US 20080178973A1

(19) **United States**

(12) **Patent Application Publication**

(10) **Pub. No.: US 2008/0178973 A1**

(43) **Pub. Date: Jul. 31, 2008**

Uchida et al.

(54) **ALUMINUM ALLOY SHEET WITH EXCELLENT FORMABILITY AND PAINT BAKE HARDENABILITY AND METHOD FOR PRODUCTION THEREOF**

(75) Inventors: **Hidetoshi Uchida**, Nagoya City (JP); **Tadashi Minoda**, Nagoya City (JP); **Mineo Asano**, Toyoake City (JP); **Yoshikazu Ozeki**, Nagoya City (JP); **Tsutomu Furuyama**, Nagoya City (JP)

Correspondence Address:
FLYNN THIEL BOUTELL & TANIS, P.C.
2026 RAMBLING ROAD
KALAMAZOO, MI 49008-1631 (US)

(73) Assignee: **SUMITOMO LIGHT METAL INDUSTRIES, LTD.**

(21) Appl. No.: **12/077,862**

(22) Filed: **Mar. 21, 2008**

Related U.S. Application Data

(62) Division of application No. 10/468,971, filed on Aug. 22, 2003, filed as application No. PCT/JP2002/002900 on Mar. 26, 2002.

(30) **Foreign Application Priority Data**

Mar. 28, 2001	(JP)	2001-091979
Mar. 28, 2001	(JP)	2001-091980
Sep. 27, 2001	(JP)	2001-295633
Mar. 8, 2002	(JP)	2002-063118
Mar. 8, 2002	(JP)	2002-063119
Mar. 20, 2002	(JP)	2002-077794
Mar. 20, 2002	(JP)	2002-077795

Publication Classification

(51) **Int. Cl.**
C22F 1/05 (2006.01)

(52) **U.S. Cl.** **148/695**

(57) **ABSTRACT**

A sheet of a 6000 type aluminum alloy containing Si and Mg as main alloy components and having an excellent formability sufficient to allow flat hemming, excellent resistance to denting, and good hardenability during baking a coating, which exhibits an anisotropy of Lankford values of more than 0.4 or the strength ratio for cube orientations of the texture thereof of 20 or more, and exhibits a minimum bend radius of 0.5 mm or less at 180° bending, even when the offset yield strength thereof exceeds 140 MPa through natural aging; and a method for producing the sheet of the aluminum alloy, which includes the steps of subjecting an ingot to a homogenization treatment, cooling to a temperature lower than 350° C. at a cooling rate of 100° C./hr or more, optionally to room temperature, heating again to a temperature of 300 to 500° C. and subjecting it to hot rolling, cold rolling the hot rolled product, and subjecting the cold rolled sheet to a solution treatment at a temperature of 400° C. or higher, followed by quenching.

ALUMINUM ALLOY SHEET WITH EXCELLENT FORMABILITY AND PAINT BAKE HARDENABILITY AND METHOD FOR PRODUCTION THEREOF

[0001] This is a division of Ser. No. 10/468,971, filed Aug. 22, 2003, which was the national stage of International Application No. PCT/JP2002-002900, filed Mar. 26, 2002, which International Application was not published in English.

TECHNICAL FIELD

[0002] The present invention relates to an aluminum alloy sheet with excellent formability and paint bake hardenability and suitable as a material for transportation parts, in particular, as an automotive outer panel, and a method for producing the same.

BACKGROUND ART

[0003] An automotive outer panel is required to have 1) formability, 2) shape fixability (shape of the press die is precisely transferred to the material by press working), 3) dent resistance, 4) corrosion resistance, 5) surface quality, and the like. Conventionally, 5000 series (Al—Mg) aluminum alloys and 6000 series (Al—Mg—Si) aluminum alloys have been applied to the automotive outer panel. The 6000 series aluminum alloy has attracted attention because high strength is obtained due to excellent paint bake hardenability, whereby further gage and weight savings are expected. Therefore, various improvements have been made on the 6000 series aluminum alloy.

[0004] Among the properties required for the automotive outer panel, although the shape fixability prefer lower yield strength, the dent resistance prefer higher yield strength. In order to solve this problem, press working are carried out for lower yield strength for shape fixability and dent resistance are improved by excellent paint bake hardenability using a 6000 series aluminum alloy (see JP 5-247610, JP 5-279822, JP 6-17208, etc.).

[0005] The 6000 series aluminum alloy has problems relating to the surface quality after forming, such as occurrence of orange peel surfaces and ridging marks (long streak-shaped defects occurring in the rolling direction during plastic working). Surface quality defects can be solved by adjusting the alloy components, managing the production conditions, and the like. For example, a method of preventing formation of coarse precipitates by homogenizing the alloy at a temperature of 500° C. or more, cooling the homogenized product to 450-350° C., and starting hot rolling in this temperature range has been proposed in order to prevent occurrence of ridging marks (see JP 7-228956). However, if the cooling rate is decreased when cooling the homogenized product from the homogenization temperature of 500° C. or more to the hot rolling temperature of 450° C., coarse Mg—Si compounds are formed. This makes it necessary to perform a solution treatment at a high temperature for a long time in the subsequent step, whereby production efficiency is decreased.

[0006] In the case of assembling an outer panel and an inner panel material, 180° bending (flat hemming), in which working conditions are severe since the ratio (R/t) of the center bending radius (R) to the sheet thickness (t) is small, is performed. However, since the 6000 series aluminum alloy has inferior bendability in comparison with the 5000 series aluminum alloy, flat hemming cannot be performed in a high press working area.

DISCLOSURE OF THE INVENTION

[0007] The present inventors have examined for further improving formability, in particular, bendability of the 6000 series aluminum alloy. As a result, it has been found that bendability of the 6000 series alloy is affected by the precipitation state of Mg—Si compounds and misorientation of adjacent crystal grains, and also found that bendability has a correlation with the Lankford value, and it is necessary to increase the anisotropy of the Lankford values in order to improve bendability. Furthermore, it has been found that bendability also has a correlation with the intensity ratio (random ratio) of cube orientation {100} <001> of the texture, and it is necessary to allow the texture to have a high degree of integration of cube orientation in order to improve bendability. In order to obtain the above properties, the present inventors have found that it is important to optimize the content of Si and Mg which are major elements of the 6000 series aluminum alloy, and to optimize the production steps, in particular, to appropriately control the cooling rate after homogenization of an ingot.

[0008] The present invention has been achieved based on the above findings. An object of the present invention is to provide an aluminum alloy sheet having excellent formability which allows flat hemming, showing no orange peel surfaces and ridging marks after forming, having excellent paint bake hardenability capable of solving the problems relating to shape fixability and dent resistance, and with excellent corrosion resistance, in particular, filiform corrosion resistance, and a method for producing the same.

[0009] An aluminum alloy sheet according to the present invention for achieving the above object is a 6000 series aluminum alloy sheet, with excellent bendability after a solution treatment and quenching, and has a minimum inner bending radius of 0.5 mm or less during 180° bending with 10% pre-stretch, even if the yield strength is further increased through natural aging. Specific embodiments of the aluminum alloy sheet are as follows.

[0010] (1) An aluminum alloy sheet comprising 0.5-1.5% of Si and 0.2-1.0% of Mg, with the balance consisting of Al and impurities, or comprising 0.8-1.2% of Si, 0.4-0.7% of Mg, and 0.1-0.3% of Zn, with the balance consisting of Al and impurities, in which the maximum diameter of Mg—Si compounds is 10 μm or less and the number of Mg—Si compounds having a diameter of 2-10 μm is 1000 per mm^2 or less.

[0011] (2) An aluminum alloy sheet comprising 0.4-1.5% of Si, 0.2-1.2% of Mg, and 0.05-0.3% of Mn, with the balance consisting of Al and impurities, in which the percentage of crystal grain boundaries in which misorientation of adjacent crystal grains is 15° or less is 20% or more.

[0012] (3) An aluminum alloy sheet comprising 0.5-2.0% of Si and 0.2-1.5% of Mg, with 0.7Si %+Mg %≦2.2%, and Si %-0.58Mg %≧0.1% being satisfied and the balance consisting of Al and impurities, in which an anisotropy of Lankford values is more than 0.4. The Lankford value r is the ratio of the logarithmic strain in the direction of the width of the sheet to the logarithmic strain in the direction of the thickness of the sheet when applying a specific amount of tensile deformation, such as 15%, to a tensile specimen, specifically, r=(logarithmic strain in the sheet width direction)/(logarithmic strain in the sheet thickness direction). The anisotropy of Lankford

values is (r0+r90-2×r45)/2 (r0: r value of a tensile specimen collected in a direction at 0° to the rolling direction, r90: r value of a tensile specimen collected in a direction at 90° to the rolling direction, and r45: r value of a tensile specimen collected in a direction at 450 to the rolling direction).

[0013] (4) An aluminum alloy sheet comprising 0.5-2.0% of Si and 0.2-1.5% of Mg, with 0.7Si %+Mg %≦2.2% being satisfied and the balance consisting of Al and impurities, in which an intensity ratio of cube orientation of crystallographic texture is 20 or more.

[0014] Specific embodiments of a method for producing the above aluminum alloy sheets are as follows.

[0015] (1) A method for producing an aluminum alloy sheet comprising homogenizing an ingot of an aluminum alloy having the above composition at a temperature of 450° C. or more, cooling the ingot to a temperature of 350-500° C. at a cooling rate of 100° C./h or more, starting hot rolling of the ingot at the temperature, cold rolling the hot-rolled product, and subjecting the cold-rolled product to a solution heat treatment at a temperature of 500° C. or more, and quenching.

[0016] (2) A method for producing an aluminum alloy sheet comprising homogenizing an ingot of an aluminum alloy having the above composition at a temperature of 450° C. or more, cooling the ingot to a temperature of less than 300° C. at a cooling rate of 100° C./h or more, heating the ingot to a temperature of 350-500° C. and starting hot rolling of the ingot, cold rolling the hot-rolled product, and subjecting the cold-rolled product to a solution heat treatment at a temperature of 500° C. or more, and quenching.

[0017] (3) A method for producing an aluminum alloy sheet comprising homogenizing an ingot of an aluminum alloy having the above composition at a temperature of 450° C. or more, cooling the ingot to a temperature of less than 300° C. at a cooling rate of 100° C./h or more, cooling the ingot to room temperature, heating the ingot to a temperature of 350-500° C. and starting hot rolling of the ingot, cold rolling the hot-rolled product, and subjecting the cold-rolled product to a solution heat treatment at a temperature of 500° C. or more, and quenching.

[0018] (4) A method for producing an aluminum alloy sheet comprising homogenizing an ingot of an aluminum alloy having the above composition at a temperature of 450° C. or more, cooling the ingot to a temperature of less than 350° C. at a cooling rate of 100° C./h or more, hot rolling the ingot at the temperature, cold rolling the hot-rolled product, and subjecting the cold-rolled product to a solution heat treatment at a temperature of 450° C. or more, and quenching.

