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(19) **United States**(12) **Patent Application Publication**  
**HASHIMOTO et al.**(10) **Pub. No.: US 2017/0121801 A1**(43) **Pub. Date: May 4, 2017**(54) **ALUMINUM ALLOY SHEET FOR VEHICLE  
STRUCTURAL COMPONENT AND METHOD  
OF MANUFACTURING THE ALUMINUM  
ALLOY SHEET**(71) Applicant: **Kabushiki Kaisha Kobe Seiko Sho  
(Kobe Steel, Ltd.)**, Kobe-shi (JP)(72) Inventors: **Takahiro HASHIMOTO**, Moka-shi  
(JP); **Takahiko NAKAMURA**,  
Moka-shi (JP); **Yasuo TAKAKI**,  
Moka-shi (JP)(73) Assignee: **Kabushiki Kaisha Kobe Seiko Sho  
(Kobe Steel, Ltd.)**, Kobe-shi (JP)(21) Appl. No.: **15/336,322**(22) Filed: **Oct. 27, 2016**(30) **Foreign Application Priority Data**

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**ABSTRACT**

Provided is a 6000-series aluminum alloy sheet suitable for a vehicle structural component. The Mg content and the Si content of an Al—Mg—Si aluminum alloy sheet are balanced in a special relationship, particularly cube orientation is increased as a texture in a surface region of the sheet, and the yield ratio of the sheet is reduced, thereby high strength of 0.2% proof stress of 220 MPa or more required for the vehicle structural component is ensured, and crashworthiness evaluated by a VDA bending test is improved.

FIG. 1

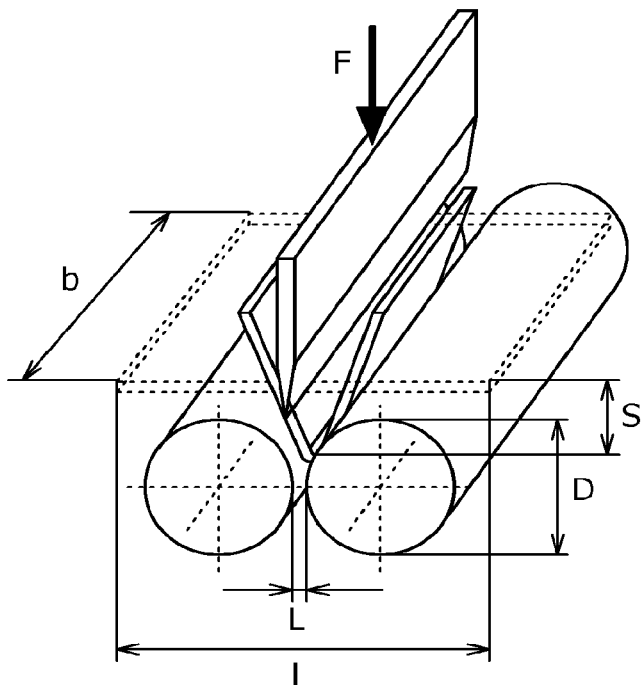
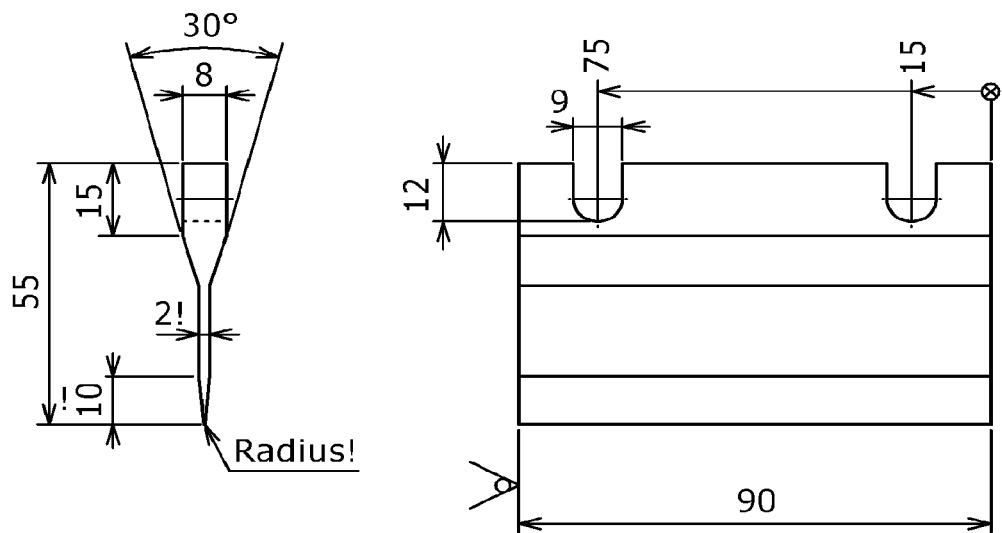


FIG. 2



# ALUMINUM ALLOY SHEET FOR VEHICLE STRUCTURAL COMPONENT AND METHOD OF MANUFACTURING THE ALUMINUM ALLOY SHEET

## BACKGROUND

[0001] The present invention relates to a 6000-series aluminum alloy sheet for a vehicle structural component, which is manufactured by common rolling (common method) and has high strength and good crashworthiness, and a method of manufacturing the aluminum alloy sheet.

[0002] The aluminum alloy sheet described in the present invention refers to a material aluminum alloy sheet including a rolled sheet such as a hot-rolled sheet or a cold-rolled sheet, which has been subjected to tempering such as solution treatment and quenching, but has not been formed into a vehicle structural component to be used and has not been subjected to artificial aging such as paint-bake hardening. Hereinafter, aluminum may be referred to as Al.

[0003] Recently, a social demand for weight saving of a vehicle body has increased more and more out of consideration for the global environment. To meet such a demand, aluminum alloy materials are used in place of previous steel materials such as steel sheets for some parts of a vehicle body, such as panels (outer panels such as a hood, a door, and a roof, and inner panels), and reinforcements such as a bumper reinforcement (bumper R/F) and a door beam.

[0004] For further weight reduction of the vehicle body, the aluminum alloy materials are necessary to be extensively used for vehicle components, particularly vehicle structural components that contribute to weight saving, such as members including a side member, frames, and pillars. However, compared with the vehicle panel materials, such vehicle structural components are necessary to be further increased in strength of a material sheet and have an additional property, i.e., crashworthiness, which leads to shock absorption or passenger protection at vehicle collision.

[0005] In this regard, an extrusion, which is manufactured by hot extruding of JIS or AA 7000-series aluminum alloy, has been generally used as a material for the reinforcement in the vehicle structural components. On the other hand, the large vehicle structural components such as the member, the frame, and the pillar are each preferably formed of a rolled sheet as a material, which is produced by hot rolling or hot rolling followed by cold rolling of a homogenized slab. However, the 7000-series aluminum alloy has not been actively put to practical use in a form of a rolled sheet because of its high strength and low formability.

[0006] Hence, JIS or AA 6000-series aluminum alloy, which is Al—Mg—Si aluminum alloy having lower strength and better formability than the 7000-series aluminum alloy, attracts attention as alloy for a rolled sheet manufactured by common rolling (common method).

[0007] The 6000-series aluminum alloy extrusion has been provided and practically used as the reinforcement, but has been rarely provided as a rolled sheet.

[0008] Japanese Unexamined Patent Application Publication No. JP2001-294965 barely describes a 6000-series aluminum alloy sheet having improved crashworthiness, which has a sheet microstructure controlled in size and aspect ratio of a grain and has a proof stress of 230 MPa or more after artificial aging.

[0009] On the other hand, the 6000-series aluminum alloy sheet is already used for the large body panels (outer panels such as a hood, a fender, a door, a roof, and a trunk lid, and inner panels) of a vehicle.

[0010] Hence, many metallurgical remedies including a composition, a microstructure, and a texture have been provided in order to combine or improve press formability and bake hardenability (BH) required for such large body panels of a vehicle.

