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SHINZATO et al.(54) **ALUMINUM ALLOY PLATE AND METHOD
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(2013.01)(57) **ABSTRACT**

The present disclosure relates to an aluminum alloy plate having a composition containing Si: 0.03 to 0.35%, Fe: 0.03 to 0.35%, Mg: 3.0 to 5.0%, Cu: more than 0.09% and less than 0.50%, and Mn: more than 0.05% and 0.35% or less in terms of mass %, with the balance including Al and inevitable impurities.

ALUMINUM ALLOY PLATE AND METHOD FOR PRODUCING THE SAME

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This is a continuation application of International Patent Application No. PCT/JP2018/026827 filed Jul. 18, 2018, which claims the benefit of Japanese Patent Application No. 2017-144874 filed Jul. 26, 2017, and the full contents of all of which are hereby incorporated by reference in their entirety.

BACKGROUND

Technical Field

[0002] This disclosure relates to an aluminum alloy plate used by being subjected to molding processing and baking finishing as a member or part used for various automobiles represented by a body sheet and body panel of automobiles, for example; a member or part used for vessels, aircrafts, and the like; or a construction material, a material for structure, and a material for other various apparatuses, home electric appliances, parts thereof, and the like, particularly to an Al—Mg based aluminum alloy plate also excellent in press-moldability and stress corrosion cracking resistance while having high tensile strength, and a method for producing the same.

Description of the Related Art

[0003] Conventionally, cold-rolled steel sheets are often used for body sheets used for automobiles. However, a demand for reducing the weight of automobiles to improve fuel consumption increases from a viewpoint of controlling global warming, reducing energy costs, and the like, recently. Hence, a trend to use aluminum alloy plates, which have strength approximately equivalent to cold-rolled steel sheets and have a specific gravity about one third of the specific gravity of cold-rolled steel sheets, for body sheets of automobiles instead of conventional cold-rolled steel sheets is increasing.

[0004] Then, as aluminum alloys for automotive body sheets, Al—Mg based alloys, for example, 5000 series Al alloys containing 3.5 mass % or more of Mg such as 5056, 5082, 5182, 5083, and 5086 are used. Since these Al—Mg based alloys have high strength and good moldability and are also excellent in weldability, these Al—Mg based alloys are used for welding structural members.

[0005] However, when the above Al—Mg based alloys are used in a state where stress is applied thereto for a long time as a structural material, a problem of easily generating stress corrosion cracking arises because the above Al—Mg alloys have high Mg contents. It is effective for preventing this stress corrosion cracking to apply surface treatment such as coating onto a substrate made of an Al—Mg based alloy. However, since there is a case where this substrate has to be used without coating as a structural material, the substrate made of an Al—Mg based alloy per se is required to have excellent stress corrosion cracking resistance.

[0006] It is known that β -phase (Al_3Mg_2) preferentially precipitates continuously at grain boundaries as time elapses, and stress corrosion cracking in Al—Mg based alloys is accelerated by this P-phase precipitating at grain boundaries. Therefore, various ways to suppress continuous

precipitation of β -phase onto grain boundaries have been proposed since before in order to prevent stress corrosion cracking in Al—Mg based alloys having high Mg contents.

[0007] For example, Japanese Patent Application Publication No. 2003-231956 describes a method for producing an Al—Mg—Cu-based aluminum alloy plate for molding processing, the method being capable of preventing P-phase from continuously precipitating onto grain boundaries during cooling by performing cooling, which is performed after solution treatment successively conducted after hot-rolling and cold-rolling, in two steps in which a condition of cooling speed differs between a high temperature region and a low temperature region so as to accelerate cooling speed in the low temperature region.

[0008] In addition, Japanese Patent Application Publication No. 2001-32031 describes an aluminum alloy plate for structure, the aluminum alloy plate containing Mg: 3.5 to 5.5%, having strength of 250 N/mm² or more after final annealing treatment, and having conductivity of 26.5 to 29.6 IACS % after the final annealing treatment. According to the description, stress corrosion cracking resistance can be improved without deteriorating strength characteristics by achieving a precipitation and solid solution state of total precipitate including (3-phase in which the conductivity is 29.6 IACS % or less.

[0009] However, since the content of Cu in the aluminum alloy plate described in Patent Literature 1 is as high as 0.5 to 1.8 mass %, there is a problem in which a coarse compound is formed as hot workability decreases, resulting in poor moldability. In addition, it is required for producing of the aluminum alloy plate to perform the cooling in two steps after performing solution treatment as well as accelerate cooling speed in the low temperature region. However, there is also a problem in which when cooling speed is accelerated, shape accuracy such as flatness after treatment deteriorates.

