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(54) **ALUMINUM ALLOY EXTRUDATE EXCELLENT IN BENDING CRUSH RESISTANCE AND CORROSION RESISTANCE**

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(57) **ABSTRACT**

Disclosed is an Al—Mg—Si aluminum alloy extrudate which contains, in terms of mass %, 0.60-1.20% Mg, 0.30-0.95% Si, 0.01-0.40% Fe, 0.30-0.52% Mn, 0.001-0.65% Cu, and 0.001-0.10% Ti and in which the contents of Mg and Si satisfy $Mg(\%)-(1.73\times Si(\%)-0.25)\geqq 0$ and the remainder comprises Al. The extrudate has an equi-axed recrystallized grain texture in which the areal proportion of recrystallized grains is 65% or higher. In examination with a TEM having a magnification of 5,000, intergranular precipitate grains having a size of 1 μm or more in terms of center-of-gravity diameter are apart from one another at an average spacing exceeding 25 μm. The average areal proportion of Goss-orientation grains is less than 8% throughout the whole thickness of this extrudate.

ALUMINUM ALLOY EXTRUDATE EXCELLENT IN BENDING CRUSH RESISTANCE AND CORROSION RESISTANCE

TECHNICAL FIELD

[0001] The present invention relates to an Al—Mg—Si aluminum alloy extrudate excellent in bending crush resistance, and to a method for manufacturing the same (hereinafter "aluminum" is also simply referred to as "Al"). As used herein the term "aluminum alloy extrudate" refers to not only any extrudates (extrudates or materials) manufactured by hot extrusion but also any members incorporated into automotive bodies as their body reinforcements (or energy absorbing members) mentioned later. Hereinafter an "Al—Mg—Si" aluminum alloy is also referred to as an "6000-series" aluminum alloy.

BACKGROUND ART

[0002] To use such 6000-series aluminum alloy (6xxx aluminum alloy) extrudates as the reinforcements, much has been suggested about their metallographic structures for improvements in transverse crushing performance as reinforcements and in bending workability (bendability) into reinforcements.

[0003] Typically, Patent literature (PTL) 1 proposes an improvement in bending workability by allowing a 6000-series aluminum alloy extrudate to have an equiaxed granular structure. According to the technique disclosed in this literature, the equiaxed granular structure is obtained when the aluminum alloy contains Mg and Si in stoichiometrically equivalent amounts and also contains transition metal elements that promote the formation of a fibrous structure, such as Mn, Cr, and Zr, in a controlled total amount of 0.1% or less, and extrusion is performed at a temperature of 500° C. or higher, immediately followed by water quenching (forced cooling), as indicated in the working examples. The resulting equiaxed granular structure has an average grain size of 100 μm or less and an aspect ratio of crystal grains of 2 or less. The aspect ratio is a length-to-thickness ratio of a crystal grain, with the length being measured in the extrusion direction.

[0004] Independently, PTL 2 proposes a technique of allowing a hollow extrudate to improve in bending workability by allowing the same to have a fibrous structure (with crystal grains elongated in the extrusion direction) in place of the equiaxed granular structure. According to the technique disclosed in PTL 2, the extrudate is manufactured from an aluminum alloy containing transition metal elements such as Mn, Cr, and Zr in a relatively large total amount of 0.45% to 0.53% by extrusion at 500° C. or higher, which is immediately followed by water quenching (forced cooling) in a water bath, as indicated in the working examples.

[0005] It is known that the fibrous structure is effective for such extrudates as side members and bumper stays to be used as energy absorbing members requiting good longitudinal crushing performance in their axial (or lengthwise) direction, so as to resist Euler buckling (bending in a dogleg shape) but undergo deformation in a bellow shape. See PTL 3 and PTL4. PTL 3 proposes an extrudate of a 6000-series aluminum alloy containing Mg and Si in stoichiometrically equivalent amounts so as to have the fibrous structure. The patent literature also suggests that the tendency toward transformation into a recrystallization structure due to Mg and Si contained in stoichiometrically equivalent amounts is avoided if the extrudate contains transition metal elements such as Mn, Cr, and Zr in a relatively large total amount of 0.5%, and extrusion is performed at 500° C. or higher and immediately followed by water quenching, as indicated in the working examples.

[0006] PTL 4 proposes an extrudate of a 6000-series aluminum alloy which contains excess Si and also contains transition metal elements such as Mn, Cr, and Zr in a relatively large total amount of from 0.25% to 0.48%, as indicated in the working examples. According to this patent literature, extrusion is performed at 500° C. and the fibrous structure has a specific thickness of recrystallized layer (GG layer) and a specific grain size, so as to exhibit not only good longitudinal crushing performance but also good transverse crushing performance.

[0007] PTL 5 suggests that an extrudate of 6000-series aluminum alloy to be used as reinforcements should have not only a fibrous structure but also an anisotropically elongating structure so as to have both good bending workability and good crush-cracking resistance. According to this patent literature, the aluminum alloy extrudate contains excess Si and also contains transition metal elements such as Mn, Cr, and Zr in a relatively large total amount of 0.15% to 0.30% as indicated in the working examples. Moreover, it mentions that extrusion should be performed at a relatively low temperature under 500° C. with a high extrusion ratio of more than 10, so that the extrudate has the fibrous structure including crystal grains elongating in the extrusion direction, with the aspect ratio of more than 5. The resulting extrudate has an anisotropic structure such that the elongation (δ1) in the direction deviating by 45 degrees from the extrusion direction is larger than elongation (δ2) and (δ3) in the direction parallel and perpendicular, respectively, to the extrusion direction.

[0008] PTL 6 suggests that an extrudate of a 6000-series aluminum alloy to be used as side members and bumper reinforcements should have a fine equiaxed granular structure (with the aspect ratio of crystal grains of 3 or less) instead of the fibrous structure so as to have both good bending workability and good impact absorbing performance. The aspect ratio is a ratio in length of the long axis to the short axis of a crystal grain. According to this patent literature, the fine equiaxed granular structure contributes to improved elongation and bending workability and also restricts the amount and size of intergranular precipitates, thereby preventing fragmentation of crystal grains from occurring at intergranular precipitates under an impact.

[0009] PTL 1: Japanese Unexamined Patent Application Publication (JP-A) No. 2002-241880

[0010] PTL 2: Japanese Unexamined Patent Application Publication (JP-A) No. H05-171328

[0011] PTL 3: Japanese Unexamined Patent Application Publication (JP-A) No. H09-256096

[0012] PTL 4: Japanese Unexamined Patent Application Publication (JP-A) No. 2003-183757

[0013] PTL 5: Japanese Unexamined Patent Application Publication (JP-A) No. 2005-105317

[0014] PTL 6: Japanese Unexamined Patent Application Publication (JP-A) No. H06-25783

SUMMARY OF INVENTION

Technical Problem

[0015] When a 6000-series aluminum alloy extrudate is practically used as automotive body reinforcements, such as bumper reinforcements and door guard bars, they usually receive a concentrated collision force in the approximately horizontal direction. In such a situation, the 6000-series aluminum alloy extrudate is poor in bending crush resistance, which is important for improvement in transverse crushing performance, even though it has the fibrous structure or anisotropic structure (as suggested in PTL 2 to 5) or it has the equiaxed granular structure (as suggested in PTL 1 and PTL 6).

[0016] To cope with collision under more critical conditions, it is necessary to improve a 6000-series aluminum alloy extrudate in bending crush resistance. Meeting this requirement, however, is limited even with the relatively strong extrudate having the fibrous structure, as well as the extrudate having the equiaxed granular structure disclosed in the PTL 1 and PTL 6.

[0017] It is also effective for improving the bending crush resistance of reinforcements to suitably design the cross sectional shape of extrudates (reinforcements), in addition to improvements in material strength. However, insufficiency in bending crush resistance, which is important for improvements in transverse crushing performance, can obviously happen, depending on the magnitude of the load, not only to aluminum alloy bumper reinforcements having an approximately rectangular, simple hollow cross-section but also to aluminum alloy bumper reinforcements provided with one or more inner ribs for further reinforcement, such as one with a single inner rib provided in a central part of the cross section in parallel with the upper and lower side walls, or one with double inner ribs provided at a certain spacing in parallel with the upper and lower side walls, or one with cross inner ribs connected to four sides of the cross section.

[0018] For these reasons, 7000-series aluminum alloy extrudates, which have higher strength than that of 6000-series aluminum alloy extrudates, have been still used mainly in energy absorbing members, such as bumper reinforcements and door guard bars, which should laterally crush (which require transverse crushing performance). However, the 7000-series aluminum alloy extrudates, as containing large amounts of alloy components, are not suitable for the recycling and have high production cost. They also have corrosion resistance inferior to that of 6000-series aluminum alloy extrudates.

[0019] The present invention has been made under these circumstances, and an object of the present invention is to provide a 6000-series aluminum alloy extrudate and a manufacturing method thereof; which aluminum alloy extrudate excels both in bending crush resistance and corrosion resistance which are required of reinforcements of automotive bodies subject to collision under more severe conditions.