[0011] For example, Japanese Patent No. 5148930 describes a material as the panel material, in which the intensity of cube orientation is increased to 20 or more in order to improve bendability in flat hemming or the like during press forming.

## SUMMARY

[0012] However, the existing 6000-series aluminum alloy sheet, in which an intensity or an average area ratio of cube orientation is increased, is a material for the vehicle panels.

[0013] On the other hand, unlike such vehicle panel applications, the vehicle structural components such as the members, the frames, and the pillars, to which the present invention is intended to be applied, are required to have properties specific to such applications as described above, such as increased strength, crashworthiness as an additional property, press formability, and corrosion resistance.

[0014] For example, in Europe, along with recent raising the level (tightening) of the collision safety standards of vehicles, the vehicle structural components such as the frames and the pillars are required to satisfy the crashworthiness evaluated by “VDA238-100 Plate bending test for metallic materials (hereinafter, referred to as VDA bending test)” standardized by German Association of the Automotive Industry (Verband der Automobilindustrie (VDA)).

[0015] However, unclear is whether it is effective in improving crashworthiness to increase the intensity or the area ratio of cube orientation in the sheet surface in order to improve bendability of the existing 6000-series aluminum alloy sheet for the vehicle panels during press forming.

[0016] In Japanese Unexamined Patent Application Publication No. JP2001-294965 that aims to improve crashworthiness, crashworthiness is evaluated based on whether a crack occurs after a 180° bending test. The VDA bending test as an evaluation test of crashworthiness of a sheet is known to correlate with the crashworthiness at vehicle collision. The VDA bending test that allows superiority of the crashworthiness to be represented by a bending angle is a quantitative evaluation test, and appropriately represents the crashworthiness.

[0017] In light of such a circumstance, an object of the present invention is to allow a 6000-series aluminum alloy sheet manufactured by common rolling to have properties specific to the vehicle structural component application, such as increased strength, crashworthiness as an additional property, press formability, and corrosion resistance.

[0018] To achieve the object, an aluminum alloy sheet for a vehicle structural component having good crashworthiness of the present invention is summarized by an Al—Mg—Si aluminum alloy sheet that contains, by mass percent, Mg: 0.3 to 1.0%, Si: 0.5 to 1.2%, and Cu: 0.08 to 0.20%, the content [Mg] of Mg and the content [Si] of Si satisfying a relationship  $[Si]/[Mg] \geq 0.7$  and a relationship  $1.4\% \leq 1.3[Mg] + [Si] \leq 1.9\%$ , the remainder consisting of Al and inevitable impurities, and has a thickness of 2.0 mm or more, in

which an average area ratio of cube orientation is 22% or more in a surface region from a surface of the sheet to a depth of 10% in the thickness direction, an yield ratio of the sheet is 0.63 or less, and when the aluminum alloy sheet is stretched by 2% and then subjected to artificial aging for 20 min at 180° C., the aluminum alloy sheet has properties including 0.2% proof stress of 220 MPa or more and crashworthiness showing a bending angle of 60° or more at a VDA bending test.

[0019] Furthermore, to achieve the object, a method of manufacturing an aluminum alloy sheet for a vehicle structural component having good crashworthiness of the present invention is summarized in that an Al—Mg—Si aluminum alloy slab, which contains, by mass percent, Mg: 0.3 to 1.0%, Si: 0.5 to 1.2%, and Cu: 0.08 to 0.20%, the content [Mg] of Mg and the content [Si] of Si satisfying a relationship  $[Si]/[Mg] \geq 0.7$  and a relationship  $1.4\% \leq 1.3 [Mg] + [Si] \leq 1.9\%$ , the remainder consisting of Al and inevitable impurities, is subjected to homogenization and then rolled into a rolled sheet having a thickness of 2.0 mm or more, the rolled sheet is subjected to solution treatment in which the rolled sheet is held for 0.1 to 30 sec within a range from 540 to 570° C., and is successively subjected to quenching, and is reheated within 10 min after finish of the quenching in such a manner that the rolled sheet is held for 3 to 20 hr within a material temperature range from 60 to 90° C. so as to be formed into an aluminum alloy sheet for a vehicle structural component, and the aluminum alloy sheet has a microstructure and properties, the microstructure including an average area ratio of cube orientation of 22% or more in a surface region from a surface of the sheet to a depth of 10% in the thickness direction, the properties including a yield ratio of 0.63 or less, and including 0.2% proof stress of 220 MPa or more and crashworthiness showing a bending angle of 60° or more at a VDA bending test when the aluminum alloy sheet is stretched by 2% and then subjected to artificial aging for 20 min at 180° C.

[0020] In the present invention, the alloy composition of the 6000-series aluminum alloy sheet is reviewed in light of a relationship between the content balance between Mg and Si or the texture and the properties specific to the applications of the vehicle structural component.

[0021] As a result, it has been found that while the aluminum alloy sheet has increased strength and crashworthiness as an additional property by balancing the content between Mg and Si and increasing the area ratio of cube orientation, the alloy sheet can have the properties specific to that applications, such as press formability and corrosion resistance. According to the present invention, the 6000-series aluminum alloy sheet suitable for the vehicle structural components can be provided.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIG. 1 is a perspective view illustrating an aspect of a VDA bending test that evaluates crashworthiness.

[0023] FIG. 2 includes front and side views of a punch in FIG. 1.

#### DETAILED DESCRIPTION

[0024] Hereinafter, an embodiment of the present invention is specifically described for each of requirements.

[0025] As a prerequisite, the Al—Mg—Si (hereinafter, also referred to as 6000-series) aluminum alloy sheet of the

present invention is used for the vehicle structural components rather than the vehicle panel materials as in the previous case.

[0026] Hence, such vehicle structural components (hereinafter, may be simply described as structural components) are required to satisfactorily have properties that are not provided in the existing vehicle panel materials, including good crashworthiness, a low yield ratio that allows the aluminum alloy sheet to be formed into a complicated shape, high post-baking proof stress, and high grain-boundary corrosion resistance. If any one of such properties is lacked, the aluminum alloy sheet cannot be used as the structural component.

[0027] More specifically, the properties required for the structural component can be defined to include press formability with a yield ratio of 0.63 or less, and include properties including BH showing 0.2% proof stress of 220 MPa or more and crashworthiness showing a bending angle of 60° or more at the VDA bending test when the aluminum alloy sheet is stretched by 2% and then subjected to artificial aging for 20 min at 180° C.

[0028] More preferably, the aluminum alloy sheet has the average area ratio of cube orientation of 35% or more, and crashworthiness showing a bending angle of 90° or more at the VDA bending test.

[0029] Hence, the requirements of the present invention described below are on the aluminum alloy sheet for the structural components, the meanings of which are to satisfactorily provide the specifically required properties.

#### Chemical (Alloy) Composition:

[0030] In the present invention, to satisfy the properties required for the structural components in terms of a composition, the Al—Mg—Si (hereinafter, also referred to as 6000-series) aluminum alloy sheet has a composition including, by mass percent, Mg: 0.3 to 1.0%, Si: 0.5 to 1.2%, and Cu: 0.08 to 0.20%, the content [Mg] of Mg and the content [Si] of Si satisfying a relationship  $[Si]/[Mg] \geq 0.7$  and a relationship  $1.4\% \leq 1.3 [Mg] + [Si] \leq 1.9\%$ , the remainder consisting of Al and inevitable impurities.

[0031] The content range and the meaning or the tolerance of each element of the 6000-series aluminum alloy sheet are now described. The percentage representing the content of each element refers to mass percent.

Mg: 0.3 to 1.0%

[0032] Mg forms a compound phase such as  $Mg_2Si$  with Si during artificial aging such as paint-bake cycle, and increases strength through precipitation of the compound phase. An excessively small content of Mg, less than 0.3%, does not ensure sufficient strength.