[0010] In addition, in the aluminum alloy plate for structure described in Patent Literature 2, Mg is the only essential component contained, and strength and conductivity after final annealing treatment are limited. However, Patent Literature 2 neither discloses nor suggests the point that inferiority and superiority of tensile strength, press-moldability, and stress corrosion cracking resistance are influenced by a certain component contained other than Mg. In addition, it is required for producing of such an aluminum alloy plate to accelerate cooling speed during casting as well as accelerate cooling speed in intermediate annealing during cold-rolling and cooling speed in cooling after heating at final annealing performed after cold-rolling, and there is a problem of causing an increase in the number of producing steps and a decrease in productivity due to strict control of producing conditions.

SUMMARY

[0011] The present disclosure is related to providing an aluminum alloy plate excellent in press-moldability and stress corrosion cracking resistance while having high tensile strength, particularly an Al—Mg based aluminum alloy plate, and a method for producing the Al—Mg based aluminum alloy plate.

[0012] According to an aspect of the present disclosure, an aluminum alloy plate has a composition containing Si: 0.03 to 0.35%, Fe: 0.03 to 0.35%, Mg: 3.0 to 5.0%, Cu: more than

0.09% and less than 0.50%, and Mn: more than 0.05% and 0.35% or less in terms of mass %, with the balance including Al and inevitable impurities.

[0013] Further, it is preferable that an intermetallic compound is present in the aluminum alloy plate, and a number density of the intermetallic compound having a circle equivalent diameter of 0.1 to 0.5 μm and not containing Cu is $1 \times 10^6/\text{mm}^2$ or less.

[0014] Further, it is preferable that an intermetallic compound is present in the aluminum alloy plate, and a number density of the intermetallic compound having a circle equivalent diameter of 0.3 to 4 μm and containing Cu is $1 \times 10^4/\text{mm}^2$ or more.

[0015] Further, it is preferable that the composition contains Cu: 0.13 to 0.35 mass %.

[0016] Further, it is preferable that the composition further contains one or two of Ti: 0.05 mass % or less and B: 0.05 mass % or less.

[0017] According to another aspect of the present disclosure, a method for producing the aluminum alloy plate contains subjecting an ingot obtained by casting an aluminum alloy material having the composition to homogenizing treatment at a first temperature within a range of 490 to 580° C.; then cooling the ingot to a second temperature within a range of 430 to 500° C. and lower than the first temperature at an average cooling speed within a range of 500 to 3000° C./h; starting hot-rolling while keeping the second temperature; subsequently performing winding at a third temperature within a range of 320 to 380° C.; and then sequentially performing cold-rolling and final annealing treatment.

[0018] Further, it is preferable that the first temperature is within a range of from 500 to 570° C.;

the second temperature is within a range of 440 to 490° C.; and the third temperature is within a range of from 340 to 360° C.

[0019] The present disclosure provides an aluminum alloy plate excellent in press-moldability and stress corrosion cracking resistance while having high tensile strength, particularly an Al—Mg based aluminum alloy plate, and a method for producing the Al—Mg based aluminum alloy plate has been made possible.

DETAILED DESCRIPTION

[0020] Next, preferred embodiments will be described.

[0021] An aluminum alloy plate according to one embodiment has a composition containing Si: 0.03 to 0.35%, Fe: 0.03 to 0.35%, Mg: 3.0 to 5.0%, Cu: more than 0.09% and less than 0.50%, and Mn: more than 0.05% and 0.35% or less in terms of mass %, with the balance including Al and inevitable impurities.

[0022] Hereinafter, reasons for the limitation in the chemical composition of the aluminum alloy plate according to one embodiment will be shown. Incidentally, the unit of every content of an element in a chemical composition is “mass %,” but is simply represented by “%” hereinafter unless otherwise stated.

[0023] (I) Chemical Composition

[0024] <Si: 0.03 to 0.35%>

[0025] Si (silicon) has a function of improving stress corrosion cracking resistance and is one of important components in one embodiment. When the Si content is less than 0.03%, preferential precipitation of P-phase (Al_3Mg_2) onto grain boundaries cannot be prevented, stress corrosion

cracking resistance deteriorates, crystal grains after final annealing coarsen, and surface roughening is likely to be caused. In addition, when the Si content exceeds 0.35%, an intermetallic compound is formed, and press-moldability, especially punch stretchability and deep drawability worsen. Therefore, the Si content is set within a range of 0.03 to 0.35% and is preferably set within a range of 0.09 to 0.25%.

[0026] <Fe: 0.03 to 0.35%>

[0027] Fe (iron) has also a function of improving stress corrosion cracking resistance and is one of important components in one embodiment as with Si. When the Fe content is less than 0.03%, preferential precipitation of P-phase (Al_3Mg_2) onto grain boundaries cannot be prevented, stress corrosion cracking resistance deteriorates, crystal grains after final annealing coarsen, and surface roughening is likely to be caused. In addition, when the Fe content exceeds 0.35%, an intermetallic compound is formed, and press-moldability, especially punch stretchability and deep drawability worsen. Therefore, the Fe content is set within a range of 0.03 to 0.35% and is preferably set within a range of 0.09 to 0.25%.