[0019] (5) A method for producing an aluminum alloy sheet comprising homogenizing an ingot of an aluminum alloy having the above composition at a temperature of 450° C. or more, cooling the ingot to a temperature of less than 350° C. at a cooling rate of 100° C./h or more, heating the ingot to a temperature of 300-500° C. and starting hot rolling of the ingot, cold rolling the hot-rolled product, and subjecting the cold-rolled product to a solution heat treatment at a temperature of 450° C. or more, and quenching.

[0020] (6) A method for producing an aluminum alloy sheet comprising homogenizing an ingot of an aluminum alloy having the above composition at a temperature of 450° C. or more, cooling the ingot to a temperature of less than 350° C. at a cooling rate of 100° C./h or more, cooling the ingot to room temperature, heating the ingot to a temperature of 300-500° C. and starting hot rolling of the ingot, cold rolling the hot-rolled product, and subjecting the cold-rolled product to a solution heat treatment at a temperature of 450° C. or more, and quenching.

PREFERRED EMBODIMENTS

[0021] Effects and reasons for limitations of the alloy components in the Al—Mg—Si alloy sheet of the present invention are described below.

[0022] Si is necessary to obtain strength and high paint bake hardenability (BH), and increases strength by forming Mg—Si compounds. The Si content is preferably 0.5-2.0%. If the Si content is less than 0.5%, sufficient strength may not be obtained by heating during baking and formability may be decreased. If the Si content exceeds 2.0%, formability and shape fixability may be insufficient due to high yield strength during press working. Moreover, corrosion resistance may be decreased after painting. The Si content is more preferably 0.4-1.5%, still more preferably 0.5-1.5%, yet more preferably 0.6-1.3%, and particularly preferably 0.8-1.2%.

[0023] Mg increases strength in the same manner as Si. The Mg content is preferably 0.2-1.5%. If the Mg content is less than 0.2%, sufficient strength may not be obtained by heating during baking. If the Mg content exceeds 1.5%, yield strength may remain high after a solution heat treatment or additional heat treatment, whereby formability and spring-back properties may be insufficient. The Mg content is more preferably 0.2-1.2%, still more preferably 0.2-1.0%, yet more preferably 0.3-0.8%, and particularly preferably 0.4-0.7%.

[0024] Si and Mg are preferably added to satisfy the relations 0.7Si %+Mg %≦2.2%, and Si %-0.58Mg %≧0.1% so that anisotropy of the Lankford values is more than 0.4 and bendability is improved. In order to increase the intensity ratio of cube orientation of the texture to obtain good bendability, Si and Mg are preferably added to satisfy the relation 0.7Si %+Mg %≦2.2%.

[0025] Zn improves zinc phosphate treatment properties during the surface treatment. The Zn content is preferably 0.5% or less. If the Zn content exceeds 0.5%, corrosion resistance may be decreased. The Zn content is still more preferably 0.1-0.3%.

[0026] Cu improves strength and formability. The Cu content is preferably 1.0% or less. If the Cu content exceeds 1.0%, corrosion resistance may be decreased. The Cu content is still more preferably 0.3-0.8%. If corrosion resistance is an important, the Cu content is preferably limited to 0.1% or less.

[0027] Mn, Cr, V, and Zr improve strength and refine crystal grains to prevent occurrence of orange peel surfaces during forming. The content of Mn, Cr, V, and Zr is preferably 1.0% or less, 0.3% or less, 0.2% or less, and 0.2% or less, respectively. If the content of Mn, Cr, V, and Zr exceeds the above upper limits, coarse intermetallic compounds may be formed, whereby formability may be decreased. The content of Mn and Zr is more preferably 0.3% or less and 0.15% or less, respectively. The content of Mn, Cr, V, and Zr is still more preferably 0.05-0.3%, 0.05-0.15%, 0.05-0.15%, and 0.05-0.15%, respectively.

[0028] In order to improve bendability by allowing the percentage of crystal grain boundaries in which misorientation of adjacent crystal grains is 15° or less to be 20% or more, Mn is added in an amount of 0.05-0.3% as an essential component.

[0029] Ti and B refine a cast structure to improve formability. The content of Ti and B is preferably 0.1% or less and 50

ppm or less, respectively. If the content of Ti and B exceeds the above upper limits, the number of coarse intermetallic compounds may be increased, whereby formability may be decreased. It is preferable to limit the Fe content to 0.5% or less, and preferably 0.3% or less as another impurity.

[0030] The production steps of the aluminum alloy sheet of the present invention are described below.

[0031] Homogenization condition: Homogenization must be performed at a temperature of 450° C. or more. If the homogenization temperature is less than 450° C., removal of ingot segregation and homogenization may be insufficient. This results in insufficient dissolution of Mg_2Si components which contribute to strength, whereby formability may be decreased. Homogenization is preferably performed at a temperature of 480° C. or more.

[0032] Cooling after homogenization: Good properties are obtained by cooling the homogenized product at a cooling rate of preferably 100° C./h or more, and still more preferably 300° C./h or more. Since large-scale equipment is necessary for increasing the cooling rate, it is preferable to manage the cooling rate in the range of 300-1000° C./h in practice. If the cooling rate is low, Mg—Si compounds are precipitated and coarsened. In a conventional cooling method, the cooling rate is about 30° C./h in the case of cooling a large slab. However, Mg—Si compounds are precipitated and coarsened during cooling at such a low cooling rate, whereby the material may not be provided with improved bendability after the solution heat treatment and quenching.

[0033] If the cooling rate is controlled in this manner, (1) appropriate distributions of Mg—Si compounds are obtained, (2) the percentage of crystal grain boundaries in which misorientation of adjacent crystal grains is 15° or less becomes 20% or more, (3) anisotropy of Lankford values is increased, and (4) the degree of integration of cube orientation is increased, whereby bendability is improved.

[0034] The cooling after homogenization must allow the temperature to be decreased to less than 350° C., and preferably less than 300° C. at a cooling rate of 100° C./h or more, preferably 150° C./h or more, and still more preferably at 300° C./h or more. The properties are affected if a region at 350° C. or more is partially present. Therefore, an ingot is cooled until the entire ingot is at 300° C. or less, and preferably 250° C. or less at the above cooling rate. There are no specific limitations to the method of cooling the homogenized ingot insofar as the necessary cooling rate is obtained. For example, water-cooling, fan cooling, mist cooling, or heat sink contact may be employed as the cooling method.

[0035] The cooling start temperature is not necessarily the homogenization temperature. The same effect can be obtained by allowing the ingot to be cooled to a temperature at which precipitation does not significantly occur, and starting cooling at a cooling rate of 100° C./h or more. For example, in the case where homogenization is performed at a temperature of 500° C. or more, the ingot may be slowly cooled to 500° C.

[0036] Hot rolling: The ingot is cooled to a specific temperature of 350-500° C. or 300-450° C. from the homogenization temperature, and hot rolling is started at the specific temperature. The ingot may be cooled to a specific temperature of 350° C. or less from the homogenization temperature, and hot rolling may be started at the specific temperature.

[0037] The ingot may be cooled to a temperature of 350° C. or less and heated to a temperature of 300-500° C., and hot rolling may be started at this temperature. The ingot may be cooled to a temperature of 350° C. or less, cooled to room temperature, heated to a temperature of 300-500° C., and hot-rolled at this temperature.

[0038] If the hot rolling start temperature is less than 300° C., deformation resistance is increased, whereby rolling efficiency is decreased. If the hot rolling start temperature exceeds 500° C., crystal grains coarsen during rolling, whereby ridging marks readily occur in the resulting material. Therefore, it is preferable to limit the hot rolling start temperature to 300-500° C. The hot rolling start temperature is still more preferably 380-450° C. taking into consideration deformation resistance and uniform microstructure.

[0039] The hot rolling finish temperature is preferably 300° C. or less. If the hot rolling finish temperature exceeds 300° C., precipitation of Mg—Si compounds easily occurs, whereby formability may be decreased. Moreover, recrystallized grains coarsen, thereby resulting in occurrence of ridging marks. Hot rolling is preferably finished at 200° C. or more taking into consideration deformation resistance during hot rolling and residual oil stains due to a coolant.

[0040] Cold rolling: The hot rolled sheet is cold rolled to the final gage.

[0041] Solution heat treatment: The solution heat treatment temperature is preferably 450° C. or more, and still more preferably 500° C. or more. If the solution heat treatment temperature is less than 500° C., dissolution of Mg—Si precipitates may be insufficient, whereby sufficient strength and formability cannot be obtained, or heat treatment for a considerably long time is needed to obtain necessary strength and formability. This is disadvantageous from the industrial point of view. There are no specific limitations to the solution heat treatment time insofar as necessary strength is obtained. The solution heat treatment time is usually 120 seconds or less from the industrial point of view.

[0042] Cooling rate during quenching: It is necessary to cool the sheet from the solution treatment temperature to 120° C. or less at a cooling rate of 5° C./s or more. It is preferable to cool the sheet at a cooling rate of 10° C./s or more. If the quenching cooling rate is too low, precipitation of eluted elements occurs, whereby strength, BH, formability, and corrosion resistance may be decreased.

[0043] Additional heat treatment: this heat treatment is performed at 40-120° C. for 50 hours or less within 60 minutes after quenching. BH is improved by this treatment. If the temperature is less than 40° C., improvement of BH is insufficient. If the temperature exceeds 120° C. or the time exceeds 50 hours, the initial yield strength is excessively increased, whereby formability or paint bake hardenability is decreased.

[0044] Reversion treatment may be performed at a temperature of 170-230° C. for 60 seconds or less within seven days after final additional heat treatment. Paint bake hardenability is further improved by the reversion treatment.

[0045] A sheet material with excellent bendability after the solution heat treatment and quenching can be obtained by applying the above production steps to an aluminum alloy having the above composition. The aluminum alloy sheet is suitably used as a lightweight automotive member having a complicated shape which is subjected to hemming, such as a hood, trunk lid, and door. Moreover, in the case where the aluminum alloy sheet is applied to a fender, roof, and the like, which are not subjected to hemming, the aluminum alloy sheet can be subjected to severe working in which the bending radius is small due to its excellent bendability after pressing the sheet into a complicated shape. Therefore, the aluminum

alloy sheet widens the range of application of aluminum materials to automotive materials, thereby contributing to a decrease in the weight of vehicles.

[0046] In order to securely improve formability, in particular, bendability, it is preferable to adjust the amount of alloy components, such as Si and Mg, and production conditions so that anisotropy of the Lankford values is 0.6 or more and the intensity ratio of cube orientation of the texture is 50 or more.

[0047] The present invention is described below by comparing examples of the present invention with comparative examples. The effects of the present invention will be demonstrated based on this comparison. The examples illustrate only one preferred embodiment of the present invention, which should not be construed as limiting the present invention.

Example 1

[0048] Aluminum alloys having compositions shown in Table 1 were cast by using a DC casting method. The resulting ingots were homogenized at 540° C. for six hours and cooled to room temperature at a cooling rate of 300° C./h. The cooled ingots were heated to a temperature of 400° C., and hot rolling was started at this temperature. The ingots were rolled to a thickness of 4.0 mm, and cold-rolled to a thickness of 1.0 mm.