[0033] If the Mg content exceeds 1.0%, the compound phase such as  $Mg_2Si$  is crystallized or precipitated as a coarse particle during casting or solution treatment, and acts as an origin of a small crack. This promotes the destruction and thus increases the yield ratio, leading to deterioration of press formability. Consequently, the Mg content is 0.3 to 1.0%.

Si: 0.5 to 1.2%

[0034] Si also forms the compound phase such as  $Mg_2Si$  with Mg during artificial aging such as paint-bake cycle, and increases strength through precipitation of the compound phase.

**[0035]** An excessively small content of Si, less than 0.5%, does not ensure sufficient strength.

**[0036]** If the Si content exceeds 1.2%, the compound phase such as  $Mg_2Si$  is crystallized or precipitated as a coarse particle during casting or solution treatment, and acts as an origin of a small crack. This promotes the destruction and thus increases the yield ratio, leading to deterioration of press formability. Consequently, the Si content is 0.5 to 1.2%.

Content [Mg] of Mg and Content [Si] of Si

**[0037]** The Mg content and the Si content [Si] are importantly balanced to improve press formability and crashworthiness in terms of the composition in addition to the content of each element.

**[0038]** In this regard, the content [Mg] of Mg and the content [Si] of Si are adjusted to satisfy a relationship  $[Si]/[Mg] \geq 0.7$  and a relationship  $1.4\% \leq 1.3 [Mg] + [Si] \leq 1.9\%$ .

$[Si]/[Mg] \geq 0.7$

**[0039]** A larger Si content or a smaller Mg content improves work hardenability through solid-solution strengthening caused by solid solution of Si into a matrix, and thus decreases the yield ratio, leading to improvement in press formability.

**[0040]** If  $[Si]/[Mg]$  is less than 0.7, sufficient work hardenability is not ensured, and the yield ratio is increased, leading to deterioration of press formability.

**[0041]** Consequently,  $[Si]/[Mg]$  is 0.7 or more. If  $[Si]/[Mg]$  is 1.8 or more, the yield ratio is further decreased, and press formability is further improved. Hence,  $[Si]/[Mg]$  is preferably 1.8 or more.

$1.4\% \leq 1.3 [Mg] + [Si] \leq 1.9\%$

**[0042]** Si and Mg form a  $\beta''$  phase as a reinforcement phase after bake hard (artificial aging), and increases strength through precipitation of such a compound phase.

**[0043]** However, if Mg or Si is excessively contained, the compound phase such as  $Mg_2Si$  is crystallized or precipitated as a coarse particle during casting or solution treatment, and acts as an origin of a small crack, which greatly deteriorates crashworthiness. Such a crystallized or precipitated state depends on the content of each of Si and Mg.

**[0044]** If  $1.3 [Mg] + [Si]$  is less than 1.4%, sufficient BH characteristics (post-baking proof stress) are not ensured.

**[0045]** If  $1.3 [Mg] + [Si]$  exceeds 1.9%, the compound phase is crystallized or precipitated as a coarse particle during casting or quenching, which extremely deteriorates crashworthiness.

**[0046]** Consequently,  $1.3 [Mg]$  (which means  $1.3 \times Mg$  content) +  $[Si]$  (which means Si content) is within a range from 1.4 to 1.9%, preferably 1.6 to 1.9%.

Cu: 0.08 to 0.20%

**[0047]** Cu is solid-solutionized in a matrix and improves work hardenability through solid-solution strengthening, and thus decreases the yield ratio, leading to improvement in press formability.

**[0048]** However, if the Cu content is excessive, more than 0.20%, a PFZ (precipitate free zone) of Cu is formed in the vicinity of a grain boundary along with age precipitation, and the zone, which is potentially baser than the inside of a

grain, is selectively dissolved in a corrosion environment, leading to deterioration of grain-boundary corrosion resistance.

**[0049]** If the Cu content is less than 0.08%, sufficient work hardenability is not provided, and thus the yield ratio is not decreased, leading to deterioration of press formability.

**[0050]** Consequently, the Cu content is within a range from 0.08 to 0.20%.

Other Elements

**[0051]** Other elements are essentially impurities in the present invention. The following upper limit is given as a tolerance for each element when the element is contaminated from a melting material for a slab, such as a scrap. The upper limit includes 0%.

**[0052]** Mn: 1.0% or less, Fe: 0.5% or less, Cr: 0.3% or less, Zr: 0.2% or less, V: 0.2% or less, Ti: 0.1% or less, Zn: 0.5% or less, Ag: 0.1% or less, and Sn: 0.15% or less.

BH (Bake Hardenability, Artificial Aging Hardenability):

**[0053]** In order to ensure strength and stiffness necessary for the vehicle structural component, BH is defined after the aluminum alloy sheet is stretched by 2% and then subjected to artificial aging (hereinafter, may be simply referred to as aging) under a special condition of  $180^\circ C \times 20$  min for better reproducibility.

**[0054]** Higher BH is better for the vehicle structural component, and an aluminum alloy sheet having BH providing 0.2% proof stress of 220 MPa or more is defined to be acceptable in the present invention.

Yield Ratio:

**[0055]** A low yield ratio means a low proof stress to tensile strength. A breaking limit is higher with higher tensile strength to a proof stress. A lower proof stress to a tensile strength leads to a smaller springback amount, leading to improvement in press formability. Consequently, the yield ratio is defined to be 0.63 or less to ensure press formability that allows the aluminum alloy sheet to be formed into a structural component having a complicated shape.

Thickness:

**[0056]** Thickness of the aluminum alloy sheet is necessary to be 2.0 mm or more to ensure the strength and the stiffness necessary for the vehicle structural component. Although the upper limit of the thickness is not specifically defined, the upper limit is about 4.0 mm in consideration of the limit of forming such as press forming, and of a weight increase range in which the effect of weight reduction is not effectively reduced compared with a steel sheet as a comparative material. One of a hot-rolled sheet and a cold-rolled sheet is appropriately selectively formed based on such a preferred thickness range (2.0 to 4.0 mm).

Area Ratio of Cube Orientation:

**[0057]** In the present invention, the area ratio of cube orientation in an appropriate surface region from the sheet surface to the depth of 10% in the thickness direction is defined to be 22% or more in order to improve crashworthiness of the sheet.

**[0058]** The meaning of "sheet surface" in the present invention is a surface of a natural oxide film (having a

thickness level of tens to hundreds nanometers) formed on (the surface of) an aluminum alloy matrix.

**[0059]** A larger area ratio of cube orientation in the surface region from the sheet surface to the depth of 10% of the thickness in the thickness (depth) direction more suppresses formation of a shear band on a bending outside, leading to improvement in crash properties of the sheet.

**[0060]** If the area ratio of cube orientation in the surface region from the sheet surface to the depth of 10% of the thickness in the thickness direction is smaller than 22%, crashworthiness is extremely deteriorated. Consequently, the area ratio of cube orientation is 22% or more in the surface region. Furthermore, since the area ratio of cube orientation of more than 35% leads to good crashworthiness, the area ratio of cube orientation in the surface region is preferably 35% or more.

#### Measurement of Area Ratio of Cube Orientation:

**[0061]** For the average area ratio of cube orientation of a grain of the sheet, the sheet surface is polished by mechanical polishing or buff polishing such that an observation surface at an appropriate depth position in the surface region from the sheet surface to the depth of 10% in the thickness direction appears as the observation surface extending parallel to a rolling plane (rolling surface) in plan view of the sheet (test specimen) of each of (three) test specimens each being taken from the appropriate depth position in the surface region from the sheet surface to the depth of 10% of the thickness in a depth direction.

**[0062]** The test specimen obtained in this way is irradiated with an electron beam at a pitch of 5  $\mu\text{m}$  with SEM-EBSD over a rectangular measurement area with a length of 1000  $\mu\text{m}$  of a side in a rolling direction of the sheet and a length of 320  $\mu\text{m}$  of a side in a sheet width direction in the observation surface.