[0028] <Mg: 3.0 to 5.0%>

[0029] Mg (magnesium) is a component having functions of enhancing work hardenability and improving punch stretchability and deep drawability. In order to exert the functions, a Mg content to be contained is required to be 3.0% or more. In addition, even when the Mg content exceeds 5.0%, no further enhancing effect of the above characteristics can be expected, and besides, stress corrosion cracking resistance and hot rollability significantly deteriorate. Therefore, the Mg content is set within a range of 3.0 to 5.0% and is preferably set within a range of 3.2 to 4.7%.

[0030] <Cu: More than 0.09 and Less than 0.50%>

[0031] Cu (copper) is a component having functions of enhancing work hardenability and improving punch stretchability and deep drawability as with Mg. In addition, Cu also has a function of suppressing precipitation of β -phase at grain boundaries and improving stress corrosion cracking resistance by forming an Al—Mg—Cu based compound. In order to exert the functions, a Cu content to be contained is required to be more than 0.09%. In addition, when the Cu content is 0.50% or more, hot workability is impaired, a coarse compound is formed, and press-moldability deteriorates. Therefore, the Cu content is set within a range of more than 0.09% and less than 0.50% and is preferably set within a range of more than 0.09% and 0.35% or less.

[0032] <Mn: More than 0.05 and 0.35% or Less>

[0033] Mn (manganese) is a component having functions of refining recrystallized grains after final annealing treatment and improving strength. In order to exert the functions, a Mn content is required to exceed 0.05%. On the other hand, when the Mn content exceeds 0.35%, a size of recrystallized grains becomes too small to cause stretcher-strain marks (strain marks (creases) appear on surface of an alloy plate) to be likely to be generated on surface of a press-molded alloy plate, and further, moldability also deteriorates.

[0034] While essential components contained in the aluminum alloy plate of one embodiment are Si, Fe, Mg, Cu, and Mn as described above, the aluminum alloy plate of one embodiment can further contain one or two of Ti: 0.05% or less and B: 0.05% or less as needed.

[0035] <One or Two of Ti: 0.05% or Less and B: 0.05% or Less>

[0036] Ti and B are components having a function of refining crystal grains of an ingot. Both Ti and B do not negatively affect press-moldability and stress corrosion cracking resistance unless their contents exceed 0.05%, and therefore, contents of Ti and B are set within a range of 0.05% or less.

[0037] <Balance: Al and Inevitable Impurities>

[0038] Components other than the above elements are Al (aluminum) and inevitable impurities.

[0039] If V, Sc, Na, Be, and Bi are contained in a range of 0.1% or less, implementation of one embodiment is not affected.

[0040] (II) Number Density of Intermetallic Compound

[0041] (i) Number Density of Intermetallic Compound Having Circle Equivalent Diameter of 0.1 to 0.5 μm and not Containing Cu being $1 \times 10^6/\text{Mm}^2$ or Less

[0042] It is preferable that in the aluminum alloy plate of one embodiment, a number density of an intermetallic compound having a circle equivalent diameter of 0.1 to 0.5 μm and not containing Cu is $1 \times 10^6/\text{mm}^2$ or less. This is because when the intermetallic compound not containing Cu has a circle equivalent diameter of more than 0.5 μm or has a number density of more than $1 \times 10^6/\text{mm}^2$, press-moldability and stress corrosion cracking resistance tend to deteriorate. In addition, when the circle equivalent diameter of the intermetallic compound not containing Cu is less than 0.1 μm , while moldability is good, stress corrosion cracking resistance tends to deteriorate. Therefore, it is preferable that the number density of the intermetallic compound having a circle equivalent diameter of 0.1 to 0.5 μm and not containing Cu is $1 \times 10^6/\text{mm}^2$ or less. Incidentally, while a lower limit of the number density of the intermetallic compound not containing Cu is not particularly limited, it is preferable that the lower limit is set to $0.5 \times 10^4/\text{mm}^2$ from a viewpoint of press-moldability. Incidentally, the “circle equivalent diameter” herein means a diameter (circle equivalent diameter) obtained by converting an area of an observed particle into an equivalent circle.

[0043] (ii) Number Density of Intermetallic Compound Having Circle Equivalent Diameter of 0.3 to 4 μm and Containing Cu being $1 \times 10^4/\text{Mm}^2$ or More