Solution To Problem

[0020] To achieve the object, the present invention provides an aluminum alloy extrudate excellent in bending crush resistance and corrosion resistance, being an extrudate of an Al—Mg—Si aluminum alloy including, in terms of percent by mass, Mg in a content of from 0.60% to 1.20%, Si in a content of from 0.30% to 0.95%, Fe in a content of from 0.01% to 0.40%, Mn in a content of from 0.30% to 0.52%, Cu in a content of from 0.001% to 0.65%, and Ti in a content of from 0.001% to 0.10%, the contents of Mg and Si satisfying condition $[\mathrm{Mg}\ (\%)]-(1.73\times[\mathrm{Si}\ (\%)]-0.25)\geqq 0$, with the remainder including Al and inevitable impurities. The aluminum alloy extrudate has an equiaxed recrystallized structure with an area ratio of recrystallized grains of 65% or more in a cross section in a thickness direction. The aluminum alloy extrudate has an average spacing of more than 25 μm between intergranular precipitates each having a size of 1 μm or more in terms of centroid diameter in observation of the structure under a transmission electron microscope (TEM) 4'5000 magnifications, and has an average area ratio of Goss orientation grains of less than 8%, throughout the entire thickness region including an outermost grain growth layer in the cross section in the thickness direction of the extrudate.

[0021] The aluminum alloy extrudate may further selectively contain at least one of Cr in a content of from 0.001% to 0.18% and Zr in a content of from 0.001% to 0.18%, as replacing part of Mn, within such a range that a total content of Mn, Cr, and Zr be from 0.30% to 0.52%.

[0022] The aluminum alloy extrudate according to the present invention, as having the specific chemical composition and structure, may have such bending crush resistance as to have a critical bending radius (R) of 3.0 mm or less without cracking in a 180-degree bending test according to a press-bending method prescribed in Japanese Industrial Standards (JIS) Z2248 in which a plate-shaped specimen is bent in an extrusion direction; and the aluminum alloy extrudate may have such corrosion resistance that a specimen does not suffer from intergranular corrosion in an alternating immersion corrosion test prescribed in International Organization for Standardization/Draft of International Standard (ISO/DIS) 11846B. The aluminum alloy extrudate will find use as energy absorbing members which crush under a load in a direction perpendicular to the extrusion direction.

[0023] The aluminum alloy extrudate having the equiaxed recrystallized structure, intergranular precipitate distribution, and texture and excelling in bending crush resistance and corrosion resistance may be manufactured by soaking a cast billet of an Al—Mg—Si aluminum alloy at a temperature of 560° C. or higher, the aluminum alloy having the chemical composition as defined above; forcedly cooling the soaked cast billet to a temperature of 400° C. or lower at an average cooling rate of 100° C./hr or more; reheating the cooled cast billet and subjecting the reheated billet to hot extrusion so that an extrudate reaches a solid solution temperature of 575° C. or higher at an extruder exit; immediately forcedly cooling the extrudate from the extruder exit at an average cooling rate of 5° C./second or more; and subjecting the cooled extrudate to aging. The aging is preferably performed under such conditions that the aged extrudate has a 0.2% yield strength of 280 MPa or more.

Advantageous Effects of Invention

[0024] The present inventors paid attention to the texture of the 6000-series (Al—Mg—Si) aluminum alloy extrudate which had not attracted attention so much in the past, and they investigated anew the effect of the texture on the bending crush resistance. As a result, they found that, of such textures, an equiaxed recrystallized structure with less Goss orientation grains significantly effectively improves the bending crush resistance.

[0025] Much has been studied about the texture of 6000-series aluminum alloy in the field of rolled plates to elucidate its effect on the press formability and bending workability of automotive panels. Bending workability includes hem formability, particularly flat hem formability. There are a number of patent literature based on such studies. Typically, it is known that the texture of 6000-series aluminum alloy is more effective in improvement of flat hem formability with an increasing ratio of the crystal grains having the Cube orientation. As known well, the Cube orientation is the major orientation of the texture in the rolled sheet of 6000-series aluminum alloy.

[0026] Unlike extrudates (for use as reinforcements), the rolled sheets of 6000-series aluminum alloy are used as automotive body panels and therefore they are very thin (about 1 mm or less) for weight saving. Moreover, when they undergo press forming (stamping) and bending, they receive a bending load which is different from collision load the extrudates receive. The bending load is applied by molds and punches almost uniformly over a broad area of the sheet. In addition, the rolled sheet has a relatively low strength (150 MPa or less in terms of 0.2% yield strength), even in the case of T4 material, in consideration of formability into automotive body panels.

[0027] The present invention, however, is intended to be adopted to an extrudate (reinforcement) which has a relatively large wall thickness of 2 mm or more than that (about 1 mm or less) of the rolled sheet and also has a rectangular hollow cross section This extrudate is a high-strength one having a 0.2% yield strength of 280 MPa or more. The above-mentioned rolled sheet receives a bending load upon hemming, but the bending load basically differs in deformation mechanism and pattern from that which the extrudate according to the present invention experiences upon vehicle collision (such as pole collision or offset collision) involving locally concentrated loads. The relation between flat hem formability and Cube orientation in the texture of rolled thin sheet of 6000-series aluminum alloy is useless for predicting how bending crush resistance varies depending on Goss orientation in the texture of the 6000-series aluminum alloy extrudate according to the present invention.

[0028] In the field of 6000-series aluminum alloy extrudate, it has been common practice to cause the extrudate to have the fibrous structure elongating in the extrusion direction in order that the resulting hollow extrudate has good crushing performance in the axial (lengthwise) direction (longitudinal crushing) and lateral (or crosswise) direction (transverse crushing), as disclosed in PTL 2 mentioned above. This technique fails to pay attention on the texture itself. Also for this reason, it is very difficult to predict how the bending crush resistance varies depending on the Goss orientation in 6000-series aluminum alloy extrudate.

[0029] According to the present invention, the 6000-series aluminum alloy extrudate is designed to have the texture in the form of equiaxed recrystallized structure with less growth of Goss orientation (grains having the Goss orientation) so as to improve bending crush resistance. Thus, the 6000-series aluminum alloy extrudate can be used as energy absorbing members, such as bumper reinforcements and door guard bars, which crush under loads in the lateral or transverse direction, in the same way as the extrudate of 7000-series aluminum alloy which has a relatively higher strength, with the former outperforming the latter in corrosion resistance.

Best Modes For Carrying Out the Invention

[0030] The 6000-series aluminum alloy extrudate according to the present invention will be illustrated in detail with reference to embodiments thereof.

Texture

[0031] The 6000-series aluminum alloy extrudate as a reinforcement improves in, bending crush resistance with a decreasing average area ratio of crystal grains having the Goss orientation (Goss orientation grains).

[0032] The present invention should meet the following requirements in order that the extrudate used as a reinforcement has improved bending crush resistance. The extrudate should have the metallographic structure whose cross section in the thickness direction shows the equiaxed recrystallized structure and also the average area ratio of Goss orientation grains is less than 8%, and preferably less than 5%, throughout the entire thickness region including an outermost grain growth layer in the cross section in the thickness direction of the extrudate.

[0033] The extrudate, if having an average area ratio of Goss orientation grains of 8% or more, may fail to improve in bending crush resistance when the extrudate is designed to have a high strength, and may fail to satisfy requirements (specifications) as automotive reinforcements.

[0034] The relation between the Goss orientation and the bending crush resistance may be described as follows.

[0035] The yield stress σy of a polycrystal is indicated by the equation: $\sigma y=M\cdot\tau_{CRSS}$ wherein M is the Taylor factor, and τ_{CRSS} is the critical resolved shear stress of crystal. The Taylor factor M is a constant corresponding to the crystal orientation, reaches a maximum of 3.674 when the tension axis is in parallel with [110] and [111], and reaches 2.449, near to the minimum 2.300, when the tension axis is in parallel with [100]. The critical resolved shear stress τ_{CRSS} has a constant value. It has been pointed out that the bending workability correlates with the Taylor factor.

[0036] The Taylor factor M reaches a maximum of 3.674 when the tension axis is in the Goss orientation, to increase the stress (yield stress cry) required upon deformation, and this often causes formation of a shear zone upon lateral bending deformation. As a result, crystal grains having the Goss orientation, if present in a large quantity, lead to deteriorated bending crush resistance.

[0037] As used herein the term "average area ratio of Goss orientation grains" is defined as the average area ratio throughout the entire thickness region including an outermost grain growth layer in a cross section in the thickness direction (cross section in a direction perpendicular to the extrusion direction; perpendicular cross section) of the extrudate. In the cross section in the thickness direction of the extrudate, there exist usually on both sides of the outermost surface the grain growth layer (GG layer or layer of coarse recrystallized structure) with a thickness of several hundred micrometers which inevitably occurs as the outermost surface comes into contact with the extrusion die. The outermost GG layer can have an orientation distribution different from that of internal equiaxed recrystallized structure other than the GG layer. Accordingly, in the present invention, the average area ratio of Goss orientation grains is prescribed in terms of the average area ratio throughout the entire thickness region including an outermost grain growth layer in a cross section in the thickness direction of the extrudate.

[0038] In addition, with the help of the crystal orientation analyzing method (SEM/EBSP method) mentioned later, it is possible to measure Goss orientation grains throughout the entire thickness region including the outermost grain growth layer, for example, over the region broader than a thickness of 2 mm of the extrudate, and it is also possible to obtain the average of the area ratios. In contrast, X-ray diffractometry (such as one for X-ray diffraction intensity), which is commonly used for measurement of the texture, is designed to measure the structure (or texture) in a relatively microscopic (small) region for each crystal grain as compared to the crystal orientation analyzing method that employs SEM/EBSP. Therefore, the X-ray diffractometry needs a large number of measurements to cover the area larger than 2 mm over the entire region in the thickness direction of the extrudate, and it is practically incapable of measuring the average area ratio of Goss orientation grains over the entire region in the thickness of the extrudates, as defined in the present invention.