**[0063]** For example, SEM (JEOLJSM5410) from JEOL Ltd. and an EBSD measurement/analysis system: OIM (Orientation Imaging Macrograph, analysis software "OIM Analysis") from TSL Solutions are used as the SEM system to determine whether each grain shows cube orientation (within 15° from an ideal orientation), and obtain area of each crystal orientation in a measured view.

**[0064]** For example, such measurement is performed by electron beam scan at a step interval of 5  $\mu\text{m}$ . Crystal orientation of an individual grain is measured at each measurement point, and is analyzed in combination with positional data of the measurement point, thereby crystal orientation of the individual grain is determined in the measurement area.

**[0065]** For each test specimen, an average area ratio (%) of grains having cube orientation to area (320000  $\mu\text{m}^2$ ) of the measurement area as the total measurement area is determined, and the measured average area ratios for the three test specimens are averaged.

**[0066]** The SEM-EBSD (EBSP) method is a general crystal orientation analyzing method with a field emission scanning electron microscope (FESEM) equipped with an electron back scattering (scattered) diffraction pattern (EBSD) system.

**[0067]** Specifically, the observation specimen for SEM-EBSD is prepared by mirror-finishing the observation specimen (sectional microstructure) through mechanical polishing. The specimen is placed in a bodytube of the FESEM, and the mirror-finished surface of the specimen is irradiated

with an electron beam to project EBSD (EBSP) onto a screen. The projected EBSD (EBSP) is photographed by a highly sensitive camera, and is loaded as an image into a computer. The computer analyzes the image and determines crystal orientation through comparison with a pattern obtained by simulation using known crystal systems. The calculated crystal orientation is registered as a three-dimensional Euler angle together with a position coordinate (x, y). This process is automatically performed on all measurement points; hence, tens of thousands to hundreds of thousands of crystal orientation data on a sheet section are obtained at the end of the measurement.

**[0068]** Hence, an observation field is wide, and information on a large number of grains, including a distribution state, average grain size, standard deviation of the average grain size, and orientation analysis, is advantageously obtained within several hours. Hence, the SEM-EBSD (EBSP) method is most suitable for a case where a texture including the area ratio of cube orientation is accurately determined as in the present invention.

**[0069]** An aluminum alloy sheet typically has a texture including the following many orientation factors (grains having such orientations), and has corresponding crystal planes. In general, a texture of a rolled recrystallized sheet of aluminum alloy mainly includes Cube orientation, Goss orientation, Brass orientation, S orientation, and Copper orientation. For a texture of a rolled sheet, the texture is represented by a rolling plane and a rolling direction, while the rolling plane is expressed by {hkl} and the rolling direction is expressed by <uvw>. According to such expression, each orientation is expressed as follows.

**[0070]** Cube orientation {001}<100>

**[0071]** Goss orientation {011}<100>

**[0072]** Brass orientation (B orientation) {011}<211>

**[0073]** Cu orientation (copper orientation) {112}<111>

**[0074]** S orientation {123}<634>

#### Crashworthiness:

**[0075]** Crashworthiness refers to the following property: When a structural component receives an impact load at vehicle collision or the like, the structural component deforms to the last without cracking or crush (or even if cracking or crush occurs) in an early stage or in a process of deformation. That is, a component having a good crashworthiness bending-deforms into concertinas without cracking or crush (or even if cracking or crush occurs).

**[0076]** For the crashworthiness in the present invention, a structural component having a crashworthiness showing a bending angle of 60° or more at the VDA bending test is defined to be acceptable for the vehicle structural component. The larger the bending angle, the better the crashworthiness, and a bending angle of 90° or more is more preferable. A structural component having a crashworthiness showing a bending angle of less than 60° cannot be used for the vehicle structural component.

**[0077]** The bending test evaluating the crashworthiness is performed as the VDA bending test in accordance with "VDA238-100 Plate bending test for metallic materials" in the standard of German Association of the Automotive Industry (Verband der Automobilindustrie (VDA)).

**[0078]** The test method is shown by a perspective view of FIG. 1. FIG. 2 illustrates a punch to be used by front and side views.

**[0079]** First, a sheet-like test specimen is horizontally placed with an equal length on both sides as illustrated by a dot line in FIG. 1 on two rolls disposed parallel to each other with a roll gap.

**[0080]** Specifically, the sheet-like test specimen is horizontally placed with an equal length on both sides on the two rolls so that its central portion is located in the middle of the roll gap such that the rolling direction of the test specimen is perpendicular to an extending direction of a sheet-like pressing bend tool vertically disposed on an upper side.

**[0081]** The pressing bend tool is pressed from the upper side to the central portion of the sheet-like test specimen to exert a load to the test specimen, so that the test specimen is press-bent (push-bent) toward the narrow roll gap, and the central portion of the bending-deformed sheet-like test specimen is forced into the narrow roll gap.

**[0082]** When the load  $F$  from the upper pressing bend tool is maximized (immediately before a bending end of the central portion of the sheet-like test specimen is cracked), an angle on a bending outside of the central portion of the sheet-like test specimen is measured as the bending angle ( $^{\circ}$ ), and the crashworthiness is evaluated by measure of the bending angle. As the bending angle is larger, bending deformation of the sheet-like test specimen continues longer without crush halfway, i.e., crashworthiness is better.

**[0083]** The test condition of the VDA bending test is described below using signs shown in FIG. 1. That is, the sheet-like test specimen has a square shape having a width  $b$  of 60 mm and a length  $l$  of 60 mm, the two rolls each have a diameter  $D$  of 30 mm, and the roll gap  $L$  is two times as large as the thickness of the sheet-like test specimen (two times as large as the thickness 2.5 mm of a cold-rolled sheet, i.e., 5 mm, in Example as described later).  $S$  is the forced depth of the central portion of the sheet-like test specimen into the roll gap when the load  $F$  is maximized.

**[0084]** As shown in FIG. 2, the punch as a sheet-like pressing bend tool has a tapered shape in such a manner that a sheeted blade (thickness 2 mm) on the lower side of the punch, which is to be pressed to the central portion of the sheet-like test specimen, has a pointed end (lower end) having a radius  $r$  of 0.2 mm.

#### Manufacturing Method:

**[0085]** A method of manufacturing the aluminum alloy sheet of the present invention is now described. The aluminum alloy sheet of the present invention is manufactured, in which a casted aluminum alloy slab having the 6000-series composition is subjected to homogenization, and is then subjected to hot rolling and cold rolling so as to have a predetermined thickness, and is further subjected to tempering such as solution treatment.

**[0086]** During such a manufacturing process, a reduction condition of cold rolling is adjusted to be within a preferred range, and the conditions of the solution treatment and the following pre-aging treatment are also adjusted to be within preferred ranges as described later in order to ensure the microstructure and texture defined in the present invention.

#### (Cooling Rate in Melting and Casting)

**[0087]** In a melting-and-casting step, molten metal of aluminum alloy, which is melted and adjusted to be within the 6000-series composition range, is casted by an appropriately selected common melting-and-casting process such

as a continuous casting process and a semi-continuous casting process (DC casting process)

#### (Homogenization)

**[0088]** Subsequently, the casted aluminum alloy slab is subjected to homogenization prior to hot rolling. The homogenization (soaking) is important for sufficient solid solution of Si and Mg in addition to eliminating segregation in a microstructure of a slab as a common purpose. Any homogenization condition including common onetime or one-stage treatment may be used without limitation as long as the purpose is achieved.

**[0089]** Homogenization temperature is 500 to 560 $^{\circ}$  C., and homogenization (holding) time is appropriately selected from a range of 1 hr or more. If the homogenization temperature is low, segregation in the grain cannot be sufficiently eliminated, and acts as an origin of fracture; hence, crashworthiness may be deteriorated.

#### (Hot Rolling)

**[0090]** After the homogenization, the slab is hot-rolled so as to be formed into a hot-rolled sheet. Hot rolling includes a rough rolling step for the slab and a finish rolling step depending on thickness of the sheet to be rolled.

