values, and corrosion resistance of Test Materials S 1 to S7 and Test Materials R1 to R5 are as follows.

. Tensile Strength, 0.2% Yield Strength, Elongation at Break, and Uniform Elongation

[0090] A No. 5 test piece as stipulated in JIS Z 2241:2011 is taken from the test material, such that the longitudinal direction is perpendicular to the rolling direction. Using this test piece, a tensile test is performed according to a method complying with JIS Z 2241:2011, and the tensile strength TS_{90} (unit: MPa), the 0.2% yield strength YS_{90} (unit: MPa), the elongation at break EL_{90} (unit: %), and the uniform elongation UL_{90} (unit: %) in the direction perpendicular to the rolling direction are each calculated. These values are as shown in Table 3 for each of the test materials.

. 0.2% Yield Strength Following Application of Pre-Strain and Aging Treatment (BHYS)

[0091] A No. 5 test piece as stipulated in JIS Z 2241:2011 is taken from the test material such that the longitudinal direction is perpendicular to the rolling direction. A tensile test is performed, according to a method complying with JIS Z 2241:2011, until a nominal strain of 2% is reached. Subsequently, the test piece is immersed in an oil bath at 170°C for 20 minutes so as to be subjected to aging treatment. A tensile test of the test piece after applying pre-strain and performing aging treatment is performed according to a method complying with JIS Z 2241:2011. The 0.2% yield strength (unit: MPa) value calculated as described above is taken as the BHYS value. The BHYS values for each of the test materials are as shown in Table 3.

·r value

[0092] A No. 5 test piece as stipulated in JIS Z 2241:2011 is taken from the test material, such that the longitudinal direction and the rolling direction are parallel. A tensile test is performed using this test piece, according to a method complying with JIS Z 2241:2011, and a nominal strain of 15% is applied to the test piece. Then, the logarithmic strain in the longitudinal direction and the logarithmic strain in the width direction of the test piece after the nominal strain was applied are calculated. Assuming that the volume of the test piece is constant, the relationship $\varepsilon_t = -(\varepsilon_l + \varepsilon_w)$ holds between the logarithmic strain in the longitudinal direction ε_l, the logarithmic strain in the width direction ε_w, and the logarithmic strain in the thickness direction ε_t of the test piece, and thus the r value r_0 in the direction parallel to the rolling direction can be calculated based on the logarithmic strain in the longitudinal direction and the logarithmic strain in the width direction of the test piece.

[0093] By performing the same tensile test as described above using a No. 5 test piece, in which the angle formed by the longitudinal direction and the rolling direction is 45°, and a test piece in which the longitudinal direction is perpendicular to the rolling direction, the r value r_{45} in the direction tilted by 45° relative to the rolling direction and the r value r_{90} in the direction perpendicular to the rolling direction can be calculated. Then, using these values, the anisotropy of the rr[1] values Δr and the average value of the r values r_{ave} are calculated based on Equations (1) and (2) below. The r values, the anisotropy of the r values Δr, and the average value of the r values r_{ave}, for each test material are as shown in Table 3. Note that, because measurements of the r values were not performed for Test Materials R3 to R5, the symbol "-" was entered in the columns for the r values in each of the directions, the anisotropy of the r values Δr, and the average value of the r values r_{ave}.

$$\Delta r = (r_0 - 2 \times r_{45} + r_{90})/2 \ldots (1)$$

$$r_{ave} = (r_0 + 2 \times r_{45} + r_{90})/4 \ldots (2)$$

[1] "r r 値" appears to be a typo for " r 値

. Corrosion Resistance

[0094] In evaluating the corrosion resistance, an intergranular-corrosion test is performed using a method complying with Method B stipulated in ISO 11846. Specifically, first, a test piece having an oblong shape with a length of 20 mm and a width of 50 mm is taken from the test material. The test piece is subjected to aging treatment by heating at a temperature of 170°C for 20 minutes using an oven. The test piece after the aging treatment is cleaned with nitric acid and thereafter rinsed with distilled water. Subsequently, the test piece is immersed for 20 h in an aqueous solution having a NaCl concentration of 30 g/L and an HCl concentration of 10 ml/L at a temperature of 20°C. After 20 hours have elapsed since the time of immersion, the test piece is removed from the aqueous solution. ."