Equiaxed Recrystallized Structure

[0039] The reason why the present invention is intended for the extrudate to have an equiaxed recrystallized structure is that the fibrous structure as disclosed in PTL 2 to 5, in which the crystal grain have an aspect ratio of more than 5 and elongate in the extrusion direction, may seldom allow an extrudate to have high strength and to excel in bending crush resistance. As used herein the term “equiaxed recrystallized structure” refers to an equiaxed granular structure in which crystal grains have an average aspect ratio of less than 5 even if crystal grains elongate in the extrusion direction. The term “aspect ratio of crystal grain” refers to the ratio of the major axis to the minor axis, with the major axis being measured in the extrusion direction and the minor axis being measured in the thickness direction.

[0040] The equiaxed recrystallized structure should have an area ratio of recrystallized grains of 65% or more in a cross section in the thickness direction. The equiaxed recrystallized structure, if having an area ratio of recrystallized grains of smaller than this range, may have insufficient bending crush resistance. The area ratio of recrystallized grains is preferably 80% or more.

[0041] The customary techniques disclosed in PTL 1 and PTL 6 mentioned above are intended for the 6000-series aluminum alloy extrudate to have the equiaxed recrystallized structure. However, though being able to provide the equiaxed recrystallized structure, the techniques fail to make Goss orientation grains be in an average area ratio of less than 8% throughout the entire region of the thickness direction of the cross section of the extrudate.

[0042] The technique disclosed in PTL 1 is designed to manufacture the extrudate in such a manner that Mg and Si are contained in stoichiometrically equivalent contents so that the equiaxed granular structure develops; the total amount of transition metal elements, such as Mn, Cr, and Zr, that promote the formation of fibrous structure is limited to 0.1% or less; and extrusion is performed at 500° C. or higher, immediately followed by water quenching for forced cooling, as in indicated in the working examples. The extrudate manufactured in this manner has an equiaxed granular structure having an average grain size of 100 μm or less and an aspect ratio of the crystal grain of 2 or less. PTL 6 discloses in its working examples an 6000-series aluminum alloy extrudate which has an excess-Si composition and optionally contains transition metal elements, such as Mn, Cr, and Zr, in a relatively large total amount of 0.34%. The extrudate does not undergo forced cooling such as water quenching (that immediately follows extrusion at 500° C.) on-line but undergoes separately solution treatment and quench hardening off-line.

[0043] In contrast, in order for the extrudate to have the grain structure such that growth of Goss orientation is suppressed to such an extent that its area ratio is less than 8% throughout the entire region of the thickness direction of the cross section of the extrudate, as intended in the present invention, it is necessary to control manufacturing conditions, typified by soaking treatment temperature, forced cooling after the soaking treatment, and extruder exit temperature. In addition, the chemical composition of the extrudate which does not contain a significantly excess amount of Si, unlike the technique disclosed in PTL 6, and contains transition metal elements, such as Mn, Cr, and Zr, in a content controlled within a specific range, is one condition for Goss orientation grains to be suppressed, as mentioned later. For these reasons, the extrudates disclosed in PTL 1 and PTL 6, which were manufactured by the process merely involving an ordinary soaking treatment without positive control mentioned above, do not suppress Goss orientation grains even when the other conditions than those mentioned above are the same as in the present invention. In other words, the extrudates according to the techniques disclosed in PTL 1 and PTL 1 and PTL 6 have the texture with random crystal orientations and hence they have an average area ratio of Goss orientation grains being inevitably higher than that in the extrudate according to the present invention. Specifically, the ordinary manufacturing method gives extrudates which have an equiaxed granular structure but fail to have an equiaxed granular structure in which Goss orientation grains are suppressed as intended in the present invention.

Measurement of Goss Orientation

[0044] The area ratio (the existence ratio) of Goss orientation grains (or orientation components of each crystal grain) is measured on the cross section (cross section in the thickness direction) typically of the flange (front wall) of the extrudate by a crystal orientation analyzing method (SEM/EBSP method) employing an EBSP (electron backscatter diffraction pattern) with help of a SEM (scanning electron microscope).

[0045] The crystal orientation analyzing method employing EBSP is carried out in such a manner that a specimen placed in the lens barrel of an SEM is irradiated with electron beams so that an EBSP is projected onto a screen. The image on the screen is photographed by a high-sensitivity camera and captured into a computer. In the computer, the image is analyzed and compared with patterns which have been obtained by simulation with known crystal systems, so that the crystal orientation is identified.

[0046] The crystal orientation analysis employing EBSP is not performed on individual crystals but is performed on a specific region of the specimen through scanning at certain intervals. Therefore, the above-mentioned process is performed on all the points of measurement automatically, and there are obtained tens to hundreds of thousands of data for crystal orientation at the end of measurement. This measuring method offers the advantage of permitting observation over a wide field of view and providing information about a large number of crystal grains, including average grain size, standard deviation of average grain size, and orientation analysis, within a few hours. Therefore, the method is most suitable for the measurement of the texture which is to be analyzed over the entire region, such as a broad region of 2 mm or more in thickness, in the thickness direction of the extrudate, including the outermost GG layer, as in the present invention.

[0047] The crystal orientation analysis employing EBSP uses a specimen for observation of structure which is taken from the cross section of the extrudate. The cross section covers all the directions in the thickness, including the outermost GG layer. The specimen is prepared by mechanical polishing, buffing, and electrolytic polishing. The resulting specimen is examined typically by JEOL JSM 5410 (supplied by Japan Electron Optics Laboratory Ltd) typically with the EBSP measuring and analyzing system "OIM" (Orientation Imaging Macrograph) bundled with an analyzing program called OIMAnalysis, supplied by TexSEM Laboratories, Inc. The analysis judges whether or not each crystal grain has a target orientation (or within 15 degrees from the ideal orientation) and then determines the density of an orientation (area ratio of grains having the orientation) in the field of view for which measurement has been carried out. Measurement is carried out at suitable several points at intervals of 3 μm or less in the cross section of the extrudate, and the measured values are averaged.

[0048] The region of specimen for measurement is usually divided into, for example, hexagonal sections and each section is irradiated with electron beams so that reflected beams form a Kikuchi pattern. Two-dimensional scanning with electron beams on the specimen surface to measure the crystal orientation at predetermined intervals gives the distribution of orientations of the specimen surface. The thus obtained Kikuchi pattern is analyzed to define the crystal orientation at the position for incident beams. Specifically, the resulting Kikuchi pattern is compared with the data of known crystal structures to identify the crystal orientation at the measurement point, based on which the average area ratio of Goss orientation grains is determined.

Texture

[0049] The texture including Goss orientation grains of the extrudate is examined in accordance with prescriptions and measurement procedure for rolled sheets, with the measurement portions being regarded as a plate.

[0050] Each orientation is represented as follows according to "Texture" written and edited by NAGASHIMA Shinichi (published by MARUZEN Co., Ltd.) and "Light Metals" edited by The Japan Institute of Light Metals, vol. 43 (1993), pp. 285-293. Cube orientation: {001}<100>; Goss orientation: {011}<100>; CR orientation: {001}<520>; RW orientation: {001}<110>[corresponding to Cube orientation turned with respect to the (100) plane]; Brass orientation: {011}<211>; S orientation: {123}<634>; Cu orientation: {112}<111>(or D orientation: {4411}<11118>); SB orientation: {681}<112>

Intergranular Precipitates

[0051] In order for the 6000-series aluminum alloy extrudate to exhibit good bending crush resistance and corrosion resistance when used as reinforcements, the present invention specifies that the extrudate has the texture in which intergranular precipitates each having a size of 1 μm or lager in terms of centroid diameter are separate from one another at an average spacing of 25 μm or more in the observation under a TEM of 5000 magnifications. The larger the average spacing between intergranular precipitates is, the better.

[0052] As used herein the term "intergranular precipitates" (precipitates present at grain boundaries) denotes compounds such as MgSi or elementary Si, which are expected from the chemical composition of the 6000-series aluminum alloy. MgSi forms, for example, β' phase to increase the strength (yield strength) of the 6000-series aluminum alloy extrudate used as reinforcements. Intergranular precipitates, however, are harmful if they are excessively coarse and they exist excessively densely (in an excessively large amount); they will cause rupture and propagate rupture even when the texture is controlled as mentioned above, thereby deteriorating the bending crush resistance and corrosion resistance of the extrudate used as automotive reinforcements. The distance between intergranular precipitates can be said as a precondition to allow the 6000-series aluminum alloy extrudate to exhibit good bending crush resistance and corrosion resistance.

[0053] In the case where intergranular precipitates 1 μm or lager in terms of the centroid diameter less than 25 μm separate from one another on average in the observation under a TEM of 5000 magnifications, intergranular precipitates are coarse and excessively close to one another and are distributed densely. Therefore, they cause intergranular rupture and propagate the rupture when they receive bending loads (crush-induced loads) upon collision. Therefore, the extrudate used as automotive reinforcements decreases in bending crush resistance even though the texture is controlled as mentioned above. Incidentally, intergranular precipitates smaller than 1 μm in terms of the centroid diameter do not affect bending crush resistance and corrosion resistance so much. Therefore, such small intergranular precipitates are not taken into account herein in order to clarify the relation between the distance between intergranular precipitates as specified in the present invention and the aforementioned properties.