[0044] It is preferable that in the aluminum alloy plate of one embodiment, a number density of an intermetallic compound having a circle equivalent diameter of 0.3 to 4 μm and containing Cu is $1 \times 10^4/\text{mm}^2$ or more. This is because when the intermetallic compound containing Cu has a circle equivalent diameter of less than 0.3 μm or has a number density of less than $1 \times 10^4/\text{mm}^2$, while moldability is good, prevention of precipitation of β -phase (Al_3Mg_2) at grain boundaries cannot be sufficiently exerted and stress corrosion cracking properties resistance tend to worsen. In addition, when the circle equivalent diameter of the intermetallic compound containing Cu exceeds 4 μm , press-moldability tends to deteriorate. Therefore, it is preferable that the number density of the intermetallic compound having a circle equivalent diameter of 0.3 to 4 μm and containing Cu is $1 \times 10^4/\text{mm}^2$ or more. Incidentally, while an upper limit of the number density of the intermetallic compound containing Cu is not particularly limited, it is preferable that the upper limit is set to $7 \times 10^5/\text{mm}^2$ from a viewpoint of press-moldability. Further, the circle equivalent diameter and number density of an intermetallic compound present in the

aluminum alloy plate can be measured by analyzing an observation photograph obtained by observing a thin film sample prepared from the aluminum alloy plate with a transmission electron microscope. In addition, whether an observed precipitate is an intermetallic compound containing Cu or an intermetallic compound not containing copper can be identified by performing an elemental analysis on each precipitate using an elemental analysis device installed in the transmission electron microscope. Further, the circle equivalent diameters and the number densities of the intermetallic compound containing Cu and the intermetallic compound not containing Copper significantly change according to producing conditions (treatment or processes) by which solid solution states or precipitation states of the intermetallic compounds are changed such as heat treatment during producing, and therefore can be controlled by producing the aluminum alloy plate with the producing method described later.

[0045] (III) Method for Producing Aluminum Alloy Plate

[0046] Next, a preferable embodiment of the method for producing the aluminum alloy plate of one embodiment will be described below.

[0047] It is especially important for the method for producing the aluminum alloy plate according to one embodiment to control cooling speed from a time point at which an ingot is subjected to homogenizing treatment and control a start temperature of hot-rolling performed thereafter within respective appropriate ranges.

[0048] First, an aluminum alloy of the above component composition (containing Si: 0.03 to 0.35%, Fe: 0.03 to 0.35%, Mg: 3.0 to 5.0%, Cu: more than 0.09% and less than 0.50%, and Mn: more than 0.05% and 0.35% or less in terms of mass %, with the balance including Al and inevitable impurities) is produced through melting according to a usual method and casted with an appropriately selected usual casting method such as a continuous casting method, a semi-continuous casting method, and the like. Then, the obtained ingot is subjected to homogenizing treatment at a first temperature, which is within a range of 490 to 580° C. and is preferably within a range of 500 to 570° C. This is because when the first temperature is less than 490° C., segregation of an additive element formed during casting is not eliminated, and sufficient moldability may not be obtained; and besides, when the first temperature exceeds 580° C., eutectic melting is caused during treatment, and cracking may be generated during hot-rolling. A treatment time of homogenizing treatment is not particularly limited and can range from 0.5 hours or more and 24 hours or less, for example.

[0049] Thereafter, after being subjected to the above homogenizing treatment, the ingot is cooled to a second temperature, which is within a range of 430 to 500° C., preferably within a range of 440 to 490° C. and is lower than the first temperature, at an average cooling speed, more preferably, an average cooling speed measured at a 1/4-thickness position of the ingot within a range of 500 to 3000° C./h, and then hot-rolling is started while keeping the second temperature. Here, formation of the intermetallic compound containing Cu has a function of improving stress corrosion cracking resistance. Meanwhile, formation of the intermetallic compound not containing Cu has a function of deteriorating stress corrosion cracking resistance. When the average cooling speed exceeds 3000° C./h, formation of the intermetallic compound containing Cu is prevented, and

stress corrosion cracking resistance tends to deteriorate. In addition, when the average cooling speed is less than 500° C./h, formation of the intermetallic compound not containing Cu is accelerated, and stress corrosion cracking resistance tends to deteriorate. Here, the reason why the “1/4-thickness position” is set as a measurement position of the average cooling speed is that the temperature history at the 1/4-thickness position highly impacts on performance of material. In addition, the reasons why the second temperature is limited to the range of 430 to 500° C. are that when the second temperature is less than 430° C., defective biting may occur during hot-rolling, and that when the second temperature exceeds 500° C., cracking may be generated during hot-rolling. Hence, in one embodiment, after being subjected to the above homogenizing treatment, the ingot is cooled to the second temperature, which is within a range of 430 to 500° C. and is lower than the first temperature at the average cooling speed within a range of 500 to 3000° C./h, and then hot-rolling is started while keeping the second temperature.

[0050] After the above described hot-rolling, winding is performed at a third temperature, which is within a range of 320 to 380° C. and is preferably within a range of 340 to 360° C., and then cold-rolling and final annealing treatment are sequentially performed. The reasons why the winding temperature is limited to the third temperature within the range of 320 to 380° C. are that when the third temperature is less than 320° C., no recrystallized structure is obtained after hot-rolling, a surface defect (strips in the rolling direction) may be generated after press-molding, and that when the third temperature exceeds 380° C., crystal grains after hot-rolling coarsen, and surface roughening may occur.