**[0091]** A reverse-type or tandem-type rolling mill is appropriately used for the rough rolling step or the finish rolling step.

**[0092]** The hot-rolled sheet has a worked structure remaining after the hot rolling and a high integration of cube orientation, and thus has a preferred average area ratio of cube orientation of 35% or more in the surface region from the sheet surface to the depth of 10% in the thickness direction, and consequently has an extremely improved crashworthiness. Hence, the hot-rolled sheet may be used as a product sheet having a final thickness of 2.0 mm or more while being not subjected to cold rolling.

#### (Cold Rolling)

**[0093]** When the hot-rolled sheet is cold-rolled into a desired thickness, cold reduction is adjusted to be 70% or less, preferably small as much as possible so that the worked structure caused by the hot rolling still remains, integration of cube orientation is increased, and an average area ratio of cube orientation is 22% or more, preferably 35% or more, in the surface region from the sheet surface to the depth of 10% in the thickness direction.

**[0094]** If the cold reduction exceeds 70%, uniform strain in a thickness direction is introduced after the cold rolling, and uniform and fine isometric grains are given during the solution heat treatment. However, since an area ratio of a crystal orientation other than the cube orientation increases, the area ratio of cube orientation in the surface region from the sheet surface to the depth of 10% in the thickness direction necessarily becomes smaller than 22%, and thus crashworthiness may be deteriorated.

**[0095]** In this regard, the cold reduction is preferably further smaller, less than 5%. If the cold reduction is less than 5%, substantially no strain is introduced by the cold rolling, so that, as with the hot-rolled sheet, a microstructure caused by the hot rolling still remains, integration of cube orientation is high, and an area ratio of cube orientation is 35% or more in the surface region from the sheet surface to

the depth of 10% in the thickness direction, leading to significant improvement in crashworthiness.

**[0096]** Consequently, the cold reduction is desirably less than 5%. Intermediate annealing may be appropriately performed between cold rolling passes.

(Solution treatment and Quenching)

**[0097]** The cold-rolled sheet is subjected to solution treatment and subsequent quenching to room temperature. The solution treatment may be performed using a common continuous heat treatment line. However, to ensure a sufficient solid-solution amount of each element such as Mg or Si, it is preferred that the cold-rolled sheet is heated to a solution treatment temperature (achieving temperature) of 540 to 570° C. and held at the temperature for 0.1 to 60 sec, and is then successively subjected to quenching.

**[0098]** If the solution temperature is lower than 540° C., sufficient solid solubility of each of Mg and Si is not ensured, and sufficient post-baking strength may not be provided. If the solution treatment temperature exceeds 570° C., the sheet may be melted because such temperature is close to the melting point. If the holding time of the solution treatment is longer than 60 sec, initial strength is high, and the yield ratio may be increased. Consequently, the solution treatment temperature is preferably 540 to 570° C., and the holding time of the solution treatment is preferably 0.1 to 60 sec.

**[0099]** The quenching subsequent to the solution treatment is conducted while cooling methods such as air cooling with a fan and water cooling with mist, spray, or immersion, and cooling conditions are selectively used to ensure a cooling rate such that the solid-solutionized Mg amount and the solid-solutionized Si amount are each not decreased by formation of precipitates mainly including Mg—Si during cooling.

(Reheating; Preliminary Aging)

**[0100]** The cold-rolled sheet is preferably reheated within 10 min after the cold-rolled sheet is thus subjected to quenching subsequent to solution treatment and thus cooled to room temperature (when the quenching has been finished), so that the sheet is held for 3 to 20 hr within a range of material temperature from 60 to 90° C.

**[0101]** If the room-temperature holding time before start of the reheating (start of the heating) is too long, a Si-rich Mg—Si cluster is formed due to room-temperature aging, and an Mg—Si cluster having a good balance between Mg and Si is less likely to be increased; hence, BH may be deteriorated. Hence, a shorter room-temperature holding time is better. The quenching subsequent to the solution treatment may be followed by the reheating with substantially no interval, and no lower limit interval is set.

**[0102]** The sheet is held for 3 to 20 hr at 60 to 90° C. in the reheating, thereby the Mg—Si cluster having a good balance between Mg and Si is formed, and thus BH is improved.

**[0103]** The reheating temperature of less than 60° C. or the holding time of less than 3 hr leads to a state similar to the state without reheating, in which the Mg—Si cluster having a good balance between Mg and Si is less likely to be increased, and thus post-paint-bake proof stress (BH) is easily reduced.

**[0104]** The reheating temperature of more than 90° C. or the holding time of more than 20 hr may provide a high initial strength and an increase in yield ratio.

**[0105]** Although the present invention is now described in detail with Example, the present invention should not be limited thereto, and modifications or alterations thereof may be made within the scope without departing from the gist described before and later, all of which are included in the technical scope of the present invention.

#### Example

**[0106]** 6000-Series aluminum alloy cold-rolled sheets having compositions shown in Table 1 were produced at different manufacturing conditions as in Table 2 so as to have different textures. The sheets were subjected to BH and evaluated in mechanical properties such as a yield ratio and strength, crashworthiness evaluated by the VDA bending test, and grain-boundary corrosion resistance as the corrosion resistance necessary for the structural component. Table 2 also shows results of such evaluation.

**[0107]** Aluminum alloys having the compositions shown in Table 1 were melted and casted. Each of the produced slabs was homogenized under a condition of 540° C.×4 hr, and was successively hot-rolled with a finish temperature of 260 to 350° C. Subsequently, the slabs were cold-rolled with reductions shown in Table 2 so as to have a final thickness of 2.5 mm, and were thus formed into cold-rolled sheets.

**[0108]** Subsequently, each of the cold-rolled sheets was heated at a heating rate of 100° C./min or more, and was subjected to solution treatment under a condition of temperature and holding time shown in Table 2, and was then successively subjected to solution treatment in which the cold-rolled sheet was dipped in water so as to be cooled to room temperature. Subsequently, sheets to be reheated were reheated into temperature regions shown in Table 2 and were held at 60° C. or more under conditions of time shown in Table 2, and were then natural-cooled to room temperature.

**[0109]** Test samples were taken from the aluminum alloy sheets. For each test sample, a texture in the surface region of a section and a yield ratio were measured. The test sample was then subjected to BH, and was then subjected to examination of mechanical properties and crashworthiness, and subjected to examination of grain-boundary corrosion resistance typically required for the vehicle structural component.

#### Average Area Ratio of Cube Orientation:

**[0110]** For the area ratio (%) of cube orientation, a section orthogonal to a sheet width direction of the reheated test sample was mechanically polished and electro-polished. Subsequently, crystal orientation in the normal direction to the section along the sheet width in the surface region was measured by the SEM-EBSD method.

**[0111]** Shift in crystal orientation within  $\pm 5^\circ$  is defined to be contained in one crystal orientation. Table 2 shows average area ratios of cube orientation in the surface region from the sheet surface to the depth of 10% in the thickness direction.

#### Mechanical Properties:

**[0112]** The mechanical properties were determined through a tensile test under the following condition. The yield ratio was obtained for a test sample after a lapse of six months (after room-temperature aging) after the reheating, and the yield ratio was evaluated such that 0.63 or less was

good, 0.60 or less was further good, and 0.64 or more was bad for the structural component.

[0113] For the post-BH proof stress, a test sample after a lapse of six months (after room-temperature aging) after the reheating was allowed to have a pre-strain of 2% as simulated press forming of a sheet by a tensile tester, and was then subjected to artificial aging under a heat treatment condition of 180° C.×20 min, and proof stress of such a test sample (AB material) was measured. The proof stress was evaluated such that 220 MPa or more was acceptable, and 230 MPa or more was good for the structural component.