Measurement of Average Spacing Between Intergranular Precipitates And Size of Intergranular Precipitates

[0054] Measurement of the average spacing between intergranular precipitates and the size of intergranular precipitates is performed on the equiaxed recrystallized structure in the cross section of the extrudate. Unlike in the observation of the texture as mentioned above, this structure excludes the outermost GG layer and includes an inner portion of the extrudate, such as the central part in the thickness direction of the extrudate. A specimen for equiaxed recrystallized structure is made into a thin film, whose structure is subsequently observed under a TEM of 5000 magnifications to measure the parameters.

[0055] The observation under a TEM is designed to examine the structure in a more microscopic (much smaller) region than in the crystal orientation analysis by means of SEM/EBSP mentioned above. It needs a huge number of measurements if observation is performed over the entire region in the thickness direction of the extrudate. To avoid this, in actual practice, observation is performed at one point in the center of the thickness such that the total field of view is 800 μm^2 or more, and this procedure is repeated at ten points an adequate distance apart in the lengthwise direction of the extrudate, and the resulting data are averaged. The centroid diameter of each intergranular precipitate is expressed in terms of the diameter of an equivalent circle (equivalent circle diameter, projected area diameter). All the intergranular precipitates in the field of view are examined for the diameter of equivalent circle (centroid diameter), and those each having a centroid diameter of 1 μm or more are selected. The average spacings between all the adjacent intergranular precipitates thus selected are measured, and the resulting data are averaged.

Chemical Composition

[0056] The chemical composition of the 6000-series aluminum alloy to which the present invention is applied will be described below. The 6000-series aluminum alloy requires properties such as satisfactory bending crush resistance and good corrosion resistance so as to be used as automotive reinforcements as mentioned above.

[0057] To meet this requirement, the 6000-series aluminum alloy extrudate (or the cast billet as a raw material thereof) to which the present invention is applied is an Al—Mg—Si aluminum alloy containing, as its chemical composition in percent by mass, Mg in a content of from 0.60% to 1.20%, Si in a content of from 0.30% to 0.95%, Fe in a content of from 0.01% to 0.40%, Mn in a content of from 0.30% to 0.52%, Cu in a content of from 0.001% to 0.65%, and Ti in a content of from 0.001% to 0.10%, the contents of Mg and Si satisfying the condition: $[\mathrm{Mg}\ (\%)] - (1.73\times[\mathrm{Si}\ (\%)]-0.25)\geqq 0$, with the remainder including Al and inevitable impurities. The chemical composition may further selectively include at least one of Cr in a content of from 0.001% to 0.18% and Zr in a content of from 0.001% to 0.18% as replacing part of Mn, with a total content of Mn, Cr, and Zr being from 0.30% to 0.52%. All percentages (%) for the contents of respective elements herein are in terms of percent by mass.

[0058] Any other elements than listed above are basically impurities. The content of such impurities should be lower than the level allowed by the Aluminum Association (AA) standards and Japanese Industrial Standards (JIS). However, contamination with impurities is liable to occur when the molten metal (melt) is prepared from not only high-purity aluminum ingots but also scraps of 6000-series alloys and other aluminum alloys in large amounts for the purpose of recycling. Reducing these impurity elements, for example, below the detection limit increases production cost, and a certain level of their content should be permitted. Therefore, other elements than listed above may be permitted according typically to the AA standards or JIS.

[0059] Preferred content and meaning thereof, or permissible content of each element in the 6000-series aluminum alloy will be illustrated below.

Si

[0060] The Si content should be from 0.30% to 0.95% on the precondition that the aforementioned condition between Si and Mg contents is satisfied. The Si content is preferably from 0.40% to 0.70%, and more preferably from 0.40% to 0.60% so as to give the balanced alloy mentioned above. Silicon (Si) is, as well as Mg, an essential element which contributes to solid-solution strengthening and forms aging precipitates (which contribute to strengthening) in crystal grains upon artificial aging treatment at a low temperature, thereby exhibiting the ability of age hardening and imparting strength (yield strength) of 280 MPa or more necessary for reinforcements. If in an excessively low content, Si may not form the compound phase upon artificial aging treatment, without attaining the age hardening and desired strength. If in an excessively high content, Si may not give the balanced alloy which has the texture specified in the present invention. An excessively high content of Si may increase intergranular precipitates and be detrimental typically to bending workability and weldability.

Mg

[0061] The Mg content should be from 0.60% to 1.20%, on the precondition that the condition between Si and Mg contents is satisfied. The Mg content is more preferably from 0.70% to 1.1% so as to give the balanced alloy. Magnesium (Mg) is an essential element which causes solid-solution strengthening and forms, together with Si, aging precipitates (which contribute to strengthening) in crystal grains upon artificial aging treatment, thereby exhibiting the ability of age strengthening and imparting strength (yield strength) of 280 MPa or more necessary for reinforcements. If in an excessively low content, Mg may not form the compound phase upon artificial aging treatment, without attaining the age hardening and desired strength. If in an excessively high content, Mg may not give the balanced alloy. An excessively high content of Mg is detrimental to bending workability.

Contents of Mg And Si

[0062] In order that the 6000-series aluminum alloy extrudate has the equiaxed recrystallized structure having an average area ratio of Goss orientation grains of less than 8% and having an average spacing of 25 μm or more between intergranular precipitates having a size of 1 μm or more in terms of centroid diameter, the contents of Mg and Si satisfies the condition $\mathrm{Mg}\ (\%)-(1.73\times\mathrm{Si}\ (\%)-0.25)\geqq 0$. This relationship was established for the 6000-series aluminum alloy specified in the present invention to be a balanced alloy which contains Mg and Si in stoichiometrically equivalent amounts or an Si-excess aluminum alloy with a relatively low content of Si.

[0063] A 6000-series aluminum alloy which contains Si in an amount more than specified by the condition $[\mathrm{Mg}\geqq 1.73\times\mathrm{Si}]$, or an aluminum alloy of Si-excess type which contains Si in a more excessively large amount, increases in yield strength upon artificial age hardening treatment at a relatively low temperature and exhibits good age hardening performance (baking hardening performance; BH performance) that imparts necessary strength. Therefore, it is commonly used in the field of 6000-series aluminum alloy sheets which need good formability and high strength after forming so that it is made into automotive panels by press forming (stamping) or bending.

[0064] However, if the 6000-series aluminum alloy extrudate according to the present invention has the Si-excess composition, Si remains undissolved during extrusion and becomes nuclei having various crystal orientations, resulting in the texture with random orientations, possibly resulting in relatively developed Goss orientation grains. The resulting extrudate also tends to have the fibrous structure elongating in the extrusion direction.

[0065] For this reason, any extrudate manufactured from an 6000-series aluminum alloy containing excess Si would not have the equiaxed recrystallized structure having an average area ratio of Goss orientation grains of less than 8% over the entire region in the thickness direction of the extrudate, the thickness region including the outermost grain growth layer, though this depends on the manufacturing conditions such as extrusion conditions. Moreover, Si, if in an excess content, may cause a larger number of coarse intergranular precipitates derived from Si, which would prevent the formation of the above-mentioned texture and the structure having an average spacing between intergranular precipitates having a size of 1 μm or more in terms of centroid diameter, which is necessary for the extrudate to exhibit good bending crush resistance and corrosion resistance as reinforcements. Therefore, if the Si content exceeds such an amount as to satisfy the condition: $\mathrm{Mg}\ (\%)-(1.73\times\mathrm{Si}\ (\%)-0.25)\geqq 0$, the extrudate would not exhibit good bending crush resistance and corrosion resistance when used as reinforcements. This depends on the manufacturing conditions such as extrusion conditions.

Fe

[0066] Iron (Fe) functions in the same way as Mn Cr, and Zr to form dispersed particles (dispersoids), impedes grain boundary migration after recrystallization, prevents crystal grains from becoming coarse, and makes crystal grains fine. Fe is an element which inevitably contaminates in a certain amount (substantial amount) from scraps as a raw material for molten metal. For these reasons, the content of Fe should be from 0.01% to 0.40%. Fe, if in an excessively low content, may not exhibit these effects. Fe, if in an excessively high content, may tend to cause coarse crystals such as Al—Fe—Si crystals, which impair properties such as fracture toughness and fatigue characteristics. The Fe content is more preferably from 0.1% to 0.3%.

Mm

[0067] Manganese (Mn) is a transition metal element like Cr and Zr and is necessary for prevention of crystal grains from becoming coarse. These elements selectively combine with other alloy elements to form dispersed particles (dispersoids) of Al—Mn and other intermetallic compounds upon soaking treatment and subsequent hot extrusion The dispersed particles are fine and dispersed densely and uniformly (to varied degrees depending on the manufacturing conditions), so that they effectively hinder grain boundary migration (as pinning effect) after recrystallization and highly effectively prevent crystal grains from becoming coarse and make crystal grains fine. Mn, if in an excessively low content, may exhibit insufficient pinning force on grain boundaries, allow the growth of Goss orientation to an average area ratio of Goss orientation grains of 8% or more to thereby tend to deteriorate bending workability. Mn is also expected to dissolve in the matrix to increase strength.

[0068] Excess Mn, however, may cause the extrudate to have the fibrous structure elongating in the extrusion direction. This prevents the formation of the equiaxed recrystallized structure having an average area ratio of Goss orientation grains of less than 8%. Moreover, excess Mn tends to form, upon melting and casting, coarse intermetallic compounds and crystals which cause rupture and cause the extrudate to decrease in required properties as reinforcements, such as bending crush resistance and corrosion resistance, and bending workability of the extrudate. Therefore, the Mn content should be from 0.3% to 0.52% (in the case where Cr and Zr are not added).