[0051] The aluminum alloy plate of one embodiment has high strength and good press-moldability, and is excellent in stress corrosion cracking resistance, and therefore, is suitable for use as materials especially in a member or part used for various automobiles represented by a body sheet and body panel of automobiles as well as a member or part used for vessels, aircrafts, and the like; or a construction material, a material for structure, and a material for other various apparatuses, home electric appliances, parts thereof, and the like, and its industrial value is great.

[0052] The above descriptions merely show several embodiments of this disclosure, and various changes can be made within the scope of the claims.

EXAMPLES

[0053] Hereinafter, examples of one embodiment will be described.

[0054] Aluminum alloys having the compositions shown in Table 1 were melted, and ingots were prepared by DC casting. Each of the obtained ingots (thickness of 30 mm, width of 175 mm) was heated to 560° C. (first temperature)

and kept at this first temperature for four hours. Thereafter, each of the ingots was cooled over a temperature range from the first temperature to the second temperature shown in Table 2 at the average cooling temperature speed shown in Table 2 and kept at the second temperature for 15 minutes, and hot-rolling was subsequently started at the second temperature (hot-rolling start temperature) to produce a plate material with a thickness of 4 mm. The winding temperature (third temperature) after hot-rolling was 360° C. Thereafter, this plate material was cold-rolled until its thickness became 1 mm, and subsequently subjected to softening treatment (final annealing treatment) in which the plate material was heated in a salt bath furnace under the conditions of 540° C. and 30 seconds and forcibly air-cooled to around room temperature by a fan. Aluminum alloy plates of Examples and Comparative Examples were produced through the above processes.

TABLE 1

Composi- tion No.	Chemical composition (mass %)							Balance
	Si	Fe	Mg	Cu	Mn	Ti	B	
1	0.15	0.15	4.00	0.30	0.22	—	—	Al and
2	0.10	0.13	4.10	0.32	0.22	—	—	inevitable
3	0.23	0.17	4.30	0.30	0.21	—	—	impurities
4	0.14	0.13	4.20	0.33	0.20	0.03	0.01	
5	0.16	0.22	4.50	0.33	0.20	—	—	
6	0.15	0.12	4.30	0.15	0.20	—	0.01	
7	0.15	0.13	4.20	0.34	0.20	—	—	
8	0.15	0.12	4.00	0.32	0.12	—	—	
9	0.15	0.13	4.00	0.33	0.24	0.03	—	
10	0.15	0.15	3.30	0.30	0.20	—	—	
11	0.15	0.15	4.60	0.30	0.20	—	—	
12	0.05	0.15	4.00	0.30	0.22	—	—	
13	0.32	0.15	4.00	0.30	0.22	—	—	
14	0.15	0.04	4.00	0.30	0.22	—	—	
15	0.15	0.33	4.00	0.30	0.22	—	—	
16	0.15	0.15	4.00	0.10	0.22	—	—	
17	0.15	0.15	4.00	0.44	0.22	—	—	
18	0.15	0.15	4.00	0.30	0.06	—	—	
19	0.15	0.15	4.00	0.30	0.27	—	—	
20	0.15	0.15	3.15	0.30	0.22	—	—	
21	0.15	0.15	4.80	0.30	0.22	—	—	
22	<u>0.02</u>	0.15	4.00	0.30	0.22	—	—	
23	<u>0.50</u>	0.15	4.00	0.30	0.22	—	—	
24	0.15	<u>0.02</u>	4.00	0.30	0.22	—	—	
25	0.15	<u>0.50</u>	4.00	0.30	0.22	—	—	
26	0.15	0.15	4.00	<u>0.03</u>	0.22	—	—	
27	0.15	0.15	4.00	<u>0.60</u>	0.22	—	—	
28	0.15	0.15	4.00	0.30	<u>0.03</u>	—	—	
29	0.15	0.15	4.00	0.30	<u>0.50</u>	—	—	
30	0.15	0.15	<u>2.50</u>	0.30	0.22	—	—	
31	0.15	0.15	<u>5.50</u>	0.30	0.22	—	—	
32	0.15	0.15	<u>0.29</u>	0.22	<u>4.00</u>	<u>0.10</u>	—	
33	0.14	0.14	<u>0.28</u>	0.21	<u>4.10</u>	—	<u>0.08</u>	
34	0.15	0.16	<u>0.30</u>	0.20	<u>4.00</u>	<u>0.10</u>	<u>0.08</u>	

(Note)

The underlined bold numerical values in the table represent numerical values beyond the appropriate ranges of the present disclosure.