[0114] The tensile test was performed at room temperature with a JIS Z2201 No. 5 test specimen (25 mm×50 mm gage length (GL)×thickness) taken from each test sample. The tensile direction of the test specimen was perpendicular to the rolling direction. The tensile speed was 5 mm/min below the 0.2% proof stress, and was 20 mm/min at or above the 0.2% proof stress. The number N of times of measurement of each of the mechanical properties was five, and an average of the measured values was calculated for each property.

#### Crashworthiness:

[0115] With the crashworthiness, a test sample after a lapse of six months (after room-temperature aging) after the reheating was allowed to have a pre-strain of 2% by a tensile tester, and was then subjected to artificial aging under a heat treatment condition of 180° C.×20 min so as to be formed as a measuring object of the VDA bending test.

[0116] Each test sample was stretched by 2% in a direction perpendicular to the rolling direction, and was then cut into a square test specimen having a thickness of 2.5 mm, a width b of 60 mm, and a length l of 60 mm.

[0117] A three-point bend test, in which the bending line was parallel to the rolling direction, was performed using the test specimen in accordance with the VDA238-100. The testing rate was 10 mm/min below a load of 30 N, and was 20 mm/min at or above the load. The bending test was set such that bending was stopped when the load was decreased by 60 N from the maximum load due to cracking or a decrease in thickness.

[0118] The bending test was performed on three sheet-like test specimens (three times) for each sample, and an average of the three measured angles was used as the bending angle (°).

[0119] The maximum bending angle (bending angle when the load F from the pressing bend tool is maximized, i.e., a bending angle immediately before a bending end of the central portion of the sheet-like test specimen is cracked) of the sheet-like test specimen subjected to the bending test was evaluated in such a manner that 90° or larger was good, 60° or larger was acceptable, and less than 60° was unacceptable for the structural component.

#### Grain-Boundary Corrosion Resistance:

[0120] The evaluation test of the grain-boundary corrosion resistance was conducted in accordance with ISO11846 Method B. After a lapse of six months (after room-temperature aging) after the reheating, a test sample was allowed to have a pre-strain of 2% by a tensile tester and then subjected to artificial aging under a heat treatment condition of 180° C.×20 min. The test sample was then dipped in 5% NaOH (60° C.) to remove a surface coating, and was then rinsed

and dipped in 70% HNO<sub>3</sub> for 1 min, and was then rinsed again and dried at room temperature.

[0121] An aqueous solution containing HCl and NaCl (containing 30 g/l of NaCl and 10±1 ml/l of 36% concentrated hydrochloric acid) was used as an etchant, and the test sample was dipped for 24 hr at 25° C. in the etchant of 5 ml per surface area 1 cm<sup>2</sup> of a material. Subsequently, corrosion products were removed by dipping in 70% HNO<sub>3</sub> and brushing using a plastic brush, and then the test sample was rinsed and dried at room temperature.

[0122] Three regions that were determined to be deeply corroded were selected by a focal depth method, and each region was buried to show a cross section, and a depth of a deepest grain-boundary corrosion in each section was measured by a light microscope.

[0123] Three test samples taken from three appropriate places of a sheet were used as the test samples. Among the measurements of the three test samples, a test sample having a largest grain-boundary corrosion depth of less than 300 μm was defined to be acceptable, and a test sample having that of 300 μm or more was defined to be unacceptable for the structural component.

[0124] As clear from Tables 1 and 2, each inventive example is within a range of the aluminum alloy composition of the present invention, and is manufactured within the range of the preferred condition.

[0125] As a result, as shown in Table 2, inventive examples Nos. 1 to 11 each show an average area ratio of cube orientation of 22% or more in a surface region from the surface of the sheet to the depth of 10% in the thickness direction, an yield ratio of 0.63 or less, and properties including 0.2% proof stress of 220 MPa or more and crashworthiness showing a bending angle of 60° or more at the VDA bending test when the aluminum alloy sheet is stretched by 2% and then subjected to artificial aging for 20 min at 180° C.

[0126] In particular, the inventive examples Nos. 1 and 2 each show a further good crashworthiness because the cube area ratio is 35% or more in the surface region from the sheet surface to the depth of 10% in the thickness direction.

[0127] The inventive example No. 3 shows a further good yield ratio and a further good post-BH proof stress because the content [Mg] of Mg and the content [Si] of Si satisfy a relationship  $[Si]/[Mg] \geq 1.8$  and a relationship  $1.6\% \leq 1.3[Mg] + [Si] \leq 1.9\%$ .

[0128] In contrast, as shown in Table 1, each comparative example is manufactured with an alloy composition out of the range of the present invention, or manufactured with a hot rolling condition out of the preferred range of the hot rolling condition while having an alloy composition within the range of the present invention. As a result, as shown in Table 2, the average area ratio of cube orientation or the yield ratio does not satisfy the requirement, and post-BH strength, crashworthiness, or grain-boundary corrosion resistance is bad.

[0129] Comparative examples Nos. 12 to 23 each have an alloy composition out of the range of the present invention.

[0130] The comparative examples Nos. 12 and 13, which correspond to alloy numbers 6 and 7, respectively, in Table 1, are each bad in post-baking proof stress because the Mg content is less than the lower limit (1.3[Mg]+[Si] is also less than the lower limit in the comparative example No. 12).

[0131] The comparative example No. 14 corresponds to alloy number 8 in Table 1, in which the yield ratio exceeds

0.63 because the Mg content exceeds the upper limit. In addition, since  $1.3 [\text{Mg}] + [\text{Si}]$  exceeds the upper limit of the present invention, crashworthiness is bad.

[0132] The comparative example No. 15 corresponds to alloy number 9 in Table 1, in which crashworthiness is bad because  $1.3 [\text{Mg}] + [\text{Si}]$  exceeds the upper limit.

[0133] The comparative example No. 16 corresponds to alloy number 10 in Table 1, in which post-BH proof stress is bad because the Si content is less than the lower limit. In addition, since  $[\text{Si}]/[\text{Mg}]$  is less than the lower limit, the yield ratio exceeds 0.63.

[0134] The comparative example No. 17 corresponds to alloy number 11 in Table 1, in which the yield ratio exceeds 0.63 because the Si content exceeds the upper limit. In addition, since  $1.3 [\text{Mg}] + [\text{Si}]$  exceeds the upper limit, crashworthiness is bad.

[0135] The comparative example No. 18 corresponds to alloy number 12 in Table 1, in which crashworthiness is bad because  $1.3 [\text{Mg}] + [\text{Si}]$  exceeds the upper limit.

[0136] The comparative example No. 19 corresponds to alloy number 13 in Table 1, in which the yield ratio exceeds 0.63 because the content of Cu is less than the lower limit. In addition, post-baking proof stress is bad.

[0137] The comparative example No. 20 corresponds to alloy number 14 in Table 1, in which grain-boundary corrosion resistance is bad because the content of Cu exceeds the upper limit.

[0138] The comparative example No. 21 corresponds to alloy number 15 in Table 1, in which the yield ratio exceeds 0.63 because the content of Mg is less than the lower limit and  $[\text{Si}]/[\text{Mg}]$  is less than the lower limit of the present invention. In addition, since  $1.3 [\text{Mg}] + [\text{Si}]$  is less than the lower limit of the present invention, post-BH proof stress is bad.

[0139] The comparative example No. 22 corresponds to alloy number 16 in Table 1, in which post-BH proof stress is bad because  $1.3 [\text{Mg}] + [\text{Si}]$  is less than the lower limit.

[0140] The comparative example No. 23 corresponds to alloy number 17 in Table 1, in which crashworthiness is bad because  $1.3 [\text{Mg}] + [\text{Si}]$  exceeds the upper limit.

[0141] The comparative examples Nos. 24 to 35 each correspond to alloy number 1 or 2 in Table 1, in each of which although the alloy composition is within the range of the present invention, a manufacturing method is out of the preferred range.

[0142] The comparative examples Nos. 24 and 25 are each bad in crashworthiness because cold reduction is too high, and the average area ratio of cube orientation in the surface region of the sheet is less than 22%.