[0049] The cold-rolled sheets were subjected to a solution heat treatment at 540° C. for five seconds, quenched to a temperature of 120° C. at a cooling rate of 30° C./s, and additionally heat treated at 100° C. for three hours after five minutes.

[0050] The final heat treated sheets were used as test materials. Tensile properties, formability, corrosion resistance, and bake hardenability were evaluated when 10 days passed after the final heat treatment, and the maximum diameter of Mg—Si compounds and the number of compounds having a diameter of 2-10 μm were measured according to the following methods. The tensile properties and a minimum bending radius for formability were also evaluated when four months passed after the final heat treatment. The results are shown in Tables 2 and 3.

[0051] Tensile property: Tensile strength (σ_B), yield strength ($\sigma_{0.2}$), and elongation (δ) were measured by performing a tensile test.

[0052] Formability: An Erichsen test (EV) was performed. A test material having a forming height of less than 10 mm was rejected. A 180° bending test for measuring the minimum bending radius after applying 10% tensile pre-strain was performed in order to evaluate hem workability. A test material having a minimum inner bending radius of 0.5 mm or less was accepted.

[0053] Corrosion resistance: The test material was subjected to a zinc phosphate treatment and electrodeposition coating using commercially available chemical treatment solutions. After painting crosscuts reaching the aluminum base material, a salt spray test was performed for 24 hours according to JIS Z2371. After allowing the test material to stand in a wet atmosphere at 50° C. and 95% for one month, the maximum length of filiform corrosion occurring from the crosscuts was measured. A test material having a maximum length of filiform corrosion of 4 mm or less was accepted.

[0054] Bake hardenability (BH): Yield strength (σ0.2) was measured after applying 2% tensile deformation and performing heat treatment at 170° C. for 20 minutes. A test material having a yield strength of 200 MPa or more was accepted.

[0055] Measurement of Mg—Si compound: The maximum diameter of Mg—Si compounds was measured by observation using an optical microscope. The distribution of compounds having a diameter of 2-10 μm was examined using an image analyzer in the range of 1 square millimeter (1 mm^2) in total provided that one pixel=0.25 μm. The Mg—Si compounds were distinguished from Al—Fe compounds by light and shade of the compounds. The detection conditions were selected at a level at which only the Mg—Si compounds were detected by confirming the compound particles in advance by point analysis.

TABLE 1

Alloy	Composition (mass %)										
	Si	Mg	Cu	Mn	Cr	V	Zr	Fe	Zn	Ti	B
1	1.0	0.5	—	—	—	—	—	0.17	0.02	0.02	5
2	0.8	0.6	0.02	0.08	—	—	—	0.17	0.02	0.02	5
3	1.1	0.5	0.01	0.08	—	—	—	0.17	0.02	0.02	5
4	1.0	0.6	0.7	0.1	—	—	—	0.17	0.02	0.02	5
5	1.2	0.4	0.01	—	0.1	—	—	0.17	0.02	0.02	5
6	1.1	0.5	0.01	0.15	—	0.12	—	0.13	0.04	0.02	5
7	1.1	0.5	0.4	0.07	—	—	0.08	0.15	0.03	0.02	5

Note:
Unit for B is ppm.

TABLE 2

Test material	Alloy	Tensile properties			Formability		Corrosion resistance	BH
		σ_B (MPa)	$\sigma_{0.2}$ (MPa)	δ (%)	EV (mm)	Minimum inner bending radius (mm)	Maximum length of filiform corrosion (mm)	$\sigma_{0.2}$ after BH (MPa)
1	1	242	125	31	10.8	0.1	0	211
2	2	245	131	30	10.4	0.2	1.5	220
3	3	243	127	32	10.6	0.1	0.5	214
4	4	274	134	31	10.5	0.2	3.5	221
5	5	257	135	32	10.6	0.2	1.0	217
6	6	259	132	30	10.2	0.3	1.0	208
7	7	268	136	30	10.3	0.2	2.5	223

TABLE 3

Test material	Alloy	Maximum diameter of Mg—Si compound (μm)	Number of compounds with diameter of 2-10 μm (/mm^2)	Properties after natural aging for 4 months: $\sigma_{0.2}$ (MPa)	Properties after natural aging for 4 months: Minimum inner bending radius (mm)
1	1	6	550	143	0.2
2	2	8	800	147	0.3
3	3	6	650	142	0.2
4	4	9	720	150	0.3
5	5	5	580	152	0.4
6	6	5	520	151	0.4
7	7	6	600	155	0.3

[0056] As shown in Tables 2 and 3, test materials Nos. 1 to 7 according to The present invention showed excellent BH of more than 200 MPa in the BH evaluation. The test materials Nos. 1 to 7 had excellent formability in which the forming height (EV) was more than 10 mm and the minimum inner bending radius was 0.5 mm or less. The test materials Nos. 1 to 7 exhibited excellent corrosion resistance in which the maximum length of filiform corrosion was 4 mm or less.

Comparative Example 1

[0057] Aluminum alloys having compositions shown in Table 4 were cast by using a DC casting method. The resulting ingots were treated by the same steps as in Example 1 to obtain cold-rolled sheets with a thickness of 1 mm. The cold-rolled sheets were subjected to a solution heat treatment and quenching under the same conditions as in Example 1, and heat treatment at 100° C. for three hours after five minutes.

[0058] The final heat treated sheets were used as test materials. Tensile properties, formability, corrosion resistance, and bake hardenability of the test materials were evaluated when 10 days passed after final heat treatment, and the maximum diameter of Mg—Si compounds and the number of compounds having a diameter of 2-10 μm were measured according to the same methods as in Example 1. The tensile properties and the minimum inner bending radius for formability evaluation were also evaluated when four months passed after the final heat treatment. The results are shown in Tables 5 and 6.

TABLE 4

Alloy	Composition (mass %): Si	Mg	Cu	Mn	Cr	V	Zr	Fe	Zn	Ti	B
8	0.3	0.6	0.01	0.05	0.01	—	—	0.2	0.03	0.02	5
9	1.9	0.6	0.01	0.05	0.01	—	—	0.2	0.03	0.02	5
10	1.1	0.1	0.01	0.05	0.01	—	—	0.2	0.03	0.02	5
11	1.1	1.4	0.01	0.05	0.01	—	—	0.2	0.03	0.02	5
12	1.1	0.5	1.5	0.05	0.01	—	—	0.2	0.03	0.02	5
13	1.1	0.5	0.02	0.5	0.01	—	—	0.2	0.03	0.02	5
14	1.1	0.5	0.02	0.02	0.4	—	—	0.2	0.03	0.02	5
15	1.1	0.5	0.02	0.02	0.01	0.4	—	0.2	0.03	0.02	5
16	1.1	0.5	0.02	0.02	0.01	—	0.3	0.2	0.03	0.02	5

Note:
Unit for B is ppm.

TABLE 5

Test material	Alloy	Tensile properties: σ_B (MPa)	Tensile properties: $\sigma_{0.2}$ (MPa)	Tensile properties: δ (%)	Formability: EV (mm)	Formability: Minimum inner bending radius (mm)	Corrosion resistance: Maximum length of filiform corrosion (mm)	BH: $\sigma_{0.2}$ after BH (MPa)
8	8	163	70	30	10.7	0	0.5	125
9	9	265	139	31	10.5	0.5	1.0	224
10	10	157	65	32	10.8	0	1.5	118
11	11	280	141	29	10.2	0.6	1.0	229
12	12	294	132	30	10.6	0.4	5.0	228
13	13	247	130	28	9.7	0.6	1.0	217
14	14	246	128	29	9.6	0.4	1.0	214
15	15	247	129	28	9.8	0.5	1.0	212
16	16	245	132	27	9.5	0.7	1.5	213

TABLE 6

Test material	Alloy	Maximum diameter of Mg—Si compound (μm)	Number of compounds with diameter of 2-10 μm (/mm^2)	Properties after natural aging for 4 months: $\sigma_{0.2}$ (MPa)	Properties after natural aging for 4 months: Minimum inner bending radius (mm)
8	8	4	300	85	0
9	9	15	1350	158	0.7
10	10	3	260	79	0
11	11	18	2430	159	0.7
12	12	9	880	154	0.5
13	13	12	1250	146	0.7
14	14	8	940	143	0.5
15	15	12	1120	146	0.6
16	16	14	1290	148	0.7

[0059] As shown in Tables 5 and 6, test material No. 8 and test material No. 10 showed insufficient BH due to low Si content and low Mg content, respectively. Test material No. 9 and test material No. 11 had insufficient bendability due to high Si content and high Mg content, respectively. Test material No. 12 had inferior filiform corrosion resistance due to high Cu content. Test materials Nos. 13 to 16 had a small forming height (EV) due to high Mn content, high Cr content, high V content, and high Zr content, respectively. Moreover, these test materials showed insufficient bendability.

Example 2 and Comparative Example 2

[0060] Ingots of the alloys Nos. 1 and 3 of Example 1 were homogenized at 540° C. for eight hours. The ingots were cooled to the hot rolling temperature after homogenization, and hot rolling was started at the temperatures shown in Table 7. The thickness of hot-rolled products was 4.5 mm. The hot-rolled products were cold-rolled to a thickness of 1 mm, subjected to a solution heat treatment under the conditions shown in Table 7, quenched to 120° C. at a cooling rate of 15° C./s, and additional heat treatment at 90° C. for five hours after 10 minutes. In Example 2 and Comparative Example 2, the ingots were cooled to the hot rolling temperature after homogenization, and hot rolling was performed at this temperature.

[0061] The final heat treated sheets were used as test materials. Tensile properties, formability, corrosion resistance, and bake hardenability of the test materials evaluated when 10 days passed after final heat treatment, and the maximum diameter of Mg—Si compounds and the number of compounds having a diameter of 2-10 μm were measured according to the same methods as in Example 1. The tensile properties and the minimum bending radius for formability evaluation were also evaluated when four months passed after the final heat treatment. Electrodeposition coating was performed after applying 10% tensile deformation in the direction at 900 to the rolling direction. The presence or absence of ridging marks was evaluated with the naked eye. The results are shown in Tables 8 and 9.