TABLE 2

Manufacturing condition No.	Homogenizing treatment process First temperature (° C.)	Average cooling speed in cooling from first temperature to second temperature after homogenizing treatment (° C./h)	Hot-rolling process Hot-rolling start temperature (second temperature) (° C.)	Winding process Winding temperature (third temperature) (° C.)
1	560	750	475	360
2		<u>450</u>	475	

TABLE 2-continued

Manufacturing condition No.	Homogenizing treatment process First temperature (° C.)	Average cooling speed in cooling from first temperature to second temperature after homogenizing treatment (° C./h)	Hot-rolling process Hot-rolling start temperature (second temperature) (° C.)	Winding process Winding temperature (third temperature) (° C.)
3		2500	475	
4		750	<u>510</u>	
5		750	450	
6		<u>20</u>	475	
7		<u>3500</u>	475	
8		750	<u>530</u>	
9		750	<u>415</u>	

(Note)

The underlined bold numerical values in the table represent numerical values beyond the appropriate ranges of the present disclosure.

[0055] (Test Method)**[0056]** [Measurement Method of Crystal Grain Size]

[0057] With respect to each of the prepared aluminum alloy plates, the crystal grain size was measured. As a confirmation method, a sample was taken from the width center part of the aluminum alloy plate; its crystal grain structure was imaged at the rolled surface; five straight lines were drawn at equal intervals in each of the longitudinal direction and the lateral direction in a field of 3 mm×3 mm; crystal grain sizes were measured by an intercept method; and an average value of the measured crystal grain sizes was calculated as the average crystal grain size (rmn). In the present Examples, crystal grain sizes of less than 50 mg are regarded as eligible, and crystal grain sizes of 50 mg or more are regarded as ineligible (surface roughening occurred).

[0058] [Calculation Method of Number Density of Intermetallic Compounds]

[0059] With respect to each of the prepared aluminum alloy plates, the center part of a cross-section parallel to the rolled surface from the center part of plate width was observed by a transmission electron microscope (TEM) at a magnification of 10,000 times using JEM-2010 manufactured by JEOL Ltd. A value to be evaluated is a diameter (circle equivalent diameter) obtained by measuring an area of an intermetallic compound in the obtained image using image analysis software “Winroof” and converting the area into an equivalent circle. Incidentally, whether Cu was contained in the compound or not was analyzed by using energy dispersive X-ray spectroscopy (EDS). The number density (per mm²) of the intermetallic compound having a circle equivalent diameter of 0.1 to 0.5 μm and not containing Cu and the number density (per mm²) of the intermetallic compound having a circle equivalent diameter of 0.3 to 4 μm and containing Cu were obtained. Observation was performed at three fields and an average value was adopted.

[0060] [Tensile Characteristics]

[0061] With respect to each of the prepared aluminum alloy plates, a specimen of JIS no. 5 was cut out in the direction perpendicular to the rolling direction, and tensile strength (MPa), yield strength (MPa), and elongation at break (%) were measured by a tensile test. Incidentally, those having tensile strength of 240 MPa or more were regarded as eligible, and those having tensile strength of less than 240 MPa were regarded as ineligible; and besides, as to yield strength, those having yield strength of 100 MPa or

more were regarded as eligible, and those having yield strength of less than 100 MPa were regarded as ineligible in the present Examples.

[0062] [Press-moldability] A stretch forming test and a drawing test were conducted to investigate press-moldability.

[0063] A blanc having a 120-mm square shape was cut out from the width center part of each of the prepared aluminum alloy plate; the bulging test was conducted by an Erichsen test apparatus using a beaded mold, with a punch having a diameter of 50 mm, and under conditions of blank holding force of 40 kN and a molding speed of 2.0 mm/s to measure a limit of the bulging height (mm) not to generate cracking; and press-moldability was evaluated from the measured value of the bulging height.

[0064] A circular plate with a diameter of 110 mm was molded from each of the prepared aluminum alloy plates; a low viscosity lubricating oil was applied thereto to prepare a test material; the drawing test was conducted by using an Erichsen test apparatus with a dice not provided with locking beads, with a flat punch having a diameter of 50 mm, and under conditions of blank holding force of 10 kN and a molding speed of 2.0 mm/s to measure a limit of the drawing height (mm) not to generate cracking; and press-moldability was evaluated from the measured value of the drawing height.

[0065] Incidentally, in the evaluation of press-moldability, bulging heights of 17 mm or more were regarded as eligible, and bulging heights of less than 17 mm were regarded as ineligible for the bulging moldability, and besides, drawing heights of 15 mm or more were regarded as eligible, and drawing heights of less than 15 mm were regarded as ineligible for the drawing moldability in the present Examples.

[0066] [Stress Corrosion Cracking Resistance]

[0067] Stress corrosion cracking resistance was evaluated as follows: a specimen taken from the width center part of each of the prepared aluminum alloy plate was cold-rolled at a processing rate of 30% and subsequently subjected to sensitization treatment in which heat treatment was performed at 120° C. for seven days; the specimen after the sensitization treatment was bent in a U-shape with bending radii of 2 mm and 3 mm and immersed in a chromic acid solution (an aqueous solution in which one liter of pure water contains CrO₃: 36 g, K₂Cr₂O₇: 30 g, and NaCl: 3 g) heated to 95° C. in a state where stress is applied, with the

both ends of the U-shaped specimen restrained; a time until stress corrosion cracking occurred was measured; and at a bending radius of 2 mm, a case where stress corrosion cracking occurred within 24 hours was rated as “poor,” a case where stress corrosion cracking did not occur over 24 hours was rated as “good,” and a case where stress corrosion

cracking did not occur over 96 hours was rated as “excellent.”