[0095] The test piece removed from the aqueous solution is cleaned with nitric acid and thereafter rinsed with distilled water. Subsequently, a cross-section of the test piece parallel to the rolling direction is observed, and the intergranular-corrosion depth is measured. The "Maximum Intergranular-Corrosion Depth" column in Table 3 indicates the maximum value of the intergranular-corrosion depth in the cross-section observed. Note that, because intergranular-corrosion tests were not performed for Test Materials S 1, S7, and R2 to R4, the symbol " - " was entered in the "Maximum Intergranular-Corrosion Depth" column.

[Table 1]

[0096]

(Table 1)

Alloy Symbol	Chemical Composition (mass%)								
	Si	Fe	Mn	Mg	Cu	Cr	Zn	Ti	Al
A1	1.0	0.29	0.50	0.54	0.18	0.01	0.44	0.03	Bal.
A2	2.1	0.37	1.2	0.49	0.35	0.04	0.22	0.08	Bal.
A3	2.0	0.35	1.2	0.46	0.19	0.04	0.93	0.07	Bal.
A4	2.0	0.36	1.2	0.47	0.09	0.04	0.93	0.07	Bal.
A5	1.3	0.16	0.81	0.40	0.21	<0.01	0.24	0.03	Bal.
A6	2.0	0.37	0.41	0.48	0.34	0.04	0.92	0.08	Bal.
A7	1.0	0.41	0.90	0.50	0.14	0.02	<0.01	0.02	Bal.
A8	2.1	0.38	1.3	0.51	0.33	0.05	0.94	0.22	Bal.
A9	3.5	0.30	1.0	0.56	0.30	0.01	0.48	0.09	Bal.
A10	1.0	0.50	0.90	1.3	0.21	0.03	0.15	0.03	Bal.
A11	0.72	0.34	0.06	0.69	0.10	0.05	0.10	0.03	Bal.
A12	1.2	0.29	0.94	0.50	0.30	0.01	0.49	0.05	Bal.

[Table 2]

[0097]

(Table 2)

Production Conditions Symbol	Homogenizing Treatment		Hot Rolling			Cold Rolling			Solution Heat Treatment
	Hold Temperature (°C)	Hold Time (h)	Heating Temperature (°C)	Hold Time (h)	Temperature at Completion (°C)	Total Rolling Reduction (%)	Intermediate Annealing	Thickness After Cold Rolling (mm)	Treatment Temperature (°C)
C1	not performed		520	4	310	75	not performed	0.9	540
C2	not performed		540	4	250	75	not performed	1.0	540
C3	not performed		560	12	250	75	not performed	1.0	530
C4	not performed		530	4	300	58	not performed	2.5	540
C5	not performed		560	3	250	75	not performed	1.0	570
C6	560	12	400	2	250	83	performed	1.0	530
C7	520	10	400	2	250	67	not performed	2.0	540

[Table 3]

[0098]

(Table 3)

Test Material Symbol	Alloy Symbol	Production Conditions Symbol	TS_{90} (MPa)	YS_{90} (MPa)	EL_{90} (%)	UL_{90} (%)	BHYS (MPa)	TS_{90}-YS_{90} (MPa)	r_0	r_{45}	r_{90}	Δr	r_{ave}	Intergranular-Corrosion Depth (μm)
S1	A1	C1	240	111	27	21.5	209	129	0.65	0.80	0.80	-0.08	0.76	-
S2	A2	C2	296	143	24	20.5	236	153	0.60	0.85	0.55	-0.27	0.71	173
S3	A3	C2	288	140	23	20.5	235	148	0.60	0.85	0.55	-0.28	0.71	121
S4	A4	C2	296	150	25	20.5	224	146	0.65	0.95	0.55	-0.35	0.78	77
S5	A5	C2	256	117	26	22.5	195	139	0.65	0.90	0.55	-0.30	0.75	104
S6	A6	C2	289	139	26	22.5	219	150	0.65	0.80	0.55	-0.20	0.70	251
S7	A7	C3	245	115	24	21.0	202	130	0.65	0.85	0.60	-0.23	0.74	-
R1	A8	C2	296	146	21	19.0	232	150	0.60	0.85	0.50	-0.30	0.70	126
R2	A9	C4	262	149	23	18.0	204	113	0.60	0.75	0.60	-0.15	0.68	-
R3	A10	C5	269	131	20	19.0	221	138	-	-	-	-	-	-
R4	A11	C6	182	75	27	24.0	174	107	-	-	-	-	-	-
R5	A12	C7	220	94	22	19.0	168	126	-	-	-	-	-	-