[0143] The comparative example No. 26 is not reheated and thus bad in post-baking proof stress.

[0144] The comparative examples Nos. 27 and 28 are not reheated and thus bad in post-baking proof stress. In addition, crashworthiness is bad because cold reduction is too high, and the average area ratio of cube orientation in the surface region of the sheet is less than 22%.

[0145] The comparative example No. 29 is bad in post-BH proof stress because solution temperature is less than the preferred lower limit.

[0146] The comparative example No. 30 has a yield ratio of more than 0.63 because solution holding time exceeds the preferred upper limit.

[0147] The comparative example No. 31 is bad in post-BH proof stress because time required before reheating exceeds 10 min.

[0148] The comparative example No. 32 is bad in post-BH proof stress because reheating temperature is less than the preferred lower limit.

[0149] The comparative example No. 33 shows a yield ratio of more than 0.63 because reheating temperature exceeds the preferred upper limit.

[0150] The comparative example No. 34 is bad in post-BH proof stress because holding time at 60° C. or more after reheating is less than the preferred lower limit.

[0151] The comparative example No. 35 shows a yield ratio of more than 0.63 because holding time at 60° C. or more after reheating exceeds the preferred upper limit.

[0152] These results of the Example support the meaning of satisfying the composition and the microstructure defined in the present invention for the vehicle structural component.

TABLE 1

| Chemical composition of aluminum alloy sheet |                             |     |      |           |                |      |      |      |  |
|----------------------------------------------|-----------------------------|-----|------|-----------|----------------|------|------|------|--|
| Alloy                                        | (mass %, the remainder: Al) |     |      |           |                |      |      |      |  |
| No.                                          | Si                          | Mg  | Cu   | [Si]/[Mg] | 1.3[Mg] + [Si] | Fe   | Mn   | Ti   |  |
| 1                                            | 0.6                         | 0.7 | 0.10 | 0.9       | 1.5            | 0.20 | 0.10 | 0.01 |  |
| 2                                            | 1                           | 0.4 | 0.17 | 2.5       | 1.5            | 0.20 | 0.10 | 0.01 |  |
| 3                                            | 1                           | 0.5 | 0.10 | 2         | 1.7            | 0.20 | 0.10 | 0.01 |  |
| 4                                            | 1                           | 0.4 | 0.10 | 2.5       | 1.5            | 0.20 | 0.10 | 0.01 |  |
| 5                                            | 0.9                         | 0.7 | 0.10 | 1.3       | 1.8            | 0.20 | 0.10 | 0.01 |  |
| 6                                            | 1                           | 0.2 | 0.10 | 5         | 1.3            | 0.20 | 0.10 | 0.01 |  |
| 7                                            | 1.2                         | 0.2 | 0.10 | 6         | 1.5            | 0.20 | 0.10 | 0.01 |  |
| 8                                            | 1                           | 1.1 | 0.10 | 0.9       | 2.4            | 0.20 | 0.10 | 0.01 |  |
| 9                                            | 1                           | 0.9 | 0.10 | 1.1       | 2.2            | 0.20 | 0.10 | 0.01 |  |
| 10                                           | 0.4                         | 0.9 | 0.10 | 0.4       | 1.6            | 0.20 | 0.10 | 0.01 |  |
| 11                                           | 1.3                         | 0.7 | 0.10 | 1.9       | 2.2            | 0.20 | 0.10 | 0.01 |  |
| 12                                           | 1.1                         | 0.7 | 0.10 | 1.6       | 2              | 0.20 | 0.10 | 0.01 |  |
| 13                                           | 0.6                         | 0.7 | 0.04 | 0.9       | 1.5            | 0.20 | 0.10 | 0.01 |  |
| 14                                           | 1                           | 0.4 | 0.23 | 2.5       | 1.5            | 0.20 | 0.10 | 0.01 |  |
| 15                                           | 0.4                         | 0.7 | 0.10 | 0.6       | 1.3            | 0.20 | 0.10 | 0.01 |  |
| 16                                           | 0.8                         | 0.4 | 0.17 | 2.0       | 1.3            | 0.20 | 0.10 | 0.01 |  |
| 17                                           | 1.1                         | 0.7 | 0.10 | 1.6       | 2              | 0.20 | 0.10 | 0.01 |  |