[0068] Evaluation results of the tensile characteristics, press-moldability, and stress corrosion cracking resistance of the aluminum alloy plate materials produced in the present Examples are shown in Table 3.

TABLE 3

Sample No.	Composition No.	Manufacturing condition No.	Number density		Average crystal grain size (μm)	Tensile characteristics Tensile strength TS (MPa)
			Intermetallic compound having circle equivalent diameter of 0.1 to 0.5 μm and not containing Cu (10 ⁴ /mm ²)	Intermetallic compound having circle equivalent diameter of 0.3 to 4 μm and containing Cu (10 ⁴ /mm ²)		
Present Working Example 1	1	1	53	5	35	278
Present Working Example 2	2	1	42	4	39	276
Present Working Example 3	3	1	61	3	32	280
Present Working Example 4	4	1	40	5	40	273
Present Working Example 5	5	1	65	6	30	275
Present Working Example 6	6	1	24	3	38	270
Present Working Example 7	7	1	70	9	35	280
Present Working Example 8	8	1	32	5	40	269
Present Working Example 9	9	1	61	4	29	275
Present Working Example 10	10	1	30	3	33	271
Present Working Example 11	11	1	45	9	37	280
Present Working Example 12	12	1	14	4	45	260
Present Working Example 13	13	1	91	3	37	267
Present Working Example 14	14	1	13	6	47	261
Present Working Example 15	15	1	93	3	39	266
Present Working Example 16	16	1	12	2	34	262
Present Working Example 17	17	1	74	32	32	265
Present Working Example 18	18	1	11	5	44	259
Present Working Example 19	19	1	79	8	25	263
Present Working Example 20	20	1	18	8	32	285
Present Working Example 21	21	1	93	7	35	280
Comparative Example 1	<u>22</u>	1	19	4	55	<u>233</u>
Comparative Example 2	<u>23</u>	1	112	7	40	259
Comparative Example 3	<u>24</u>	1	17	3	60	243
Comparative Example 4	<u>25</u>	1	109	3	30	255
Comparative Example 5	<u>26</u>	1	13	0.3	25	258
Comparative Example 6	<u>27</u>	1	Cracking occurred during hot-rolling			—
Comparative Example 7	<u>28</u>	1	12	8	55	<u>235</u>
Comparative Example 8	<u>29</u>	1	103	5	23	268
Comparative Example 9	<u>30</u>	1	11	8	34	<u>230</u>
Comparative Example 10	<u>31</u>	1	103	7	35	265
Comparative Example 11	1	<u>2</u>	51	7	33	260
Present Working Example 22	1	3	18	8	32	272
Comparative Example 12	1	<u>4</u>	84	3	29	278
Present Working Example 23	1	<u>5</u>	17	0.8	30	250
Comparative Example 13	1	<u>6</u>	0.3	7	33	<u>230</u>
Comparative Example 14	1	<u>7</u>	87	0.2	29	257
Comparative Example 15	1	<u>8</u>	Cracking occurred during hot-rolling			—
Comparative Example 16	1	<u>9</u>	Hot-rolling was impossible due to defective biting			—
Comparative Example 17	<u>32</u>	1	44	6	30	280
Comparative Example 18	<u>33</u>	1	50	3	38	276
Comparative Example 19	<u>34</u>	1	52	7	30	282

Sample No.	Tensile characteristics				
	Yield		Press-moldability		Stress corrosion cracking resistance
	strength YS (MPa)	Elongation at break (%)	Bulging height (mm)	Drawing height (mm)	
Present Working Example 1	126	32	19.3	20.0	Excellent
Present Working Example 2	125	31	19.6	20.2	Excellent
Present Working Example 3	127	33	19.0	19.0	Excellent
Present Working Example 4	122	33	19.0	20.0	Excellent
Present Working Example 5	123	30	19.3	19.1	Excellent