TABLE 7

Test material	Alloy	Cooling rate after homogenization (° C./h)	Hot rolling start temperature (° C.)	Solution heat treatment condition (° C.)-(sec)
17	1	150	370	550-3
18	1	800	450	520-5
19	3	200	400	530-7
20	3	600	440	550-5
21	3	2000	470	560-3
22	1	30	420	550-3
23	1	70	400	550-3
24	1	200	550	520-7
25	3	150	410	450-3
26	3	20	450	520-5

TABLE 8

Test material	Alloy	Tensile properties: σ_B (MPa)	Tensile properties: $\sigma_{0.2}$ (MPa)	Tensile properties: δ (%)	Formability: EV (mm)	Formability: Minimum inner bending radius (mm)	Formability: Occurrence of ridging mark	Corrosion resistance Maximum length of filiform corrosion (mm)	BH $\sigma_{0.2}$ after BH (MPa)
17	1	243	123	30	10.7	0.1	None	1.0	210
18	1	248	126	31	10.6	0	None	1.5	218
19	3	244	125	31	10.5	0	None	0.5	215
20	3	249	127	30	10.4	0	None	0.5	216
21	3	252	129	31	10.5	0.1	None	0.5	215
22	1	195	80	30	10.8	0	None	1.0	180
23	1	207	92	30	10.7	0	None	1.0	188

TABLE 8-continued

Test material	Alloy	Tensile properties σ_B (MPa)	$\sigma_{0.2}$ (MPa)	δ (%)	Formability EV (mm)	Minimum inner bending radius (mm)	Occurrence of ridging mark	Corrosion resistance Maximum length of filiform corrosion (mm)	BH $\sigma_{0.2}$ after BH (MPa)
24	1	245	127	31	10.5	0.2	Observed	0.5	220
25	3	201	92	32	10.5	0	None	2.0	162
26	3	210	105	31	10.7	0	None	1.5	185

TABLE 9

Test material	Alloy	Maximum diameter of Mg—Si compound (μm)	Number of compounds with diameter of 2-10 μm (/mm^2)	Properties after natural aging for 4 months $\sigma_{0.2}$ (MPa)	Minimum inner bending radius (mm)
17	1	8	470	141	0.2
18	1	7	630	143	0.1
19	3	6	570	142	0
20	3	6	660	142	0.1
21	3	6	750	142	0.1
22	1	22	1800	97	0
23	1	17	1520	108	0
24	1	8	1360	146	0.3
25	3	15	2520	106	0
26	3	26	2400	127	0

[0062] As shown in Tables 8 and 9, test materials Nos. 17 to 21 according to the present invention showed excellent tensile strength, BH, formability, and corrosion resistance, and maintained excellent bendability after natural aging for four months. Test materials Nos. 22, 23, and 26 had low tensile strength since the cooling rate after homogenization was low. Moreover, these test materials showed insufficient BH. Ridging marks occurred in test material No. 24 due to grain growth during hot rolling since the hot rolling temperature was high. Test material No. 25 had a low tensile strength and inferior BH due to a low solution heat treatment temperature.

Example 3 and Comparative Example 3

[0063] Aluminum alloys having compositions shown in Table 10 were cast by using a DC casting method. The resulting ingots were homogenized at 540° C. for six hours and cooled to room temperature at a cooling rate of 300° C./h. The ingots were then heated to a temperature of 400° C. Hot rolling was started at this temperature. The ingots were hot-rolled to a thickness of 4.0 mm, and cold-rolled to a thickness of 1.0 mm.

[0064] The cold-rolled sheets were subjected to a solution heat treatment at 540° C. for five seconds, quenched to a temperature of 120° C. at a cooling rate of 30° C./s, and additionally heat treated at 90° C. for three hours after five minutes.

[0065] The final heat treated sheets were used as test materials. Tensile properties, formability, corrosion resistance, and bake hardenability of the test materials were evaluated when 10 days passed after final heat treatment, and the maximum diameter of Mg—Si compounds and the number of compounds having a diameter of 2-10 μm were measured according to the same methods as in Example 1. The tensile properties and the minimum bending radius for formability evaluation were also evaluated when four months passed after the final heat treatment. The results are shown in Tables 11 and 12.

TABLE 10

Alloy	Composition (mass %) Si	Mg	Zn	Cu	Mn	Cr	V	Zr	Fe	Ti	B
17	1.0	0.5	0.18	—	—	—	—	—	0.17	0.02	5
18	0.9	0.6	0.28	—	—	—	—	—	0.17	0.02	5
19	1.1	0.45	0.2	0.01	0.01	—	—	—	0.14	0.02	5
20	1.0	0.5	0.15	0.03	0.04	0.1	—	—	0.15	0.02	5
21	1.1	0.6	0.2	0.02	0.03	—	0.1	—	0.17	0.02	5
22	1.2	0.7	0.25	0.01	0.05	0.2	—	0.08	0.14	0.02	5
23	0.3	0.6	0.2	0.02	0.08	—	—	—	0.16	0.02	5
24	1.6	0.6	0.2	0.02	0.07	—	—	—	0.16	0.02	5
25	1.1	0.1	0.2	0.01	0.15	—	—	—	0.16	0.02	5
26	1.1	1.4	0.2	0.01	0.08	—	—	—	0.16	0.02	5
27	1.1	0.5	0.04	0.02	—	—	—	—	0.16	0.02	5
28	1.1	0.5	0.6	0.01	0.1	0.1	—	—	0.16	0.02	5
29	1.1	0.5	0.2	0.02	0.07	—	—	—	0.5	0.02	5

Note:
Unit for B is ppm.

TABLE 11

		Tensile properties			Formability		Corrosion resistance	BH
Test material	Alloy	σ_B (MPa)	$\sigma_{0.2}$ (MPa)	δ (%)	EV (mm)	Minimum inner bending radius (mm)	Maximum length of filiform corrosion (mm)	$\sigma_{0.2}$ after BH (MPa)
27	17	243	124	30	10.8	0	0.5	208
28	18	247	126	30	10.6	0.1	1.5	210
29	19	246	128	31	10.8	0	1.0	213
30	20	247	125	31	10.6	0	1.5	209
31	21	249	127	30	10.6	0.1	1.5	211
32	22	251	129	29	10.5	0.2	1.5	214
33	23	186	75	31	10.8	0	0	149
34	24	254	137	30	10.9	0.3	1.0	216
35	25	182	77	32	11	0	1	172
36	26	280	142	29	10.2	0.6	1.0	229
37	27	245	128	30	10.4	0	2.0	215
38	28	247	132	29	10.6	0	3.0	218
39	29	252	134	28	9.4	0.4	1.5	221

TABLE 12

			Number of	Properties after natural aging for 4 months	
Test material	Alloy	Maximum diameter of Mg—Si compound (μm)	compounds with diameter of 2-10 μm (/mm^2)	$\sigma_{0.2}$ (MPa)	Minimum inner bending radius (mm)
27	17	8	560	142	0.1
28	18	9	820	144	0.2
29	19	7	540	145	0.1
30	20	8	810	145	0.1
31	21	8	820	144	0.1
32	22	9	830	146	0.2
33	23	6	380	93	0
34	24	12	890	156	0.5
35	25	5	250	94	0
36	26	18	2430	158	0.7
37	27	8	710	144	0.1
38	28	7	860	150	0.2
39	29	8	1140	150	0.5

[0066] As shown in Tables 11 and 12, test materials Nos. 27 to 32 according to the present invention showed excellent BH of more than 200 MPa in the BH evaluation. The test materials Nos. 27 to 32 had excellent formability in which the forming height (EV) was more than 10 mm and the minimum inner bending radius was 0.2 mm or less. The test materials Nos. 27 to 32 exhibited excellent corrosion resistance in which the maximum length of filiform corrosion was 2 mm or less.

[0067] On the contrary, test material No. 33 and test material No. 35 showed insufficient BH due to low Si content and low Mg content, respectively. Test material No. 34 and test material No. 36 exhibited insufficient bendability due to high Si content and high Mg content, respectively. Test materials Nos. 37 and 38 exhibited inferior filiform corrosion resistance due to low Zn content and high Zn content, respectively. Test material No. 39 had a small forming height (EV) due to high Fe content. Moreover, the test material No. 39 showed insufficient bendability.

Example 4 and Comparative Example 4

[0068] Ingots of the alloy No. 17 of Example 3 were homogenized at 540° C. for five hours. The ingots were cooled and hot-rolled to a thickness of 5.0 mm under conditions shown in Table 13. The hot-rolled products were cold-rolled to a thickness of 1.0 mm, subjected to a solution heat treatment under conditions shown in Table 13, quenched to 120° C. at a cooling rate of 150° C./s, and additionally heat treated at 80° C. for two hours after five minutes. In Example 4 and Comparative Example 4, the ingots were cooled to the hot rolling temperature after homogenization, and hot rolling was started at this temperature.

[0069] The final heat treated sheets were used as test materials. Tensile properties, formability, corrosion resistance, and bake hardenability of the test materials were evaluated when 10 days passed after final heat treatment, and the maximum diameter of Mg—Si compounds and the number of compounds having a diameter of 2-10 μm were measured according to the same methods as in Example 1. The tensile properties and the minimum bending radius for formability evaluation were also evaluated when four months passed after the final heat treatment. Electrodeposition coating was performed after applying 10% tensile deformation in the direction at 900 to the rolling direction. The presence or absence of

ridging marks was evaluated with the naked eye. The results are shown in Tables 14 and 15.

TABLE 13

Test material	Alloy	Cooling rate after homogenization (° C./h)	Hot rolling start temperature (° C.)	Solution heat treatment condition (° C.)-(sec)
40	17	300	400	550-5
41	17	200	470	530-10
42	17	600	440	540-10
43	17	40	450	550-5
44	17	300	540	520-10
45	17	250	420	450-10

ing ingots were homogenized at 540° C. for six hours and cooled to room temperature at a cooling rate of 300° C./h. The ingots were heated to a temperature of 400° C., and hot rolling was started at this temperature. The ingots were hot-rolled to a thickness of 4.0 mm, and cold-rolled to a thickness of 1.0 mm.

[0072] The cold-rolled sheets were subjected to a solution heat treatment at 540° C. for five seconds, quenched to a temperature of 120° C. at a cooling rate of 30° C./s, and additionally heat treated at 100° C. for three hours after five minutes.

[0073] The final heat treated sheets were used as test materials. Tensile properties, formability, corrosion resistance, and bake hardenability of the test materials were evaluated according to the same methods as in Example 1 when 10 days

TABLE 14

		Tensile properties			Formability			Corrosion resistance	BH
						Inner minimum bending		Maximum length	$\sigma_{0.2}$ after
Test material	Alloy	σ_B (MPa)	$\sigma_{0.2}$ (MPa)	δ (%)	EV (mm)	radius (mm)	Occurrence of ridging mark	of filiform corrosion (mm)	BH (MPa)
40	17	245	125	30	10.7	0	None	0.5	207
41	17	240	124	31	10.8	0	None	1.0	208
42	17	247	128	30	10.7	0	None	1.0	207
43	17	205	97	30	10.8	0	None	1.0	175
44	17	248	129	31	10.5	0.1	Observed	0.5	209
45	17	195	84	31	11.0	0	None	0.5	162

TABLE 15

			Number of	Properties after natural aging for 4 months	
Test material	Alloy	Maximum diameter of Mg—Si compound (μm)	compounds with diameter of 2-10 μm (/mm^2)	$\sigma_{0.2}$ (MPa)	Minimum inner bending radius (mm)
40	17	7	620	141	0.1
41	17	8	750	140	0.1
42	17	7	580	144	0.1
43	17	15	1360	111	0
44	17	7	1550	146	0.2
45	17	18	2420	97	0

[0070] As shown in Tables 14 and 15, test materials Nos. 40 to 42 according to the present invention showed excellent tensile strength, BH, formability, and corrosion resistance, and maintained excellent bendability after natural aging for four months. Test material No. 43 had a low tensile strength and insufficient BH since the cooling rate after homogenization was low. Ridging marks occurred in test material No. 44 due to texture growth during hot rolling, since the hot rolling temperature was high. Test material No. 45 had a low tensile strength and inferior BH due to a low solution treatment temperature.