Cu

[0069] Copper (Cu) contributes to improved strength through solid-solution strengthening and also remarkably promotes age hardening of the final product upon aging treatment. The content of Cu should therefore be from 0.001% to 0.65%. Cu, if in an excessively low content, may not exhibit the effects mentioned above. In contrast, excess Cu may cause the extrudate to be highly susceptible to stress corrosion cracking and intergranular corrosion, thereby deteriorating corrosion resistance and durability. The Cu content should therefore be as specified above. The Cu content is more preferably from 0.2% to 0.5%.

Ti

[0070] Titanium (Ti) makes crystal grains in an ingot fine and allows the extrudate to have the structure including such fine crystal grains. The extrudate should contain Ti in a content of from 0.001% to 0.10%. When the source of Ti contains boron (B), the content of B should be from 1 to 300 ppm. Ti, if in an excessively low content, may not exhibit the above-mentioned effects. In contrast, excess Ti may form coarse crystals and may cause the extrudate to decrease in required properties as reinforcements, such as bending crush resistance and corrosion resistance, and in bending workability of the extrudate. Therefore, an adequate content of Ti is in the range specified above.

At Least One of Cr And Zr

[0071] Chromium (Cr) and zirconium (Zr) form dispersed particles (dispersoids) of Al—Cr, Al—Zr, and other intermetallic compounds, thereby effectively preventing crystal grains from becoming coarse (as pinning effect), as with Mn. However, excess Cr and Zr, like excess Mn, may cause the extrudate to have the fibrous structure which elongates in the extrusion direction. When the aforementioned effects are necessary, part of Mn is replaced with at least one of Cr in a content of from 0.001% to 0.18% and Zr in a content of from 0.001% to 0.18% with a total content of Mn, Cr, and Zr of from 0.30% to 0.52%. Mn is desirably contained in a content of 0.13% or more so as to cause a preferential growth of Cube orientation grains and to relatively suppress a growth of Goss orientation grains. Within this range, Zr is preferably contained in a content of from 0.1% to 0.18%. This enables the extrudate to have a further lower average area ratio of Goss orientation grains of less than 5% to further improve bending workability while having an area ratio of recrystallized grains of 65% or more. The improved bending workability means that, even when the extrudate has an identical critical bending radius R to that of one having a Zr content out of the above-specified range, shows smaller cracking when the extrudate is bent over the critical bending radius R and suffers from cracking. These are achieved by the manufacturing method according to the present invention, in which the cast billet is soaked at a high temperature, the soaked billet is reheated to a high temperature, extruded at a high rate and at a high extruder exit temperature. Specifically, the heating at a high temperature slightly weakens the pinning force derived from Al—Zr intermetallic compound particles, allows a preferential growth of Cube orientation grains having a high growth rate, and relatively impedes a growth of Goss orientation grains.

Zn

[0072] Zinc (Zn) is contained in the 6000-series aluminum alloy as an impurity. Zn, if present in a content of 0.001% or more, effectively improves the strength due to solid-solution strengthening and accelerates age hardening, as with Cu. In contrast, Zn, if present in an excessively high content, may cause the extrudate structure to have remarkably high susceptibility to stress corrosion cracking and intergranular corrosion and to have insufficient corrosion resistance and durability. For these reasons, an acceptable Zn content is 0.25% or less, as with a JIS 6061 alloy.

Sectional Shape of Extrudate

[0073] The 6000-series aluminum alloy extrudate may have a suitable sectional shape selected so as to exhibit good bending crush resistance when used as reinforcements. The sectional shape is preferably hollow so that the extrudate has a light weight and good bending crush resistance required of reinforcements. The hollow sectional shape may typically (basically) be rectangular. The rectangular shape includes two flanges (front and rear walls) and two webs (upper and lower walls connecting the both flanges). The rectangular cross section may additionally have one or more inner ribs for reinforcement (and for improvement in bending crush resistance). Possible arrangements using such inner ribs include one with a single inner rib provided in a central part of the cross section in parallel with the upper and lower side walls, or one with double inner ribs provided at a certain spacing in parallel with the upper and lower side walls, or one with cross ribs connected to four sides of the cross section.

[0074] The sectional shape may be modified such that the flanges are wider than the distance between the webs (or the edges of the flanges extend beyond the webs horizontally or vertically), or the flanges and webs may be curved inward or outward instead of being straight. The hollow sectional shape may be uniform over the entire length of the extrudate (reinforcement) or may vary from one place to another along the length partially or sequentially. Such variation may be chosen freely in view of reinforcement design. The extrudate to be used as the bumper reinforcement may have a hollow sectional shape which is not completely closed but is partially opened in any of walls and sides, instead of being the hollow shape with completely closed cross section as described above. The partially opened sectional shape is, however, less strong than the completely closed one and disadvantageous for weight saving and bending crush resistance.

Wall Thickness of Extrudate

[0075] The extrudate should have an adequate wall thickness in relation to the sectional shape so as to exhibit better bending crush resistance required of reinforcements. Since the present invention is intended for automotive reinforcements that absorb energy upon collision, the extrudate should have a certain wall thickness unlike body panels of rolled thin sheets, so as to exhibit good bending crush resistance required of reinforcements. A larger wall thickness is desirable for good bending crush resistance, but an excessively large thickness increases weight, which is contrary to weight saving. Therefore, an adequate wall thickness may be selected within a range of 2 to 7 mm. It is not always necessary that the parts such as flanges, webs, and inner ribs constituting the above-mentioned sectional shape have the same thickness, but they may have different thicknesses. For example, the flanges which receive loads upon collision may be thicker than other parts.

Manufacturing Method

[0076] The method for manufacturing the 6000-series aluminum alloy extrudate will be illustrated below. The extrudate according to the present invention refers to one which undergoes refining (thermal refining), such as quenching and artificial age hardening treatment, after hot extrusion. The manufacturing process itself is ordinary and known, except typically for the conditions for controlling the texture.

[0077] The manufacturing method for the extrudate according to the present invention starts with preparing a billet from the 6000-series aluminum alloy. The billet is subjected to soaking, followed by cooling approximately to room temperature. The billet is, heated again to a temperature for solution treatment and then subjected to hot extrusion. The extrudate is immediately cooled to a temperature of 190° C. or lower (or down to room temperature) for forced cooling on-line. In this way there is obtained the extrudate having the specific sectional shape. The extrudate that has passed through the series of hot extrusion steps also has undergone solution and quenching treatments. Subsequently, the extrudate undergoes cutting and straightening treatment and optional suitable refining such as artificial age hardening. Alternatively, the artificial age hardening may be performed simultaneously with paint baking after the extrudate (as a reinforcement) has been built into the automotive body and the automotive body has been painted, instead of being performed preliminarily while the extrudate still remains as such.

Melting And Casting

[0078] In the melting and casting step, an aluminum alloy having the above-mentioned chemical composition conforming to 6000 series is melted, and the molten metal is cast according to a suitable common procedure, such as continuous casting or semicontinuous casting (e.g., direct chill casting (DC casting)).

Soaking Heat Treatment

[0079] The billet of aluminum alloy which has been cast as mentioned above subsequently undergoes soaking heat treatment. Soaking temperature itself is chosen within high temperatures of 560° C. or higher and lower than the melting point, and optimally chosen within temperatures of from 560° C. to 590° C. The soaking heat treatment (soaking) is intended to homogenize the structure, specifically, to eliminate segregation from the crystal grains in the structure of the billet, thereby making alloy elements and coarse compounds into a complete solid solution. Soaking at a lower temperature than specified above may not completely eliminate segregation from crystal grains; and residual segregation may cause rupture. Soaking at a temperature of lower than 560° C. may fail to give an equiaxed recrystallized structure (particularly in the case where the alloy contains Zr in a content of from 0.1% to 0.18%), or even if giving the equiaxed recrystallized structure, may cause the extrudate to have a high area ratio of Goss orientation grains and to have insufficient bending crush resistance.

[0080] After the soaking, the billet undergoes forced cooling to 400° C. or lower (or further down to room temperature) at an average cooling rate of 100° C./hr or more. Forced cooling is preferably accomplished at a higher cooling rate by air blowing or with water. Once 400° C. or lower is reached after soaking, forced cooling may be stopped at the temperature, or switched to self-cooling down to mom temperature, or continued down to mom temperature, as arbitrarily chosen.

[0081] The cooling rate mentioned above is quite different from one employed in a customary procedure where billets are allowed to cool outside the soaking pit. In this case the cooling rate is usually about 40° C./hr at the highest, depending on the size of billets; it never exceeds 100° C./hr as mentioned above. Such slow cooling results in that MgSi compounds, which have dissolved temporarily into solid solution during soaking treatment at a high temperature, combine, during cooling, with FeAl compounds, which remain undissolved because of their high melting points, to form other composite compounds (precipitates). Such composite compounds (precipitates), once formed, remain undissolved in the extrusion process and become nuclei having various crystal orientations like excess Si mentioned above, thereby altering the structure into a texture with random orientations. This impedes the development of Cube orientation grains, relatively increases the ratio of Goss orientation grains, and impairs bending crush resistance.

Hot Extrusion

[0082] Next, the billet undergoes reheating and hot extrusion so that the temperature of the extrudate (at the exit of the extruder) be 575° C. or higher, which is high enough to keep the extrudate in solution form. Immediately after extrusion, the extrudate undergoes forced cooling to 190° C. or lower (or further down to room temperature) at an average cooling rate of 5° C./min or higher. This forced cooling is necessary to achieve T5 refining, which is preferably combined with subsequent artificial aging to achieve T6 refining (aging) or T7 refining (over aging). Once the temperature of the extrudate reaches 190° C. or below through cooling immediately after extrusion, forced cooling may be stopped at the temperature, or switched to self-cooling down to room temperature, or continued down to mom temperature, as arbitrarily chosen. For T5 refining, the extrudate at the exit of the extruder is kept at 575° C. or higher, which is high enough to keep the extrudate in solution form. The extrudate undergoes solution treatment on-line (as the result of extrusion) and, immediately thereafter, undergoes forced cooling (for quenching) down to the neighborhood of room temperature on-line (on the exit side of the extruder).