[0099] As shown in Table 3, Test Materials S1 to S7 are prepared by performing hot rolling, cold rolling, solution heat treatment, and pre-aging treatment on the ingots having the aforementioned specific chemical compositions, without performing intermediate annealing. The values for BHYS, uniform elongation, and the anisotropy of the r values Δr of Test Materials S 1 to S7 can thereby be set in the aforementioned specific ranges. Test Materials S 1 to S7, which have such mechanical properties, have high strength, and also excel in formability.

[0100] Because the Mn content and the Ti content in Test Material R1 are greater than the aforementioned specific ranges, the uniform elongation of Test Material R1 is lower than that of Test Materials S 1 to S7. Therefore, Test Material R1 has inferior formability compared to Test Materials S1 to S7.

[0101] Because the Si content in Test Material R2 is greater than the aforementioned specific range, the uniform elongation of Test Material R2 is lower than that of Test Materials S 1 to S7. Therefore, Test Material R2 has inferior formability compared to Test Materials S 1 to S7.

[0102] Because the Fe content and the Mg content in Test Material R3 are greater than the aforementioned specific ranges, the uniform elongation of Test Material R3 is lower than that of Test Materials S 1 to S7. Therefore, test material R3 has inferior formability compared to Test Materials S1 to S7.

[0103] Because the Si content and the Mn content in Test Material R4 are less than the aforementioned specific ranges and the Mg content is greater than the aforementioned specific range, the BHYS of Test Material R3[2] is lower than that of Test Materials S 1 to S7. Therefore, the strength of Test Material R3[3] after paint baking is inferior to that of Test Materials S 1 to S7.

[2] "試験材 R 3 の B H Y S " appears to be a typo for "試験材 R 4 の B H Y S." [3] "試験材 R 3 は試験材 S 1 ~ S 7 に比べて焼付塗装後の強度" appears to be a typo for 試験材R 4は試験材 S 1 ~ S 7 に比べて焼付塗装後の強度."

[0104] Because the average cooling rate after the homogenizing treatment was slow for Test Material R5, the uniform elongation and the BHYS of Test Material R5 are lower than those of Test Materials S 1 to S7. Therefore, Test Material R5 has inferior strength and formability compared to Test Materials S1 to S7.

[0105] Here, although specific aspects of the aluminum-alloy rolled sheet and the production method of the same according to the present invention have been described based on working examples, specific aspects of the aluminum-alloy rolled sheet according to the present invention and the production method thereof are not limited to the aspects in the working examples, and the configuration can be modified as appropriate within a scope that does not depart from the gist of the present invention.

Claims

1. An aluminum-alloy rolled sheet: having a chemical composition containing Si: 0.80 mass% or more and 2.5 mass% or less, Mn: 0.40 mass% or more and 1.2 mass% or less, Mg: 0.25 mass% or more and 0.65 mass% or less, and Fe: 0.050 mass% or more and 0.45 mass% or less, the remainder being composed of Al and unavoidable impurities;

   the uniform elongation value in a direction perpendicular to rolling being 19.5% or greater;
   having properties such that, after introducing a pre-strain of 2%, and thereafter performing aging treatment under conditions of a hold temperature of 170°C and a hold time of 20 minutes, the 0.2% yield strength in the direction perpendicular to rolling is 175 MPa or greater; and
   the value Δr of the anisotropy of the Lankford values expressed by the following Equation (1) being -0.50 or greater and 0 or less.

   $$\Delta r = (r_0 - 2 \times r_{45} + r_{90})/2 \ldots (1)$$

   (It is provided that, in Equation (1) above, r_0 represents the Lankford value in the rolling direction, r_{45} represents the Lankford value in the 45° direction relative to the rolling direction, and r_{90} represents the Lankford value in the direction perpendicular to rolling.)

2. The aluminum-alloy rolled sheet according to claim 1, wherein the aluminum-alloy rolled sheet further contains one or two or more elements selected from the group consisting of Cu: 0.0010 mass% or more and 1.0 mass% or less, Cr: 0.0010 mass% or more and 0.10 mass% or less, Zn: 0.0010 mass% or more and 1.0 mass% or less, and Ti: 0.0050 mass% or more and 0.20 mass% or less.