TABLE 3-continued

Present Working Example 6	120	31	19.4	18.1	Excellent
Present Working Example 7	122	31	20.0	21.0	Excellent
Present Working Example 8	119	31	19.9	19.3	Excellent
Present Working Example 9	123	31	19.1	19.2	Excellent
Present Working Example 10	120	31	19.0	19.0	Excellent
Present Working Example 11	124	33	20.0	20.0	Excellent
Present Working Example 12	115	32	19.2	21.0	Good
Present Working Example 13	118	32	18.0	16.0	Good
Present Working Example 14	114	33	19.5	21.2	Good
Present Working Example 15	117	33	18.2	15.8	Good
Present Working Example 16	113	32	18.2	18.3	Good
Present Working Example 17	117	34	19.5	18.5	Good
Present Working Example 18	110	32	19.4	18.1	Good
Present Working Example 19	115	31	18.0	16.0	Good
Present Working Example 20	120	30	17.3	15.8	Good
Present Working Example 21	133	33	19.0	20.0	Good
Comparative Example 1	<u>95</u>	32	17.0	15.0	Poor
Comparative Example 2	113	32	<u>16.0</u>	<u>14.0</u>	Poor
Comparative Example 3	<u>96</u>	33	17.5	15.5	Poor
Comparative Example 4	110	33	18.0	18.0	Poor
Comparative Example 5	112	32	<u>15.3</u>	<u>13.0</u>	Poor
Comparative Example 6	—	—	—	—	—
Comparative Example 7	88	32	19.3	19.5	Poor
Comparative Example 8	120	31	<u>16.0</u>	<u>14.0</u>	Poor
Comparative Example 9	85	30	<u>16.2</u>	<u>14.3</u>	Poor
Comparative Example 10	143	33	18.0	18.0	Poor
Comparative Example 11	115	32	17.5	16.5	Excellent
Present Working Example 22	121	32	17.3	16.4	Good
Comparative Example 12	125	31	19.2	17.3	Good
Present Working Example 23	109	31	17.8	18.3	Excellent
Comparative Example 13	<u>98</u>	31	<u>18.3</u>	<u>14.3</u>	Poor
Comparative Example 14	115	33	18.2	15.8	Poor
Comparative Example 15	—	—	—	—	—
Comparative Example 16	—	—	—	—	—
Comparative Example 17	133	30	<u>15.0</u>	<u>13.0</u>	Excellent
Comparative Example 18	125	31	<u>15.2</u>	<u>13.6</u>	Excellent
Comparative Example 19	132	30	<u>15.1</u>	<u>13.3</u>	Excellent

(Note)

The underlined bold numerical values or symbols in the table represent that they are beyond the appropriate ranges of the present disclosure or that characteristics thereof are ineligible.

[0069] According to the evaluation results shown in Table 3, all of Present Working Examples 1 to 23 had tensile strength as high as 240 MPa, bulging heights of 17 mm or more, and drawing heights as high as 15 mm or more as well, and were also excellent in stress corrosion cracking resistance. On the other hand, Comparative Examples 1 to 10 and 17 to 19, which had compositions beyond the appropriate ranges of the present disclosure, and Comparative Examples 11 to 16, which were produced under producing conditions beyond the appropriate ranges of the present disclosure, were all inferior in at least one of tensile characteristics, press-moldability, and stress corrosion cracking resistance.

What is claimed is:

1. An aluminum alloy plate having a composition comprising Si: 0.03 to 0.35%, Fe: 0.03 to 0.35%, Mg: 3.0 to 5.0%, Cu: more than 0.09% and less than 0.50%, and Mn: more than 0.05% and 0.35% or less in terms of mass %, with a balance including Al and inevitable impurities.

2. The aluminum alloy plate according to claim 1, wherein an intermetallic compound is present in the aluminum alloy plate, and a number density of the intermetallic compound having a circle equivalent diameter of 0.1 to 0.5 μm and not containing Cu is $1 \times 10^6/\text{mm}^2$ or less.

3. The aluminum alloy plate according to claim 1, wherein an intermetallic compound is present in the aluminum alloy plate, and a number density of the intermetallic compound

having a circle equivalent diameter of 0.3 to 4 μm and containing Cu is 1×10^4 molecules/ mm^2 or more.

4. The aluminum alloy plate according to claim 1, wherein the composition contains Cu: 0.13 to 0.35 mass %.

5. The aluminum alloy plate according to claim 1, wherein the composition further contains one or two of Ti: 0.05 mass % or less and B: 0.05 mass % or less.

6. A method for producing an aluminum alloy plate having a composition containing Si: 0.03 to 0.35%, Fe: 0.03 to 0.35%, Mg: 3.0 to 5.0%, Cu: more than 0.09% and less than 0.50%, and Mn: more than 0.05% and 0.35% or less in terms of mass %, with a balance including Al and inevitable impurities, wherein the method comprises:

subjecting an ingot obtained by casting an aluminum alloy material having the composition to homogenizing treatment at a first temperature within a range of 490 to 580° C.;

then cooling the ingot to a second temperature within a range of 430 to 500° C. and lower than the first temperature at an average cooling speed within a range of 500 to 3000° C./h;

starting hot-rolling while keeping the second temperature; subsequently performing winding at a third temperature within a range of 320 to 380° C.; and

then sequentially performing cold-rolling and final annealing treatment.

7. The method for producing an aluminum alloy plate according to claim 6, wherein

the first temperature is within a range of 500 to 570° C.;

the second temperature is within a range of 440 to 490° C.; and

the third temperature is within a range of 340 to 360° C.

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