Example 5

[0071] Aluminum alloys having compositions shown in Table 16 were cast by using a DC casting method. The result-

passed after final heat treatment. In addition, misorientation distributions of crystal grain boundaries were measured according to the following method. The results are shown in Table 17.

[0074] Measurement of misorientation distribution of crystal grain boundaries: The surface of the test material was ground using emery paper and mirror-ground by electrolytic grinding. The test material was set in a scanning electron microscope (SEM). The tilt angle distributions of the crystal grain boundaries were measured by measuring the crystal grain orientation at a pitch of 10 □m using an EBSP device installed in the SEM at an observation magnification of 100 times to calculate the percentage of crystal grain boundaries at 150 or less.

TABLE 16

Alloy	Composition (mass %)										
	Si	Mg	Cu	Mn	Cr	V	Zr	Fe	Zn	Ti	B
30	1.0	0.5	—	0.05	—	—	—	0.13	0.01	0.02	5
31	0.8	0.6	0.02	0.08	—	—	—	0.15	0.01	0.03	7
32	1.2	0.4	0.01	0.08	—	—	—	0.16	0.02	0.02	6
33	1.1	0.5	0.01	0.08	—	—	—	0.19	0.28	0.02	4
34	1.0	0.5	0.7	0.10	—	—	—	0.16	0.02	0.03	5
35	1.1	0.4	0.01	0.05	0.10	—	—	0.17	0.02	0.03	6
36	1.1	0.5	0.01	0.15	—	0.13	—	0.13	0.04	0.02	5
37	1.1	0.5	0.5	0.07	—	—	0.08	0.15	0.03	0.02	4

Note:
Unit for B is ppm.

TABLE 17

Test material	Alloy	Percentage of crystal grain boundaries at 15° or less (%)	Tensile properties			Formability		Corrosion resistance	BH
			σ_B (MPa)	$\sigma_{0.2}$ (MPa)	δ (%)	EV (mm)	Minimum inner bending radius (mm)	Maximum length of filiform corrosion (mm)	$\sigma_{0.2}$ after BH (MPa)
46	30	38	242	125	32	10.5	0.1	0	213
47	31	35	247	134	31	10.2	0.2	1.3	222
48	32	42	242	125	32	10.7	0.1	0.4	213
49	33	41	242	126	30	10.5	0.1	0	216
50	34	36	278	139	30	10.4	0.1	3.2	225
51	35	43	261	136	32	10.5	0.2	1.2	218
52	36	46	258	129	29	10.4	0.2	1.1	210
53	37	42	265	135	30	10.5	0.2	2.7	222

[0075] As shown in Table 17, test materials Nos. 46 to 53 according to the conditions of the present invention showed excellent BH of more than 200 MPa in the BH evaluation. The test materials Nos. 46 to 53 had excellent formability in which the forming height (EV) was more than 10 mm and the minimum inner bending radius was 0.2 mm or less. The test materials Nos. 46 to 53 exhibited excellent corrosion resistance in which the maximum length of filiform corrosion was 4 mm or less.

Comparative Example 5

[0076] Aluminum alloys having compositions shown in Table 18 were cast by using a DC casting method. The resulting ingots were treated by the same steps as in Example 5 to obtain cold-rolled sheets with a thickness of 1.0 mm. The cold-rolled sheets were subjected to a solution heat treatment and quenched under the same conditions as in Example 1. The quenched products were additionally heat treated at 100° C. for three hours after five minutes.

[0077] The final heat treated sheets were used as test materials. Tensile properties, formability, corrosion resistance, and bake hardenability of the test materials were evaluated when 10 days passed after final heat treatment, and misorientation distributions of crystal grain boundaries were measured according to the same methods as in Example 5. The results are shown in Table 19.

TABLE 18

Alloy	Composition (mass %)										
	Si	Mg	Cu	Mn	Cr	V	Zr	Fe	Zn	Ti	B
38	0.3	0.5	0.02	0.06	0.01	—	—	0.15	0.02	0.03	5
39	1.7	0.5	0.02	0.05	0.01	—	—	0.14	0.03	0.02	6
40	1.0	0.1	0.02	0.04	0.01	—	—	0.17	0.02	0.03	4
41	1.1	1.5	0.02	0.05	0.01	—	—	0.16	0.03	0.03	5
42	1.0	0.5	0.02	0.06	0.01	—	—	0.13	0.6	0.02	4
43	1.1	0.6	1.3	0.05	0.01	—	—	0.15	0.03	0.02	6
44	1.0	0.5	0.01	0.5	0.01	—	—	0.17	0.03	0.03	4
45	1.0	0.5	0.01	0.06	0.4	—	—	0.16	0.02	0.02	5
46	1.1	0.6	0.01	0.05	0.01	0.4	—	0.14	0.02	0.03	4
47	1.1	0.6	0.01	0.06	0.01	—	0.23	0.16	0.03	0.02	5
48	1.0	0.6	0.02	0.02	0.01	—	—	0.14	0.02	0.03	5

Note:
Unit for B is ppm.

TABLE 19

Test material	Alloy	Percentage of crystal grain boundaries at 15° or less (%)	Tensile properties σ_B (MPa)	Tensile properties $\sigma_{0.2}$ (MPa)	Tensile properties δ (%)	Formability EV (mm)	Formability Minimum inner bending radius (mm)	Corrosion resistance Maximum length of filiform corrosion (mm)	BH $\sigma_{0.2}$ after BH (MPa)
54	38	27	161	68	29	10.8	0	0.4	123
55	39	42	268	142	31	10.6	0.6	1.1	226
56	40	31	160	68	32	10.7	0	1.6	119
57	41	39	279	140	30	10.2	0.7	1.1	228
58	42	41	248	125	31	10.6	0.2	6.8	220
59	43	35	291	129	29	10.5	0.4	5.5	226
60	44	46	245	128	27	9.5	0.7	0.9	215
61	45	51	244	126	29	9.6	0.8	1.1	213
62	46	48	251	131	28	9.8	0.8	1.0	214
63	47	43	244	130	27	9.5	0.7	1.3	214
64	48	17	243	124	30	10.3	0.8	0.4	210

[0078] As shown in Table 19, test material No. 54 and test material No. 56 exhibited insufficient BH due to low Si content and low Mg content, respectively. Test material No. 55 and test material No. 57 exhibited insufficient bendability due to high Si content and high Mg content, respectively. Test material No. 58 and test material No. 59 showed inferior filiform corrosion resistance due to high Zn content and high Cu content, respectively. Test materials Nos. 60 to 63 had a small forming height (EV) and insufficient bendability due to high Mn content, high Cr content, high V content, and high Zr content, respectively. Test material No. 64 exhibited insufficient bendability since the percentage of crystal grain boundaries in which misorientation of adjacent crystal grains was 15° or less was less than 20% due to low Mn content.

Example 6

[0079] Ingots of the alloy No. 30 shown in Table 16 used in Example 5 were subjected to homogenization, hot rolling, cold rolling, solution heat treatment, additional heat treatment, and reversion treatment under conditions shown in Table 20 to obtain test materials Nos. 65 to 71. In this example, the ingots were cooled to the hot rolling temperature after homogenization, and hot rolling was started at this temperature. Moreover, the homogenization time was six hours, the thickness of the hot-rolled sheet was 4.0 mm, the thickness of the cold-rolled sheet was 1.0 mm, and the period of time between quenching and additional heat treatment was five minutes. The test material No. 65 was subjected to the reversion treatment at 200° C. for three seconds after the additional heat treatment. The reversion treatment was performed when one day was passed after the additional heat treatment.

[0080] Tensile properties, formability, corrosion resistance, and bake hardenability of the test materials were evaluated when 10 days passed after final heat treatment, and misorientation distributions of crystal grain boundaries were measured according to the same methods as in Example 5. The results are shown in Table 21. Electrodeposition coating was performed after applying 10% tensile deformation in the direction at 90° to the rolling direction. The presence or absence of ridging marks was evaluated with the naked eye. As a result, occurrence of ridging marks was not observed at all.

TABLE 20

Test material	Alloy	Homogenization Temp. (° C.)	Homogenization Cooling rate after homogenization (° C./h)	Hot rolling Start temperature (° C.)	Solution heat treatment Temp. (° C.)	Solution heat treatment Time (s)	Solution heat treatment Cooling rate (° C./s)	Additional heat treatment Temp. (° C.)	Additional heat treatment Time (h)
65	30	540	300	400	550	5	30	100	3
66	30	520	300	400	550	5	30	100	3
67	30	540	200	400	550	5	30	100	3
68	30	540	300	450	550	5	30	100	3
69	30	540	300	400	520	30	30	100	3
70	30	540	300	400	550	5	10	100	3
71	30	540	300	400	550	10	30	60	5

TABLE 21

Test material	Alloy	Percentage of crystal grain boundaries at 15° or less (%)	Tensile properties σ_B (MPa)	Tensile properties $\sigma_{0.2}$ (MPa)	Tensile properties δ (%)	Formability EV (mm)	Formability Minimum inner bending radius (mm)	Corrosion resistance Maximum length of filiform corrosion (mm)	BH $\sigma_{0.2}$ after BH (MPa)
65	30	41	237	122	31	10.8	0.1	0.3	226
66	30	47	238	117	30	10.4	0.3	0.6	206
67	30	24	241	124	31	10.7	0.3	0.5	206
68	30	27	245	126	31	10.9	0	0.2	215
69	30	48	235	118	31	10.6	0	0.4	207
70	30	37	239	122	31	10.7	0.2	0.6	208
71	30	35	245	126	31	10.7	0.1	0.2	204

[0081] As shown in Table 21, the test materials Nos. 65 to 71 according to The present invention showed excellent tensile strength, BH, formability, and corrosion resistance. Moreover, occurrence of ridging marks was not observed at all.

Comparative Example 6

[0082] Ingots of the alloy No. 30 shown in Table 16 used in Example 5 were subjected to homogenization, hot rolling, cold rolling, solution heat treatment, additional heat treatment, and reversion treatment under conditions shown in Table 22 to obtain test materials Nos. 72 to 80. In this example, the ingots were cooled to the hot rolling temperature after homogenization, and hot rolling was started at this temperature. Moreover, the homogenization time was six hours, the thickness of the hot-rolled sheet was 4.0 mm, the thickness of the cold-rolled sheet was 1.0 mm, and the period of time between quenching and additional heat treatment was five minutes. The test material No. 80 was subjected to the reversion treatment at 300° C. for 30 seconds. The reversion treatment was performed when one day passed after the additional heat treatment.