[0083] The temperature upon hot extrusion may be rather low so that cube orientations develop easily and the texture of the extrudate becomes the equiaxed recrystallized structure in which Cube orientation grains become a domination, and the average area ratio of Goss orientation grains is less than 8% over the entire region in the thickness direction of the cross section of extrudate. However, if the temperature of the extrudate at the exit of the extruder is lower than 575° C. (which is the solution temperature), an equiaxed recrystallized structure having an area ratio of recrystallized grains of 65% or more may not be obtained, coarse intergranular precipitates (e.g., Mg—Si compounds (precipitates) and elementary Si) remain undissolved in the matrix and they start rupture to impair bending crush resistance and corrosion resistance. To meet the trade-off requirements, it is desirable to select a lower possible temperature of 575° C. or higher (solution temperature) for the extrudate at the exit of the extruder. However, it is not always necessary to reheat the cast billet to 500° C. or higher for extrusion, as long as the temperature of the extrudate at the extruder exit be 575° C. or higher by the action of heat generation during hot extrusion. Extrusion at an excessively low rate may fail to allow the extrudate to have a temperature within the solution temperature range. However, extrusion at a low rate tends to allow Cube orientation grains to accumulate, whereas extrusion at a high rate tends to allow Goss orientation grains to accumulate. For these reasons, it is preferred to select such an extrusion rate that the temperature of the extrudate can be risen to a solid solution temperature without decrease in Cube orientation grains and increase in Goss orientation grains.

[0084] The temperature of the extrudate at the extruder exit refers to the temperature of the extrude surface immediately downstream from the die exit (at a distance of 0 mm from the exit). When the temperature immediately downstream from the die exit is difficult to be measured, the aforementioned temperature may be determined by measuring the temperature of the extrudate surface at a certain distance from the die exit (the position where temperature measurement can be performed varies depending on the extrusion press to be used) with a contact type thermometer; and, from the measured temperature, calculating backward the temperature immediately downstream from the die exit using a cooling curve of the extrudate which has been measured in advance.

[0085] Forced cooling for quenching down to 190° C. or below (or further down to room temperature) at an average cooling rate of 5° C./second or more immediately after extrusion is intended for the extrudate as reinforcements to improve in bending crush resistance. Specifically, forced cooling alters the texture of the extrudate into the equiaxed recrystallized structure having an average area ratio of Goss orientation grains of less than 8%. In addition, forced cooling also gives rise to intergranular precipitates having a size of 1 μm or more in terms of centroid diameter and are separated from one another at an average spacing of 25 μm or more so as to improve bending crush resistance and corrosion resistance. Forced cooling immediately after extrusion is preferably performed through cooling with water. In this process, the forced cooling may be performed on-line with any forced cooling means arranged near the exit of the extruder, such as mist, shower or spray typically of water, or water bath, alone or in combination. The cooling rate for forced cooling means with water can generally be 10° C./second or more, while varying depending on the specifications of facilities.

[0086] The T5 refining treatment saves post-extrusion steps such as reheating, solution treatment, and quenching for the extrudate. Under certain circumstances or for the sake of convenience, the T5 refining treatment may be replaced by the T6 refining treatment which includes separate reheating of the extrudate after hot extrusion to 500° C. or higher, and subsequent solution treatment, quenching, and artificial aging treatment, to give a T6 refining extrudate.

Aging Treatment

[0087] The extrudate undergoes artificial aging treatment after cutting to a predetermined length or straightening treatment. Artificial aging treatment is preferably carried out at a temperature of from 150° C. to 250° C. for a necessary period of time. Duration of aging treatment controls age hardening, and may be properly selected to maximize strength (peak aging) or extended for overaging that improves corrosion resistance.

EXAMPLES

[0088] Next, some working examples of the present invention will be illustrated below. Samples of extrudates were prepared from 6000-series aluminum alloys varying in composition as given in Tables 1 and 2 and under different conditions as given in Tables 3 and 4. The extrudates each have a rectangular sectional shape with a center inner rib. Each sample was examined for structure and properties (such as mechanical properties and bending crush resistance) as shown in Tables 5 and 6.

TABLE 1

	Chemical Composition (percent by mass)											
	Number	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Mn + Cr + Zr	Mg—(1.73Si-0.25)
Examples	1	0.544	0.189	0.352	0.343	0.945	0.001	0.014	0.022	0.143	0.49	0.25
	2	0.544	0.189	0.352	0.343	0.945	0.001	0.014	0.022	0.143	0.49	0.25
	3	0.544	0.189	0.352	0.343	0.945	0.001	0.014	0.022	0.143	0.49	0.25
	4	0.534	0.197	0.335	0.352	0.914	0.000	0.012	0.020	0.141	0.49	0.24
	5	0.538	0.215	0.348	0.202	0.955	0.052	0.008	0.022	0.145	0.40	0.27
	6	0.521	0.206	0.348	0.350	0.959	0.000	0.008	0.002	0.000	0.35	0.31
	7	0.581	0.200	0.344	0.351	0.927	0.050	0.012	0.023	0.001	0.40	0.17
	8	0.564	0.222	0.358	0.350	0.910	0.000	0.015	0.022	0.154	0.50	0.18
	9	0.549	0.194	0.331	0.361	0.903	0.000	0.012	0.023	0.156	0.52	0.20
	10	0.542	0.192	0.364	0.344	0.959	0.000	0.009	0.022	0.144	0.49	0.27
	11	0.450	0.210	0.352	0.351	0.720	0.000	0.010	0.021	0.150	0.50	0.19
	12	0.400	0.210	0.600	0.350	0.796	0.053	0.000	0.019	0.000	0.40	0.35
	13	0.700	0.150	0.150	0.350	1.100	0.000	0.010	0.020	0.020	0.37	0.14
Comparative Examples	1	0.534	0.197	0.335	0.352	0.914	0.001	0.012	0.020	0.141	0.49	0.24
	2	0.560	0.182	0.349	0.204	0.925	0.047	0.014	0.023	0.000	0.25*	0.21
	3	0.553	0.187	0.344	0.204	0.940	0.052	0.008	0.022	0.000	0.26*	0.23
	4	0.553	0.187	0.344	0.204	0.940	0.052	0.008	0.022	0.000	0.26*	0.23
	5	0.538	0.215	0.348	0.202	0.955	0.052	0.008	0.022	0.145	0.40	0.27
	6	0.581	0.200	0.344	0.351	0.927	0.050	0.012	0.023	0.001	0.40	0.17

*Data out of the conditions specified in the present invention

TABLE 2

	Chemical Composition (percent by mass)											
	Number	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Mn + Cr + Zr	Mg—(1.73Si-0.25)
Comparative Examples	7	0.584	0.214	0.347	0.354	0.934	0.049	0.000	0.022	0.140	0.54*	0.17
	8	0.584	0.214	0.347	0.354	0.934	0.049	0.000	0.022	0.140	0.54*	0.17
	9	0.549	0.194	0.331	0.350	0.903	0.000	0.012	0.023	0.156	0.51	0.20
	10	0.900	0.080	0.160	0.100	0.570	0.050	0.000	0.020	0.000	0.15*	−0.74*
	11	0.410	0.200	0.170	0.000	0.750	0.050	0.000	0.020	0.000	0.05*	0.29
	12	0.588	0.224	0.356	0.358	0.922	0.000	0.013	0.023	0.156	0.51	0.15
	13	0.564	0.222	0.358	0.350	0.910	0.000	0.015	0.022	0.154	0.50	0.18
	14	0.588	0.224	0.356	0.358	0.922	0.000	0.013	0.023	0.156	0.51	0.15
	15	0.970*	0.140	0.160	0.000	0.590*	0.050	0.010	0.020	0.000	0.05*	−0.84*
	16	0.574	0.500*	0.353	0.198	0.954	0.050	0.012	0.018	0.007	0.26*	0.21
	17	0.400	0.200	0.800*	0.050	0.800	0.050	0.100	0.020	0.000	0.10*	0.36
	18	0.400	0.200	0.150	0.550*	0.800	0.050	0.020	0.020	0.000	0.60*	0.36
	19	0.850	0.200	0.150	0.050	1.300*	0.050	0.100	0.020	0.000	0.10*	0.08
	20	0.400	0.200	0.150	0.150	0.800	0.200*	0.000	0.020	0.200*	0.55*	0.36
	21	0.400	0.200	0.150	0.050	0.800	0.050	0.350*	0.020	0.000	0.10*	0.36
	22	0.400	0.200	0.150	0.050	0.800	0.050	0.000	0.200*	0.000	0.10*	0.36
	23	0.220*	0.200	0.150	0.100	0.400*	0.050	0.000	0.020	0.000	0.15*	0.27
	24	0.549	0.194	0.331	0.361	0.903	0.000	0.012	0.023	0.156	0.52	0.20