3. The aluminum-alloy rolled sheet according to claim 1 or 2, wherein the Cu content in the aluminum-alloy rolled sheet is less than 0.40 mass%.

4. The aluminum-alloy rolled sheet according to any one of claims 1 to 3, wherein the aluminum-alloy rolled sheet contains Ti: 0.0050 mass% or more and 0.20 mass% or less and B: more than 0 ppm by mass and 500 ppm by mass or less.

5. The aluminum-alloy rolled sheet according to any one of claims 1 to 4, wherein the aluminum-alloy rolled sheet further contains one or two elements selected from the group consisting of Zr: more than 0 mass% and less than 0.10 mass% and Bi: more than 0 mass% and less than 0.20 mass%.

6. The aluminum-alloy rolled sheet according to any one of claims 1 to 5, wherein the Lankford value r_{45} in the 45° direction relative to the rolling direction of the aluminum-alloy rolled sheet is 0.45 or greater, and the average value r_{ave} of the Lankford values of the aluminum-alloy rolled sheet expressed by the following Equation (2) is 0.65 or greater.

$$r_{ave} = (r_0 + 2 \times r_{45} + r_{90})/4 \ldots (2)$$

7. The aluminum-alloy rolled sheet according to any one of claims 1 to 6, wherein the tensile strength TS in the direction perpendicular to rolling of the aluminum-alloy rolled sheet is 230 MPa or greater, and the difference TS - YS between the tensile strength TS and the 0.2% yield strength YS of the aluminum-alloy rolled sheet is 110 MPa or greater.

8. A production method of the aluminum-alloy rolled sheet according to any one of claims 1 to 7, wherein:

   an ingot having the aforementioned chemical composition is prepared;
   subsequently, a hot-rolled sheet is prepared by performing hot rolling on the ingot;
   after the hot rolling, one or more cold rolling passes are performed on the hot-rolled sheet, without performing intermediate annealing, to prepare an aluminum-alloy rolled sheet; and
   after the cold rolling, the aluminum-alloy rolled sheet is subjected to solution heat treatment by heating the aluminum-alloy rolled sheet and thereafter performing quenching on the aluminum-alloy rolled sheet.

9. The production method of the aluminum-alloy rolled sheet according to claim 8, wherein aluminum scrap material is used as at least a portion of the casting materials, when preparing the ingot.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/038914

A. CLASSIFICATION OF SUBJECT MATTER

C22C 21/02(2006.01)i; ***C22F 1/00***(2006.01)i; ***C22F 1/043***(2006.01)i; ***C22F 1/047***(2006.01)i; ***C22F 1/05***(2006.01)i
FI: C22C21/02; C22F1/00 602; C22F1/00 623; C22F1/00 630A; C22F1/00 630K; C22F1/00 631A; C22F1/00 682; C22F1/00 683; C22F1/00 685Z; C22F1/00 691B; C22F1/00 691C; C22F1/00 692A; C22F1/00 692B; C22F1/00 694A; C22F1/00 694B; C22F1/043; C22F1/047; C22F1/05

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)

C22C21/02; C22F1/00; C22F1/043; C22F1/047; C22F1/05

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	JP 2017-48451 A (HONDA MOTOR CO LTD) 09 March 2017 (2017-03-09) claim 1, paragraphs [0006], [0010], [0018]-[0020], [0024]-[0039], [0046], table 1, A1, table 2, inventive example 1	2-5, 7-8
Y		9
Y	JP 2021-59774 A (UACJ CORP) 15 April 2021 (2021-04-15) paragraph [0060]	9
A	JP 2015-40340 A (UACJ CORP) 02 March 2015 (2015-03-02) paragraphs [0054]-[0055]	1-9
A	JP 2009-41045 A (NIPPON STEEL CORP) 26 February 2009 (2009-02-26) claim 1, paragraph [0052], table 1	1-9

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

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 December 2022	**10 January 2023**

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

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/038914

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2017-48451 A	09 March 2017	(Family: none)	
JP 2021-59774 A	15 April 2021	US 2021/0108293 A1 paragraph [0086] CN 112626383 A	
JP 2015-40340 A	02 March 2015	(Family: none)	
JP 2009-41045 A	26 February 2009	(Family: none)	

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 2017048452 A **[0004]**