[0083] Tensile properties, formability, corrosion resistance, and bake hardenability of the test materials were evaluated when 10 days passed after final heat treatment, and misorientation distributions of crystal grain boundaries were measured according to the same methods as in Example 5. The results are shown in Table 23. Electrodeposition coating was performed after applying 10% tensile deformation in the direction at 900 to the rolling direction. The presence or absence of ridging marks was evaluated with the naked eye. As a result, occurrence of ridging marks was observed in the test material No. 74.

TABLE 22

Test material	Alloy	Homogenization Temp. (° C.)	Homogenization Cooling rate after homogenization (° C./h)	Hot rolling Start temperature (° C.)	Solution heat treatment Temp. (° C.)	Solution heat treatment Time (s)	Solution heat treatment Cooling rate (° C./s)	Additional heat treatment Temp. (° C.)	Additional heat treatment Time (h)
72	30	450	300	400	550	5	30	100	3
73	30	540	100	400	560	10	30	100	3
74	30	540	50	400	560	20	30	100	3
75	30	540	300	500	550	5	30	100	3
76	30	540	300	400	470	10	30	100	3
77	30	540	300	400	550	5	1	100	3
78	30	540	300	400	550	5	30	—	—
79	30	540	300	400	550	5	30	140	72
80	30	540	300	400	550	5	30	100	3

TABLE 23

Test material	Alloy	Percentage of crystal grain boundaries at 15° or less (%)	Tensile properties σ_B (MPa)	Tensile properties $\sigma_{0.2}$ (MPa)	Tensile properties δ (%)	Formability EV (mm)	Formability Minimum inner bending radius (mm)	Corrosion resistance Maximum length of filiform corrosion (mm)	BH $\sigma_{0.2}$ after BH (MPa)
72	30	18	215	102	30	9.3	0.8	1.3	172
73	30	15	225	110	31	10.3	0.7	0.7	195
74	30	11	221	107	31	10.4	0.8	0.8	191
75	30	16	243	127	32	10.6	0.7	0.4	218
76	30	43	209	96	27	9.4	0	1.2	164
77	30	35	213	99	28	9.4	0.7	6.2	183
78	30	32	241	124	31	10.8	0.1	0.3	175
79	30	38	281	165	29	9.6	0.4	0.4	228
80	30	36	181	82	30	9.8	0.2	0.2	153

[0084] As shown in Table 23, the test material No. 72 had low EV and insufficient bendability due to a low homogenization temperature. Moreover, the test material No. 72 showed inferior BH. The test materials Nos. 73 and 74 showed insufficient bendability and inferior BH due to a low cooling rate after homogenization. Ridging marks occurred in the test material No. 75 due to inferior bendability since the hot rolling start temperature was high. The test material No. 76 had low strength and low EV due to a low solution treatment temperature. Moreover, the test material No. 76 had low BH. The test material No. 77 showed insufficient EV, bendability, and corrosion resistance due to a low quenching rate after the solution heat treatment. Moreover, the test material No. 77 showed insufficient strength and BH. The test material No. 78 had low BH since additional heat treatment was not performed. The test material No. 79 had low EV since the additional heat treatment was performed at a high temperature for a long period of time. The test material No. 80 had low strength and low BH since the reversion treatment temperature was high. Moreover, the test material No. 80 had low EV.

Example 7

[0085] Aluminum alloys having compositions shown in Table 24 were cast by using a DC casting method. The resulting ingots were homogenized at 550° C. for six hours and cooled to 200° C. at a cooling rate of 600° C./h. The ingots were cooled to room temperature, heated to 420° C., and hot-rolled to a thickness of 4.5 mm. The hot rolling finish temperature was 250° C.

[0086] The hot-rolled products were cold-rolled to a thickness of 1.0 mm. The cold-rolled sheets were subjected to a solution heat treatment at 540° C. for 20 seconds and quenched to 120° C. at a cooling rate of 30° C./s. The quenched sheets were additionally heat treated at 100° C. for three hours after three minutes.

[0087] Tensile performance, anisotropy of Lankford values, bake hardenability (BH), and bendability of the aluminum alloy sheets were evaluated according to the following methods when 10 days passed after the final heat treatment. The results are shown in Table 25.

[0088] Tensile performance: Tensile specimens were collected in three directions (at 0°, 45°, and 90° to the rolling direction), and subjected to a tensile test to determine average values of tensile strength, yield strength, and elongation as the tensile performance.

[0089] Anisotropy of Lankford values: Tensile specimens were collected in three directions (at 0°, 45°, and 90° to the rolling direction), and subjected to a tensile test to determine the Lankford values r at 15% deformation, and to calculate anisotropy of the Lankford values.

[0090] Bake hardenability (BH): Yield strength was measured after applying 2% tensile deformation in the rolling direction and performing heat treatment at 170° C. for 20 minutes. A test material having a yield strength of 200 MPa or more was accepted.

[0091] Bendability: A 180° bending test for measuring the minimum bending radius was performed after applying 15% tensile prestrain. A test material having a minimum inner bending radius of 0.1 mm or less was accepted.

TABLE 24

Alloy	Composition (wt %) Si	Mg	Zn	Cu	Mn	Cr	V	Zr	Fe	Ti	B
49	1.0	0.65	—	—	—	—	—	—	0.25	0.03	10
50	1.0	0.48	—	0.02	0.09	—	—	—	0.17	0.02	5
51	0.91	0.53	0.18	0.01	0.1	—	—	—	0.18	0.02	5
52	1.0	0.4	0.02	0.72	0.1	—	—	—	0.18	0.02	5
53	1.6	0.34	—	—	—	0.05	—	—	0.18	0.02	5
54	1.1	0.54	0.02	—	0.05	—	0.08	—	0.13	0.01	7
55	0.8	1.1	0.01	0.02	0.07	—	—	0.08	0.15	0.02	5

Note:
Unit for B is ppm.

TABLE 25

Test material	Alloy	Tensile performance: Tensile strength (MPa)	Tensile performance: Yield strength (MPa)	Tensile performance: Elongation (%)	Yield strength after BH (MPa)	Anisotropy of Lankford values r	Minimum inner bending radius (mm)
81	49	246	132	30	212	0.66	0.0
82	50	237	122	31	206	0.73	0.0
83	51	241	130	30	210	0.70	0.0
84	52	266	127	31	220	0.45	0.1
85	53	252	141	31	223	0.62	0.1
86	54	239	132	30	219	0.66	0.0
87	55	254	138	29	226	0.57	0.1

[0092] As shown in Table 25, test materials Nos. 81 to 87 according to the present invention excelled in strength and BH, had anisotropy of the Lankford values of more than 0.4, and showed excellent minimum bending properties. Bendability after natural aging for four months was evaluated. As a result, the test materials of all the alloys had a minimum bending radius of 0.0-0.1.

Comparative Example 7

[0093] Aluminum alloys having compositions shown in Table 26 were cast by using a DC casting method. The resulting ingots were treated by the same steps as in Example 7. Tensile performance, anisotropy of Lankford values, bake hardenability (BH), and bendability of the aluminum alloy sheets were evaluated according to the same methods as in Example 7 when 10 days passed after the final heat treatment. The results are shown in Table 27.

TABLE 26

Alloy	Composition (wt %): Si	Mg	Zn	Cu	Mn	Cr	V	Zr	Fe	Ti	B
56	0.34	0.6	—	0.01	0.06	0.01	—	—	0.2	0.02	5
57	2.4	0.5	—	0.01	0.06	—	—	—	0.18	0.02	5
58	1.1	0.14	—	0.01	—	0.05	—	—	0.15	0.02	5
59	0.7	1.4	0.1	0.01	—	0.05	—	—	0.15	0.02	5
60	1.7	1.3	—	0.01	0.06	—	—	—	0.18	0.02	5
61	1.1	0.48	—	1.5	—	—	—	0.1	0.18	0.02	5

TABLE 26-continued

Alloy	Composition (wt %): Si	Mg	Zn	Cu	Mn	Cr	V	Zr	Fe	Ti	B
62	1.1	0.53	—	0.02	1.2	—	—	—	0.15	0.02	5
63	1.1	0.53	—	0.03	—	0.4	—	—	0.17	0.02	5
64	1.1	0.45	—	0.02	—	0.01	0.4	—	0.22	0.02	5
65	1.1	0.61	—	0.01	—	—	—	0.3	0.14	0.02	5

Note:
Unit for B is ppm.

TABLE 27

Test material	Alloy	Tensile performance: Tensile strength (MPa)	Tensile performance: Yield strength (MPa)	Tensile performance: Elongation (%)	Yield strength after BH (MPa)	Anisotropy of Lankford values r	Minimum inner bending radius (mm)
88	56	152	83	29	123	0.62	0.0
89	57	263	148	31	231	0.34	0.6
90	58	162	85	30	132	0.62	0.0
91	59	249	138	29	194	0.26	0.6
92	60	270	154	28	230	0.31	0.6
93	61	283	147	30	243	0.38	0.7
94	62	253	141	29	227	0.26	0.6
95	63	242	133	28	218	0.32	0.5
96	64	239	135	29	217	0.22	0.6
97	65	242	141	28	220	0.15	0.7

[0094] As shown in Table 27, test material No. 88 and test material No. 90 exhibited low strength and insufficient BH due to low Si content and low Mg content, respectively. Test material No. 89 had high strength due to high Si content, whereby anisotropy of Lankford values was decreased and bendability was insufficient. Test material No. 91 had a small anisotropy of Lankford values since the value for (Si %-0.58Mg %) was smaller than 0.1%, whereby minimum bendability was insufficient.

[0095] Test material No. 92 had a small anisotropy of Lankford values since (0.7Si %+Mg %) exceeded 2.2%, whereby bendability was insufficient. Test materials No. 93 to 97 had a small anisotropy of Lankford values due to high Cu content, high Mn content, high Cr content, high V content, and high Zr content, respectively, whereby bendability was insufficient.

Example 8 and Comparative Example 8

[0096] The alloy No. 50 shown in Table 24 was cast by using a DC casting method. The resulting ingots were homogenized at 540° C. for 10 hours and cooled to 250° C. at cooling rates shown in Table 28. The ingots were then cooled to room temperature. The ingots were heated to the temperatures shown in Table 28 and hot-rolled to a thickness of 4.2 mm. The hot rolling finish temperature was 280° C. The hot-rolled products were cold-rolled to obtain sheets with a thickness of 1.0 mm. Only test material No. 107 was cold-rolled to a thickness of 3.0 mm and subjected to process annealing at 450° C. for 30 seconds.

[0097] The cold-rolled sheets were subjected to a solution heat treatment at 550° C. for 10 seconds and quenched to 120° C. at a cooling rate of 30° C./s. The quenched sheets were additionally heat treated at 100° C. for three hours after three minutes. Tensile performance, anisotropy of Lankford values, BH, and bendability of the aluminum alloy sheets obtained by these steps were evaluated according to the same methods as in Example 7.