*Data out of the conditions specified in the present invention

TABLE 3

	Manufacturing Method							
	Number	Soaking temperature (° C.) (for 4 hrs)	Rate of cooling after soaking (° C./hr)	Billet heating temperature (° C.)	Extrusion rate (m/min)	Die exit temperature (° C.)	Rate of cooling immediately after extrusion (° C./s)	Artificial aging
Examples	1	590	100 or more	500	10	578	13	190° C. for 3 hrs
	2	580	100 or more	500	10	579	14	190° C. for 3 hrs
	3	570	100 or more	500	10	578	13	190° C. for 3 hrs
	4	560	100 or more	500	10	576	13	190° C. for 3 hrs
	5	580	100 or more	500	10	575	13	190° C. for 3 hrs
	6	580	100 or more	500	10	576	13	190° C. for 3 hrs
	7	580	100 or more	500	10	578	13	190° C. for 3 hrs
	8	580	100 or more	530	6	578	9	190° C. for 3 hrs
	9	580	100 or more	520	6	579	9	190° C. for 3 hrs
	10	580	100 or more	500	10	578	13	190° C. for 3 hrs
	11	580	100 or more	500	10	581	13	190° C. for 3 hrs

TABLE 3-continued

		Manufacturing Method							
	Number	Soaking temperature (° C.) (for 4 hrs)	Rate of cooling after soaking (° C./hr)	Billet heating temperature (° C.)	Extrusion rate (m/min)	Die exit temperature (° C.)	Rate of cooling immediately after extrusion (° C./s)	Artificial aging
	12	560	100 or more	500	10	580	13	190° C. for 3 hrs
	13	580	100 or more	500	10	579	13	190° C. for 3 hrs
Comparative Examples	1	550*	100 or more	500	10	575	13	190° C. for 3 hrs
	2	580	100 or more	500	10	575	13	190° C. for 3 hrs
	3	560	100 or more	500	10	575	13	190° C. for 3 hrs
	4	550*	100 or more	500	10	575	13	190° C. for 3 hrs
	5	550*	100 or more	500	10	575	13	190° C. for 3 hrs
	6	550*	100 or more	500	10	575	13	190° C. for 3 hrs

*Data out of the conditions specified in the present invention

TABLE 4

		Manufacturing Method						
	Number	Soaking temperature (° C.) (for 4 hrs)	Cooling rate after soaking (° C./hr)	Billet heating temperature (° C.)	Extrusion rate (m/min)	Die exit temperature (° C.)	Cooling rate immediately after extrusion (° C./s)	Artificial aging
Comparative Examples	7	580	100 or more	500	10	575	13	190° C. for 3 hrs
	8	550*	100 or more	500	10	575	13	190° C. for 3 hrs
	9	580	100 or more	480*	6	564*	9	190° C. for 3 hrs
	10	580	100 or more	500	10	575	13	190° C. for 3 hrs
	11	550*	100 or more	500	3	530*	4*	190° C. for 3 hrs
	12	580	100 or more	500	7	570*	11	190° C. for 3 hrs
	13	580	100 or more	530	5	564*	8	190° C. for 3 hrs
	14	580	100 or more	495*	10	574*	13	190° C. for 3 hrs
	15	580	100 or more	500	10	575	13	190° C. for 3 hrs
	16	580	100 or more	500	10	575	13	190° C. for 3 hrs
	17	560	100 or more	500	10	575	13	190° C. for 3 hrs
	18	560	100 or more	500	10	575	13	190° C. for 3 hrs
	19	580	100 or more	500	10	575	13	190° C. for 3 hrs
	20	560	100 or more	500	10	575	13	190° C. for 3 hrs
	21	560	100 or more	500	10	530*	10	190° C. for 3 hrs
	22	560	100 or more	500	10	530*	10	190° C. for 3 hrs
	23	560	100 or more	500	10	530*	10	190° C. for 3 hrs
	24	580	40*	520	6	577	13	190° C. for 3 hrs

*Data out of the conditions specified in the present invention

[0089] More specifically, each sample of the extrudate was prepared in the following manner. Initially, the aluminum alloy whose chemical composition is given in Table 1 or 2 was melted and east into a billet. The billet underwent soaking treatment at a temperature given in Table 3 or 4, followed by cooling to room temperature at an average cooling rate (° C./hr) given in Table 3 or 4 through forced air cooling by a blower. The cooled billet was heated again to a temperature given in Table 3 or 4, and immediately subjected to hot extrusion at an extrusion rate (m/min) given in Table 3 or 4. A temperature (° C.) measured at the exit of the extruder (temperature of the extrudate attained at the die exit) is shown in Table 3 or 4. Immediately after extrusion, the extrudate underwent forced cooling to the neighborhood of room temperature through water spraying (samples other than Comparative Example 11) and air cooling with a blower (Comparative Example 11). Thus there was obtained an extrudate having a rectangular sectional shape with a central inner rib. The average cooling rate of each of samples according to the examples and comparative examples immediately after extrusion to a surface temperature of 190° C. is shown in Table 3 or 4. The resulting extrudate underwent artificial age hardening treatment under conditions given in Table 3 or 4.

[0090] The extrudates having a rectangular sectional shape with a central inner rib have outer dimensions corresponding to those for bumper reinforcements and have the following dimensions. The flanges (the front and rear walls) are each 40 mm long and 2.3 mm thick. The webs (the side walls) and the central inner rib are each 40 mm long and 2.0 mm thick. The extrudate was cut to a length of 1300 mm.

[0091] After artificial age hardening treatment, the web (side wall) of the extrudate was cut into a specimen in sheet form. The specimen was examined for structure and characteristic properties. The results are shown in Tables 5 and 6.

Specimen Structure

Average Area Ratio of Goss Orientation Grains

[0092] After refining as mentioned above and being left stand at room temperature for 15 days, the specimen was examined for texture by means of the SEM-EBSP. The texture was analyzed to obtain the average area ratio (%) of Goss orientation grains over the entire region of the cross section in the thickness direction, including the outermost grain growth layer.

[0093] Each specimen was also examined by the SEM-EBSP for the recrystallized structure in terms of the aspect ratio of crystal grains. The structure having an average aspect ratio of crystal grains of 5 or less was identified as an equiaxed granular structure, and one having an average aspect ratio of crystal grains of more than 5 was identified as a fibrous structure. In the column of "Recrystallization" in Tables 5 and 6, one having an equiaxed granular structure content of 50% or more is indicated as an "equiaxed recrystallized structure", and one having an equiaxed granular structure content of less than 50% is indicated as a "fibrous structure". In all the examples and comparative examples, recrystallized portions were fully composed of equiaxed granular structure.

Properties of Specimen

[0094] After refining mentioned above and being left stand at room temperature for 30 days, the specimen was examined for properties, such as 0.2% yield strength ("As yield strength" in MPa), elongation (%), as well as bending crush resistance and corrosion resistance. The results are also shown in Tables 5 and 6.

Tensile Test

[0095] The specimen was cut into a sample, No. 13 B sample conforming to JIS Z22201, which measures 12.5 mm in width, 50 mm in gauge length, and 2.0 mm in thickness as extruded, and the sample underwent tensile test at room temperature. The sample length and tensile force are parallel with the extrusion direction. The tensile force was applied at a rate of 5 mm/min up to the 0.2% yield strength and 20 mm/min thereafter. Five measurements (N=5) were averaged to determine respective mechanical properties.

Test For Bending Crush Resistance (Bending Workability)

[0096] The specimen (in sheet form) was bent to 180 degrees according to the press-bending method prescribed in JIS Z2248, in a direction perpendicular to the extrusion direction (so that the bending line be in parallel with the extrusion direction). The bending test was repeated ten times, and a critical bending radius R (mm) without rupture due to cracking in the outside of the bent corner (or in the stretched side) in all the ten bending tests was determined. A specimen with a decreasing critical bending radius R was evaluated as having more satisfactory bending crush resistance. Any specimen having a critical bending radius of more than 3.0 mm is regarded as good in bending crush resistance and advantageously usable as automotive reinforcements.

Test For Corrosion Resistance

[0097] The specimen was tested for corrosion resistance by dipping under the following conditions according to ISO/DIS 11846B. The test method includes dipping the specimen in an aqueous solution containing 30 g/L of NaCl and 10 mL/L of HCl for 24 hours at room temperature and subsequently observing the cross section of the specimen to detect intergranular corrosion cracking. The specimen was rated by the following criteria: ×: Intergranular corrosion cracking occurred; Δ: Intergranular corrosion occurred but intergranular corrosion cracking did not occur; ○: Neither intergranular corrosion cracking nor intergranular corrosion occurred (including the case where surficial general corrosion occurred).

TABLE 5

		Properties of Extrudate								
	No.	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Average spacing between intergranular precipitates (μm)	Recrystalization	Area ratio of Goss orientation grains (%)	Area ratio of recrystalized grains (%)	Critical bending radius R (mm)	Corrosion resistance
Examples	1	328	301	12	>25	100% Equiaxed recrystalized structure	3	100	3.0	○
	2	330	302	12	>25	87% Equiaxed recrystalized structure	3	87	3.0	○
	3	329	303	11	>25	88% Equiaxed recrystalized structure	1	88	3.0	○
	4	341	313	11	>25	67% Equiaxed recrystalized structure	2	67	3.0	○
	5	337	317	11	>25	72% Equiaxed recrystalized structure	2	72	3.0	○
	6	327	303	12	>25	100% Equiaxed recrystalized structure	6	100	3.0	○
	7	333	308	12	>25	100% Equiaxed recrystalized structure	6	100	3.0	○
	8	332	306	12	>25	91% Equiaxed recrystalized structure	7	91	3.0	○
	9	322	294	10	>25	100% Equiaxed recrystalized structure	6	100	3.0	○
	10	323	290	12	>25	100% Equiaxed recrystalized structure	3	100	3.0	○
	11	304	281	11	>25	100% Equiaxed recrystalized structure	3	100	3.0	○
	12	325	287	14	>25	100% Equiaxed recrystalized structure	7	100	2.0	○
	13	336	306	11	>25	100% Equiaxed recrystalized structure	6	100	3.0	○
Comparative Examples	1	347	319	12	>25	Fibrous structure*	3	28	5.0*	○
	2	331	309	12	>25	100% Equiaxed recrystalized structure	8*	100	5.0*	○
	3	331	305	12	>25	100% Equiaxed recrystalized structure	11*	100	5.0*	○
	4	327	304	12	>25	81% Equiaxed recrystalized structure	9*	81	6.0*	○
	5	348	324	10	>25	Fibrous structure*	3	40	5.0*	○
	6	329	306	10	>25	87% Equiaxed recrystalized structure	8*	87	5.0*	○

*Data out of, or inferior to, the conditions specified in the present invention.