TABLE 2

| Classification         | No. | Alloy number<br>in Table 1 | Time from _____       |                                  |                   | Reheating _____        |                                  |                 | Reheated aluminum _____   |                                                         |             | Grain-Boundary<br>Corrosion<br>Resistance |                          |                                             |
|------------------------|-----|----------------------------|-----------------------|----------------------------------|-------------------|------------------------|----------------------------------|-----------------|---------------------------|---------------------------------------------------------|-------------|-------------------------------------------|--------------------------|---------------------------------------------|
|                        |     |                            | Solution<br>treatment | Achieving<br>temperature<br>° C. | Holding<br>time s | to<br>reheating<br>min | Achieving<br>temperature<br>° C. | Holding<br>time | from<br>60 to<br>90° C. h | area ratio of cube<br>orientation in<br>sheet surface % | Yield ratio |                                           | 0.2% Proof<br>stress MPa | Crashworthiness<br>evaluated by<br>VDA test |
|                        |     |                            |                       |                                  |                   |                        |                                  |                 |                           |                                                         |             |                                           |                          |                                             |
| Inventive<br>example   | 1   | 1                          | 560                   | 10                               | 5                 | 5                      | 80                               | 5               | 46                        | 0.62                                                    | 222         | Good                                      | Acceptable               |                                             |
|                        | 2   | 2                          | 550                   | 10                               | 5                 | 5                      | 80                               | 5               | 39                        | 0.59                                                    | 228         | Good                                      | Acceptable               |                                             |
|                        | 3   | 3                          | 550                   | 10                               | 5                 | 5                      | 70                               | 5               | 28                        | 0.58                                                    | 255         | Acceptable                                | Acceptable               |                                             |
|                        | 4   | 2                          | 550                   | 10                               | 5                 | 5                      | 80                               | 5               | 25                        | 0.59                                                    | 236         | Acceptable                                | Acceptable               |                                             |
|                        | 5   | 4                          | 550                   | 10                               | 5                 | 5                      | 70                               | 5               | 24                        | 0.59                                                    | 230         | Acceptable                                | Acceptable               |                                             |
|                        | 6   | 5                          | 550                   | 10                               | 5                 | 5                      | 70                               | 5               | 27                        | 0.62                                                    | 242         | Acceptable                                | Acceptable               |                                             |
|                        | 7   | 1                          | 550                   | 1                                | 5                 | 5                      | 70                               | 5               | 25                        | 0.61                                                    | 222         | Acceptable                                | Acceptable               |                                             |
|                        | 8   | 1                          | 550                   | 10                               | 5                 | 5                      | 70                               | 5               | 26                        | 0.62                                                    | 225         | Acceptable                                | Acceptable               |                                             |
|                        | 9   | 1                          | 550                   | 30                               | 5                 | 5                      | 70                               | 5               | 24                        | 0.62                                                    | 230         | Acceptable                                | Acceptable               |                                             |
|                        | 10  | 1                          | 550                   | 10                               | 5                 | 5                      | 70                               | 5               | 24                        | 0.62                                                    | 232         | Acceptable                                | Acceptable               |                                             |
| Comparative<br>example | 11  | 1                          | 550                   | 10                               | 5                 | 5                      | 70                               | 15              | 28                        | 0.62                                                    | 225         | Acceptable                                | Acceptable               |                                             |
|                        | 12  | 6                          | 550                   | 10                               | 5                 | 5                      | 70                               | 5               | 25                        | 0.57                                                    | 204         | Acceptable                                | Acceptable               |                                             |
|                        | 13  | 7                          | 550                   | 10                               | 5                 | 5                      | 70                               | 5               | 26                        | 0.63                                                    | 217         | Acceptable                                | Acceptable               |                                             |
|                        | 14  | 8                          | 550                   | 10                               | 5                 | 5                      | 70                               | 5               | 25                        | 0.64                                                    | 279         | Unacceptable                              | Acceptable               |                                             |
|                        | 15  | 9                          | 550                   | 10                               | 5                 | 5                      | 70                               | 5               | 26                        | 0.62                                                    | 262         | Unacceptable                              | Acceptable               |                                             |
|                        | 16  | 10                         | 550                   | 10                               | 5                 | 5                      | 70                               | 5               | 25                        | 0.65                                                    | 217         | Acceptable                                | Acceptable               |                                             |
|                        | 17  | 11                         | 550                   | 10                               | 5                 | 5                      | 70                               | 5               | 28                        | 0.64                                                    | 265         | Unacceptable                              | Acceptable               |                                             |
|                        | 18  | 12                         | 550                   | 10                               | 5                 | 5                      | 70                               | 5               | 27                        | 0.62                                                    | 262         | Unacceptable                              | Acceptable               |                                             |
|                        | 19  | 13                         | 550                   | 10                               | 5                 | 5                      | 70                               | 5               | 24                        | 0.64                                                    | 213         | Acceptable                                | Acceptable               |                                             |
|                        | 20  | 14                         | 550                   | 10                               | 5                 | 5                      | 70                               | 5               | 25                        | 0.58                                                    | 234         | Acceptable                                | Unacceptable             |                                             |
|                        | 21  | 15                         | 560                   | 10                               | 5                 | 5                      | 70                               | 5               | 25                        | 0.64                                                    | 206         | Acceptable                                | Acceptable               |                                             |
|                        | 22  | 16                         | 550                   | 10                               | 5                 | 5                      | 80                               | 5               | 24                        | 0.58                                                    | 215         | Acceptable                                | Acceptable               |                                             |
|                        | 23  | 17                         | 550                   | 10                               | 5                 | 5                      | 80                               | 5               | 26                        | 0.61                                                    | 252         | Unacceptable                              | Acceptable               |                                             |
|                        | 24  | 2                          | 550                   | 10                               | 5                 | 5                      | 70                               | 5               | 20                        | 0.59                                                    | 227         | Unacceptable                              | Acceptable               |                                             |
|                        | 25  | 2                          | 550                   | 10                               | 5                 | 5                      | 70                               | 5               | 18                        | 0.59                                                    | 230         | Unacceptable                              | Acceptable               |                                             |
|                        | 26  | 1                          | 550                   | 10                               | 5                 |                        | Not<br>reheated                  |                 | 25                        | 0.61                                                    | 183         | Good                                      | Acceptable               |                                             |
|                        | 27  | 1                          | 550                   | 10                               | 5                 |                        | Not<br>reheated                  |                 | 20                        | 0.61                                                    | 180         | Unacceptable                              | Acceptable               |                                             |
|                        | 28  | 1                          | 550                   | 10                               | 5                 |                        | Not<br>reheated                  |                 | 17                        | 0.60                                                    | 180         | Unacceptable                              | Acceptable               |                                             |
|                        | 29  | 1                          | 530                   | 10                               | 5                 |                        |                                  | 5               | 24                        | 0.61                                                    | 215         | Acceptable                                | Acceptable               |                                             |
|                        | 30  | 1                          | 550                   | 90                               | 5                 |                        |                                  | 5               | 28                        | 0.64                                                    | 236         | Acceptable                                | Acceptable               |                                             |
|                        | 31  | 1                          | 550                   | 10                               | 15                |                        |                                  | 5               | 28                        | 0.61                                                    | 214         | Acceptable                                | Acceptable               |                                             |
|                        | 32  | 1                          | 550                   | 10                               | 5                 |                        |                                  | —               | 25                        | 0.58                                                    | 205         | Acceptable                                | Acceptable               |                                             |
|                        | 33  | 1                          | 550                   | 10                               | 5                 |                        |                                  | 5               | 26                        | 0.65                                                    | 235         | Acceptable                                | Acceptable               |                                             |
|                        | 34  | 1                          | 550                   | 10                               | 5                 |                        |                                  | 1               | 27                        | 0.61                                                    | 201         | Acceptable                                | Acceptable               |                                             |
|                        | 35  | 1                          | 550                   | 10                               | 5                 |                        |                                  | 25              | 27                        | 0.64                                                    | 230         | Acceptable                                | Acceptable               |                                             |

[0153] According to the present invention, a 6000-series aluminum alloy sheet manufactured by common rolling can be allowed to have properties specific to the vehicle structural component application, such as increased strength, crashworthiness as an additional property, press formability, and corrosion resistance. Hence, the 6000-series aluminum alloy sheet can be extensively used for the vehicle structural component.

What is claimed is:

1. An aluminum alloy sheet for a vehicle structural component, comprising an Al—Mg—Si aluminum alloy sheet that contains, by mass percent, Mg: 0.3 to 1.0%, Si: 0.5 to 1.2%, and Cu: 0.08 to 0.20%, content [Mg] of Mg and content [Si] of Si satisfying a relationship  $[Si]/[Mg] \geq 0.7$  and a relationship  $1.4\% \leq 1.3 [Mg] + [Si] \leq 1.9\%$ , the remainder consisting of Al and inevitable impurities, and has a thickness of 2.0 mm or more, wherein an average area ratio of cube orientation is 22% or more in a surface region from a surface of the sheet to a depth of 10% in the thickness direction, an yield ratio of the sheet is 0.63 or less, and when the aluminum alloy sheet is stretched by 2% and then subjected to artificial aging for 20 min at 180° C., the aluminum alloy sheet has properties including 0.2% proof stress of 220 MPa or more and crashworthiness showing a bending angle of 60° or more at a VDA bending test.

2. The aluminum alloy sheet according to claim 1, wherein the content [Mg] of Mg and the content [Si] of Si further satisfy a relationship  $[Si]/[Mg] \geq 1.8$  and a relationship  $1.6\% \leq 1.3 [Mg] + [Si] \leq 1.9\%$ .

3. The aluminum alloy sheet according to claim 1, wherein the aluminum alloy sheet has the average area ratio of cube orientation of 35% or more, and crashworthiness showing the bending angle of 90° or more at the VDA bending test.

4. The aluminum alloy sheet according to claim 2, wherein the aluminum alloy sheet has the average area ratio of cube orientation of 35% or more, and crashworthiness showing the bending angle of 90° or more at the VDA bending test.

5. A method of manufacturing an aluminum alloy sheet for a vehicle structural component, wherein an Al—Mg—Si aluminum alloy slab containing, by mass percent, Mg: 0.3 to 1.0%, Si: 0.5 to 1.2%, and Cu: 0.08 to 0.20%, content [Mg] of Mg and content [Si] of Si satisfying a relationship  $[Si]/[Mg] \geq 0.7$  and a relationship  $1.4\% \leq 1.3 [Mg] + [Si] \leq 1.9\%$ , the remainder consisting of Al and inevitable impurities is subjected to homogenization and then rolled into a rolled sheet having a thickness of 2.0 mm or more, the rolled sheet is subjected to solution treatment in which the rolled sheet is held for 0.1 to 30 sec within a range from 540 to 570° C., and is successively subjected to quenching, and is reheated within 10 min after finish of the quenching in such a manner that the rolled sheet is held for 3 to 20 hr within a material temperature range from 60 to 90° C. so as to be formed into an aluminum alloy sheet for a vehicle structural component, and the aluminum alloy sheet has a microstructure and properties, the microstructure including an average area ratio of cube orientation of 22% or more in a surface region from a surface of the sheet to a depth of 10% in the thickness direction, the properties including a yield ratio of 0.63 or less, and including 0.2% proof stress of 220 MPa or more and crashworthiness showing a bending angle of 60° or more at a VDA bending test when the aluminum alloy sheet is stretched by 2% and then subjected to artificial aging for 20 min at 180° C.

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