[0098] For the evaluation of ridging marks, tensile specimens were collected in the direction at 90° to the rolling direction and subjected to 10% tensile deformation and electrodeposition coating. The presence or absence of ridging marks was then evaluated.

[0099] The results are shown in Table 29.

TABLE 28

Condition	Cooling rate after homogenization (° C./h)	Hot rolling start temperature (° C.)
a	550	420
b	200	400
c	3000	430
d	480	480
e	480	360
f	380	550
g	3000	530
h	50	400
i	30	520
j	550	420

[0100] As shown in Table 29, test materials Nos. 98 to 102 according to The present invention excelled in strength and BH, had an anisotropy of Lankford values of more than 0.4, and showed excellent minimum bending properties.

[0101] On the contrary, ridging marks occurred in test materials Nos. 103 and 104 due to a high hot rolling temperature. Test material No. 105 had a small anisotropy of Lankford values due to a low cooling rate after homogenization, whereby bendability was insufficient. Ridging marks occurred in test material No. 106 due to a high hot rolling temperature and a low cooling rate after homogenization. Moreover, the test material No. 106 had a small anisotropy of Lankford values, whereby bendability was insufficient. Test material No. 107 had a small anisotropy of Lankford values since process annealing was performed, whereby bendability was insufficient.

Example 9

[0102] The alloy No. 50 shown in Table 24 was cast by using a DC casting method. The resulting ingots were homogenized at 550° C. for eight hours and cooled to 200° C. at a cooling rate of 500° C./h. The ingots were cooled to room temperature, heated to 400° C., and hot-rolled to a thickness of 4.2 mm. The hot rolling finish temperature was 260° C.

[0103] The hot-rolled products were cold-rolled to obtain sheets with a thickness of 1.0 mm. The cold-rolled sheets were subjected to a solution heat treatment at 550° C. for four seconds and quenched to 120° C. at a cooling rate of 40° C./s. The quenched sheets were additionally heat treated at 100° C. for two hours after two minutes.

[0104] The aluminum alloy sheets obtained by these steps were subjected to measurements of tensile strength, yield strength, elongation, Lankford value r, yield strength after BH, and minimum bending radius in the directions at 0°, 45°, and 90° to the rolling direction by using the same methods as in Example 7 when seven days passed after the final heat treatment. Anisotropy of Lankford values r was calculated and the presence or absence of ridging marks was evaluated. The results are shown in Table 30. As shown in Table 30, excellent properties were obtained in all the directions.

TABLE 29

		Tensile performance			Yield		Minimum	
Test material	Condition	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	strength after BH (MPa)	Anisotropy of Lankford values r	inner bending radius (mm)	Occurrence of ridging mark
98	a	230	121	30	210	0.55	0.0	None
99	b	218	118	31	207	0.62	0.0	None
100	c	234	132	30	226	0.58	0.1	None
101	d	241	130	31	230	0.51	0.1	None
102	e	225	123	32	219	0.67	0.0	None
103	f	236	127	31	227	0.45	0.3	Observed
104	g	238	131	29	222	0.33	0.3	Observed
105	h	212	107	31	193	0.25	0.5	None
106	i	231	125	30	214	0.18	0.6	Observed
107	j	224	118	29	204	0.1	0.4	None

TABLE 30

Angle to rolling direction	Tensile performance: Tensile strength (MPa)	Yield (MPa)	Elongation (%)	Yield strength after BH (MPa)	n value	r value	Anisotropy of Lankford values r	Minimum inner bending radius (mm)	Occurrence of ridging mark
0°	241	128	23	227	0.26	0.66	0.61	0.0	None
45°	225	112	37	205	0.29	0.18		0.0	None
90°	234	122	30	221	0.27	0.92		0.0	None

Example 10

[0105] Aluminum alloys having compositions shown in Table 31 were cast by using a DC casting method. The resulting ingots were homogenized at 550° C. for six hours and cooled to 200° C. at a cooling rate of 450° C./h. The ingots were then cooled to room temperature, heated to 420° C., and hot-rolled to a thickness of 4.5 mm. The hot rolling finish temperature was 250° C.

[0106] The hot-rolled products were cold-rolled to obtain sheets with a thickness of 1.0 mm. The cold-rolled sheets were subjected to a solution heat treatment at 540° C. for 20 seconds and quenched to 120° C. at a cooling rate of 30° C./s. The sheets were additionally heat treated at 100° C. for three hours after three minutes.

[0107] The aluminum alloy sheets were subjected to a tensile test when 10 days passed after the final heat treatment. Bake hardenability (BH), intensity ratio (random ratio) of cube orientation, and bendability were evaluated according to the following methods. The results are shown in Table 32.

[0108] Intensity ratio of cube orientation: The intensity ratio of cube orientation was calculated by a series expansion method proposed by Bunge using an ODF analysis device in which the expansion order of even-numbered terms was 22 and the expansion order of odd-numbered terms was 19.

[0109] Bake hardenability (BH): Yield strength was measured after applying 2% tensile deformation and performing heat treatment at 170° C. for 20 minutes. A test material having a yield strength of 200 MPa or more was accepted.

[0110] Bendability: A 180° bending test for measuring the minimum bending radius was performed after applying 15% tensile prestrain. A test material having a minimum inner bending radius of 0.2 mm or less was accepted.

TABLE 31

Alloy	Composition (wt %): Si	Mg	Zn	Cu	Mn	Cr	V	Zr	Fe	Ti	B
66	1.0	0.62	—	—	—	—	—	—	0.24	0.03	10
67	1.0	0.46	—	0.01	0.08	—	—	—	0.16	0.02	5
68	0.94	0.53	0.18	0.01	0.10	—	—	—	0.15	0.02	5
69	1.0	0.42	0.04	0.75	0.10	—	—	—	0.15	0.02	5
70	1.6	0.36	—	—	—	0.06	—	—	0.15	0.02	5
71	1.1	0.54	0.02	—	0.05	—	0.09	—	0.12	0.01	7
72	0.9	1.1	0.01	0.02	0.07	—	—	0.07	0.14	0.02	5

Note:

Unit for B is ppm.

TABLE 32

Test material	Alloy	Tensile performance: Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Yield strength after BH (MPa)	Intensity ratio of cube orientation	Minimum inner bending radius (mm)
108	66	244	130	31	208	63	0.1
109	67	238	123	31	207	82	0.0
110	68	239	128	31	212	57	0.1
111	69	263	125	30	222	38	0.2
112	70	252	147	31	226	44	0.2
113	71	241	134	30	221	78	0.1
114	72	253	136	30	228	27	0.2

[0111] As shown in Table 32, test materials Nos. 108 to 114 according to the present invention excelled in strength and BH, had an intensity ratio of cube orientation of more than 20, and showed excellent minimum bending properties. Bendability after natural aging for four months was measured. As a result, the test materials of all the alloys had a minimum bending radius of 0.4 or less although the yield strength exceeded 160 MPa.

Comparative Example 9

[0112] Aluminum alloys having compositions shown in Table 33 were cast by using a DC casting method. The resulting ingots were treated by the same steps as in Example 10. Tensile performance, bake hardenability (BH), intensity ratio of cube orientation, and bendability of the aluminum alloy sheets were evaluated according to the same methods as in Example 10 when 10 days passed after the final heat treatment. The results are shown in Table 34.

TABLE 33

	Composition (wt %)										
Alloy	Si	Mg	Zn	Cu	Mn	Cr	V	Zr	Fe	Ti	B
73	0.37	0.62	—	0.01	0.06	0.01	—	—	0.22	0.02	5
74	2.4	0.61	—	0.01	0.06	—	—	—	0.17	0.02	5
75	1.1	0.13	—	0.01	—	0.05	—	—	0.14	0.02	5
76	0.7	1.8	0.1	0.01	—	0.05	—	—	0.14	0.02	5
77	1.7	0.46	—	1.5	—	—	—	0.12	0.17	0.02	5
78	1.1	0.55	—	0.02	1.3	—	—	—	0.14	0.02	5
79	1.1	0.54	—	0.03	—	0.4	—	—	0.17	0.02	5
80	1.1	0.47	—	0.02	—	0.01	0.4	—	0.24	0.02	5
81	1.1	0.63	—	0.01	—	—	—	0.3	0.13	0.02	5

Note:
Unit for B is ppm.

TABLE 34

		Tensile performance			Yield	Intensity	
Test material	Alloy	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	strength after BH (MPa)	ratio of cube orientation	Minimum inner bending radius (mm)
115	73	148	79	30	119	51	0.0
116	74	261	147	31	228	16	0.6
117	75	155	75	29	127	66	0.0
118	76	270	149	29	283	14	0.6
119	77	281	145	29	244	8	0.7
120	78	251	140	29	228	14	0.6
121	79	243	132	27	220	15	0.6
122	80	236	133	29	218	12	0.6
123	81	238	139	29	222	17	0.7

[0113] As shown in Table 34, test material No. 115 and test material No. 117 had low strength and insufficient BH due to low Si content and low Mg content, respectively. Test material No. 116 and test material No. 118 showed high strength since (0.7Si %+Mg %) exceeded 2.2% due to high Si content and high Mg content, respectively. As a result, the degree of integration of cube orientation was decreased, whereby bendability was insufficient.

[0114] The degree of integration of cube orientation was decreased in test materials Nos. 119 to 123 due to high Cu content, high Mn content, high Cr content, high V content, and high Zr content, respectively, whereby bendability was insufficient.

Example 11 and Comparative Example 10

[0115] The alloy No. 67 shown in Table 31 was cast by using a DC casting method. The resulting ingots were homogenized at 550° C. for five hours and cooled to 250° C. at a cooling rate shown in Table 35. The ingots were heated to a temperature shown in Table 35 and hot-rolled to a thickness of 4.4 mm. The hot rolling finish temperature was 250° C. The hot-rolled products were cold-rolled to obtain sheets with a thickness of 1.0 mm. Annealing process was performed at 400° C. for two hours after hot rolling under a condition "t".

[0116] The sheets were subjected to a solution heat treatment at 550° C. for five seconds and quenched to 120° C. at a cooling rate of 30° C./s. The quenched sheets were additionally heat treated at 100° C. for three hours after three minutes. Tensile performance, BH, intensity ratio of cube orientation, and bendability of the aluminum alloy sheets obtained by these steps were evaluated according to the same methods as in Example 10.

[0117] For the evaluation of ridging marks, tensile specimens were collected in the direction at 900 to the rolling direction and subjected to 10% tensile deformation and electrodeposition coating. The presence or absence of ridging marks was then evaluated.

[0118] The results are shown in Table 36.

TABLE 35

Condition	Cooling rate after homogenization (° C./h)	Hot rolling start temperature (° C.)
k	550	420
l	200	430
m	3500	410
n	500	470
o	450	350
p	360	540
q	2000	520
r	50	410
s	25	530
t	500	420

TABLE 36

		Tensile performance			Yield			
Test material	Condition	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	strength after BH (MPa)	Intensity ratio of cube orientation	Minimum inner bending radius (mm)	Occurrence of ridging mark
124	k	232	122	29	213	77	0.0	None
125	l	224	120	31	206	85	0.0	None
126	m	232	131	30	227	73	0.1	None
127	n	241	131	31	232	70	0.1	None
128	o	225	123	31	220	83	0.0	None
129	p	235	126	30	224	35	0.3	Observed
130	q	230	126	28	218	28	0.3	Observed
131	r	214	109	30	190	11	0.5	None
132	s	233	123	30	213	7	0.6	Observed
133	t	226	118	30	208	15	0.4	None

[0119] As shown in Table 36, test materials Nos. 124 to 128 according to the present invention excelled in strength and BH, had an intensity ratio of cube orientation of more than 20, and showed excellent minimum bending properties.

[0120] On the contrary, ridging marks occurred in test materials Nos. 129 and 130 due to a high hot rolling temperature. Test material No. 131 had a small degree of integration of cube orientation due to a low cooling rate after homogenization, whereby bendability was insufficient. Ridging marks occurred in test material No. 132 due to a high hot rolling temperature and a low cooling rate after homogenization. Moreover, the test material No. 132 had a small degree of integration of cube orientation, whereby bendability was insufficient. Test material No. 133 had a small degree of integration of cube orientation since process annealing was performed, whereby bendability was insufficient.

INDUSTRIAL APPLICABILITY

[0121] According to The present invention, an aluminum alloy sheet having excellent bendability which allows flat hemming, excellent bake hardenability, and excellent corrosion resistance, and a method for producing the same can be provided. The aluminum alloy sheet is suitably used as a lightweight automotive member having a complicated shape which is subjected to hemming, such as an automotive hood, trunk lid, and door.

What is claimed is:

1. A method for producing an aluminum alloy sheet with excellent bendability and paint bake hardenability, said aluminum alloy sheet having an intensity ratio of cube orientation of crystal graphic texture of 20 or more and being made from an aluminum alloy comprising 0.5-2.0 mass % of Si, 0.2-1.5 mass % of Mg, with the relationship 0.7 Si mass %+Mg mass %≦2.2% being satisfied, and the balance consisting of Al and impurities, the method comprising homogenizing an ingot of the aluminum alloy at a temperature of 450° C. or more, cooling the ingot to a specific temperature of less than 350° C. at a cooling rate of 100° C./h or more, hot-rolling the ingot at the specific temperature to form a hot-rolled product, cold-rolling the hot-rolled product to form a cold-rolled product, subjecting the cold-rolled product to a solution heat treatment at a temperature of 450° C. or more, and quenching.

2. A method for producing an aluminum alloy sheet with excellent bendability and paint bake hardenability, said aluminum alloy sheet having an intensity ratio of cube orientation of crystal graphic texture of 20 or more and being made from an aluminum alloy comprising 0.5-2.0 mass % of Si, 0.2-1.5 mass % of Mg, with the relationship 0.7 Si mass %+Mg mass %≦2.2% being satisfied, and the balance consisting of Al and impurities, the method comprising homogenizing an ingot of the aluminum alloy at a temperature of 450° C. or more, cooling the ingot to a temperature of less than 350° C. at a cooling rate of 100° C./h or more, heating the ingot to a temperature of 300-500° C. and starting hot-rolling of the ingot to form a hot-rolled product, cold-rolling the hot-rolled product to form a cold-rolled product, subjecting the cold-rolled product to a solution heat treatment at a temperature of 450° C. or more, and quenching.

3. A method for producing an aluminum alloy sheet with excellent bendability and paint bake hardenability, said aluminum alloy sheet having an intensity ratio of cube orientation of crystal graphic texture of 20 or more and being made from an aluminum alloy comprising 0.5-2.0 mass % of Si, 0.2-1.5 mass % of Mg, with the relationship 0.7 Si mass %+Mg mass %≦2.2% being satisfied, and the balance consisting of Al and impurities, the method comprising homogenizing an ingot of the aluminum alloy at a temperature of 450° C. or more, cooling the ingot to a temperature of less than 350° C. at a cooling rate of 100° C./h or more, cooling the ingot to room temperature, heating the ingot to a temperature of 300-500° C. and starting hot-rolling of the ingot to form a hot-rolled product, cold-rolling the hot-rolled product to form

a cold-rolled product, subjecting the cold-rolled product to a solution heat treatment at a temperature of 450° C. or more, and quenching.

4. The method for producing the aluminum alloy sheet according to claim **1**, wherein the hot-rolling is finished at a temperature of 300° C. or less.

5. The method for producing the aluminum alloy sheet according to claim **1**, comprising quenching the solution-treated product to 120° C. at a cooling rate of 5° C./s or more, and subjecting the quenched product to a heat treatment at a temperature of 40-120° C. for 50 hours or less within 60 minutes after the quenching.

6. The method for producing the aluminum alloy sheet according to claim **5**, comprising subjecting the heat-treated product to a reversion treatment at a temperature of 170-230° C. for 60 seconds or less within seven days after the heat treatment.

7. The method for producing the aluminum alloy sheet according to claim **2**, wherein the hot rolling is finished at a temperature of 300° C. or less.

8. The method for producing the aluminum alloy sheet according to claim **2**, comprising quenching the solution-treated product to 120° C. at a cooling rate of 5° C./s or more, and subjecting the quenched product to a heat treatment at a temperature of 40-120° C. for 50 hours or less within 60 minutes after the quenching.

9. The method for producing the aluminum alloy sheet according to claim **8**, comprising subjecting the heat-treated product to a reversion treatment at a temperature of 170-230° C. for 60 seconds or less within seven days after the heat treatment.

10. The method for producing the aluminum alloy sheet according to claim **3**, wherein the hot rolling is finished at a temperature of 300° C. or less.

11. The method for producing the aluminum alloy sheet according to claim **3**, comprising quenching the solution-treated product to 120° C. at a cooling rate of 5° C./s or more, and subjecting the quenched product to a heat treatment at a temperature of 40-120° C. for 50 hours or less within 60 minutes after the quenching.

12. The method for producing the aluminum alloy sheet according to claim **11**, comprising subjecting the heat-treated product to a reversion treatment at a temperature of 170-230° C. for 60 seconds or less within seven days after the heat treatment.

13. The method for producing the aluminum alloy sheet according to claim **1**, wherein the aluminum alloy further comprises at least one of up to 0.5 mass % of Zn, up to 1.0 mass % of Cu, up to 1.0 mass % of Mn, up to 0.3 mass % of Cr, up to 0.2 mass % of V, up to 0.2 mass % of Zr, up to 0.1 mass % of Ti and up to 50 ppm of B.

14. The method for producing the aluminum alloy sheet according to claim **4**, wherein the aluminum alloy further comprises at least one of up to 0.5 mass % of Zn, up to 1.0 mass % of Cu, up to 1.0 mass % of Mn, up to 0.3 mass % of Cr, up to 0.2 mass % of V, up to 0.2 mass % of Zr, up to 0.1 mass % of Ti and up to 50 ppm of B.

15. The method for producing the aluminum alloy sheet according to claim **5**, wherein the aluminum alloy further comprises at least one of up to 0.5 mass % of Zn, up to 1.0 mass % of Cu, up to 1.0 mass % of Mn, up to 0.3 mass % of Cr, up to 0.2 mass % of V, up to 0.2 mass % of Zr, up to 0.1 mass % of Ti and up to 50 ppm of B.

16. The method for producing the aluminum alloy sheet according to claim **6**, wherein the aluminum alloy further comprises at least one of up to 0.5 mass % of Zn, up to 1.0 mass % of Cu, up to 1.0 mass % of Mn, up to 0.3 mass % of Cr, up to 0.2 mass % of V, up to 0.2 mass % of Zr, up to 0.1 mass % of Ti and up to 50 ppm of B.

17. The method for producing the aluminum alloy sheet according to claim **2**, wherein the aluminum alloy further comprises at least one of up to 0.5 mass % of Zn, up to 1.0 mass % of Cu, up to 1.0 mass % of Mn, up to 0.3 mass % of Cr, up to 0.2 mass % of V, up to 0.2 mass % of Zr, up to 0.1 mass % of Ti and up to 50 ppm of B.

18. The method for producing the aluminum alloy sheet according to claim **7**, wherein the aluminum alloy further comprises at least one of up to 0.5 mass % of Zn, up to 1.0 mass % of Cu, up to 1.0 mass % of Mn, up to 0.3 mass % of Cr, up to 0.2 mass % of V, up to 0.2 mass % of Zr, up to 0.1 mass % of Ti and up to 50 ppm of B.

19. The method for producing the aluminum alloy sheet according to claim **8**, wherein the aluminum alloy further comprises at least one of up to 0.5 mass % of Zn, up to 1.0 mass % of Cu, up to 1.0 mass % of Mn, up to 0.3 mass % of Cr, up to 0.2 mass % of V, up to 0.2 mass % of Zr, up to 0.1 mass % of Ti and up to 50 ppm of B.

20. The method for producing the aluminum alloy sheet according to claim **9**, wherein the aluminum alloy further comprises at least one of up to 0.5 mass % of Zn, up to 1.0 mass % of Cu, up to 1.0 mass % of Mn, up to 0.3 mass % of Cr, up to 0.2 mass % of V, up to 0.2 mass % of Zr, up to 0.1 mass % of Ti and up to 50 ppm of B.

21. The method for producing the aluminum alloy sheet according to claim **3**, wherein the aluminum alloy further comprises at least one of up to 0.5 mass % of Zn, up to 1.0 mass % of Cu, up to 1.0 mass % of Mn, up to 0.3 mass % of Cr, up to 0.2 mass % of V, up to 0.2 mass % of Zr, up to 0.1 mass % of Ti and up to 50 ppm of B.

22. The method for producing the aluminum alloy sheet according to claim **10**, wherein the aluminum alloy further comprises at least one of up to 0.5 mass % of Zn, up to 1.0 mass % of Cu, up to 1.0 mass % of Mn, up to 0.3 mass % of Cr, up to 0.2 mass % of V, up to 0.2 mass % of Zr, up to 0.1 mass % of Ti and up to 50 ppm of B.

23. The method for producing the aluminum alloy sheet according to claim **11**, wherein the aluminum alloy further comprises at least one of up to 0.5 mass % of Zn, up to 1.0 mass % of Cu, up to 1.0 mass % of Mn, up to 0.3 mass % of Cr, up to 0.2 mass % of V, up to 0.2 mass % of Zr, up to 0.1 mass % of Ti and up to 50 ppm of B.

24. The method for producing the aluminum alloy sheet according to claim **12**, wherein the aluminum alloy further comprises at least one of up to 0.5 mass % of Zn, up to 1.0 mass % of Cu, up to 1.0 mass % of Mn, up to 0.3 mass % of Cr, up to 0.2 mass % of V, up to 0.2 mass % of Zr, up to 0.1 mass % of Ti and up to 50 ppm of B.

* * * * *