TABLE 6

		Properties of Extrudate								
	No.	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Average spacing between intergranular precipitates (μm)	Recrystalization	Area ratio of Goss orientation grains (%)	Area ratio of recrystalized grains (%)	Critical bending radius R (mm)	Corrosion resistance
Comparative Examples	7	346	315	12	>25	Fibrous structure*	3	46	4.0*	○
	8	348	318	11	>25	Fibrous structure*	3	37	4.0*	○
	9	283	248*	10	10.0*	Fibrous structure*	4	40	3.0	○
	10	343	328	10	5.0*	98% Equiaxed recrystalized structure	13*	98	10 or more*	Δ*
	11	290	260*	14	3.0*	100% Equiaxed recrystalized structure	10*	100	2.0	Δ*
	12	307	271*	11	10.0*	60% Equiaxed recrystalized structure	2	60*	3.0	○
	13	336	303	11	10.0*	Fibrous structure*	3	40	5.0*	○
	14	315	286	12	10.0*	98% Equiaxed recrystalized structure	7	98	4.0*	○
	15	343	327	10	2.8*	100% Equiaxed recrystalized structure	10*	100	10 or more*	○
	16	319	288	13	2.8*	100% Equiaxed recrystalized structure	11*	100	4.0*	○
	17	365	313	15	2.0*	100% Equiaxed recrystalized structure	10*	100	4.0*	X*
	18	299	266*	12	2.8*	Fibrous structure*	4	40	5.0*	○
	19	312	288	12	2.8*	100% Equiaxed recrystalized structure	11*	100	10.0*	○
	20	263	238*	11	2.8*	Fibrous structure*	4	45	4.0*	○
	21	298	277*	10	2.0*	100% Equiaxed recrystalized structure	13*	100	6.0*	X*
	22	247	236*	10	>30	100% Equiaxed recrystalized structure	9*	100	10.0*	○
	23	182	151*	15	>30	100% Equiaxed recrystalized structure	11*	100	1.0	○
	24	327	296	12	10.0*	100% Equiaxed recrystalized structure	6	100	5.0*	○

*Data out of, or inferior to, the conditions specified in the present invention.

[0098] As shown in Tables 1 to 4, specimens in Examples 1 to 10 contain Mg and. Si in contents specified by the present invention and undergo soaking and hot extrusion under preferred conditions with regard to soaking temperature, forced cooling after soaking, billet heating temperature, temperature at the extruder exit, and forced cooling immediately after extrusion. Therefore, as demonstrated in Table 5, they have the equiaxed recrystallized grain structure (area ratio of recrystallized grains of 65% or more) having the area ratio of Goss orientation grains and the average spacing of intergranular precipitates, as specified in the present invention. The specimens in the examples therefore excel in bending crush resistance and corrosion resistance, and also excel in mechanical properties such as strength (280 MPa or more) and elongation. These outstanding characteristic properties suggest that the extrudates have such good bending crush resistance required of reinforcements as to be adaptable as automotive reinforcements which might encounter more serious collisions such as pole collision and offset collision.

[0099] In contrast, specimens in Comparative Examples 1, 5, and 6, as undergoing soaking at low temperatures, are poor in bending crush resistance. Specifically, specimens in Comparative Examples 1 and 5 (having the chemical composition containing Zr in the specific content) fail to have an equiaxed recrystallized structure (having an area ratio of recrystallized grains of 65% or more); and the specimen in Comparative Example 6 (having the chemical composition containing no Zr) suffers from large accumulation of Goss orientation grains due to insufficient pining force.

[0100] The specimens in Comparative Examples 2 to 4, as having an excessively low total content of Mn, Cr, and Zr, suffer from the growth of Goss orientation grains due to insufficient pinning force and are thereby poor in bending crush resistance, although they have an equiaxed recrystallized structure (having an area ratio of recrystallized grains of 65% or more).

[0101] The specimens in Comparative Examples 7 and 8, as having an excessively high total content of Mn, Cr, and Zr, have a fibrous structure (having an area ratio of recrystallized grains of less than 50%) and are poor in bending crush resistance, both in the case where the specimen was manufactured according to the method of the present invention (Comparative Example 7) and the case where the specimen underwent soaking at a temperature lower than the range specified in the present invention (Comparative Example 8).

[0102] The specimen in Comparative Example 9, as undergoing extrusion at a low temperature and a low rate, has a low temperature at the extruder exit, thereby has a fibrous structure (having an area ratio of recrystallized grains of less than 65%) and is poor in yield strength.

[0103] The specimen in Comparative Example 10, as having a chemical composition containing excess Si, suffers from the development of Goss orientation grains, is poor in bending crush resistance, and has insufficient corrosion resistance due to increase in coarse intergranular precipitates, although having an equiaxed recrystallized structure.

[0104] The specimen in Comparative Example 11, as undergoing forced cooling immediately after extrusion at a low cooling rate and thus suffering from quench delay suffers from increase in coarse intergranular precipitates and insufficient corrosion resistance.

[0105] The specimens in Comparative Examples 12 to 14, as having a low temperature at the extruder exit and thereby suffering from increase in coarse intergranular precipitates, fail to have an equiaxed recrystallized structure having an area ratio of recrystallized grains of 65% or more. Specifically, the specimen in Comparative Example 12 has a poor strength, whereas the specimen in Comparative Example 13 having a fibrous structure and the specimen in Comparative Example 14 including an equiaxed recrystallized structure (having an area ratio of recrystallized grains of 65% or more) have poor bending crush resistance.

[0106] The specimen in Comparative Example 15 has an excessively high Si content, the specimen in Comparative Example 16 has an excessively high Fe content, the specimen in Comparative Example 18 has an excessively high Mn content, the specimen in Comparative Example 19 has an excessively high Mg content, the specimen in Comparative Example 20 has excessively high Cr and Zr contents, and the specimen in Comparative Example 22 has an excessively high Ti content, each being inferior in bending crush resistance. The specimen in Comparative Example 17 has an excessively high Cu content, and the specimen in Comparative Example 21 has an excessively high Zn content, each being inferior in corrosion resistance. The specimen in Comparative Example 23 has insufficient Si and Mg contents and thereby has insufficient strength (yield strength). The specimen in Comparative Example 24, as undergoing post-soaking cooling at an excessively low rate and thereby suffering from the generation of coarse Mg—Si compounds, has poor bending crush resistance.

[0107] The foregoing results of Examples demonstrate that the chemical composition, structure, or preferred manufacturing conditions specified in the present invention are critical or effective for the extrudate to have good bending crush resistance, mechanical properties, and other properties.

INDUSTRIAL APPLICABILITY

[0108] The present invention provides the 6000-series aluminum alloy extrudate and the manufacturing method thereof, which extrudate has both good bending crush resistance and good corrosion resistance required of reinforcements for automotive bodies. The extrudate is suitable for use as automotive body reinforcements, such as bumper reinforcements and door guard bars, which need outstanding transverse crushing performance.

1. An aluminum alloy extrudate excellent in bending crush resistance and corrosion resistance, being an extrudate of an Al—Mg—Si aluminum alloy comprising, in terms of percent by mass, Mg in a content of from 0.60% to 1.20%, Si in a content of from 0.30% to 0.95%, Fe in a content of from 0.01% to 0.40%, Mn in a content of from 0.30% to 0.52%, Cu in a content of from 0.001% to 0.65%, and Ti in a content of from 0.001% to 0.10%, the contents of Mg and Si satisfying condition: $[\mathrm{Mg}\ (\%)]-(1.73\times[\mathrm{Si}\ (\%)]-0.25)\geqq 0$, with the remainder including Al and inevitable impurities, wherein the extrudate has an equiaxed recrystallized structure with an area ratio of recrystallized grains of 65% or more in a cross section in a thickness direction, wherein the aluminum alloy extrudate has an average spacing of more than 25 μm between intergranular precipitates each having a size of 1 μm or more in terms of centroid diameter in observation of the structure under a transmission electron microscope (TEM) of 5000 magnifications, and wherein the aluminum alloy extrudate has an average area ratio of Goss orientation grains of less than 8%, throughout the entire thickness region including an outermost grain growth layer in the cross section in the thickness direction of the extrudate.

2. The aluminum alloy extrudate excellent in bending crush resistance and corrosion resistance according to claim **1**, further comprising at least one of Cr in a content of from 0.001% to 0.18% and Zr in a content of from 0.001% to 0.18% as replacing part of Mn, and having a total content of Mn, Cr, and Zr of from 0.30% to 0.52%.

3. The aluminum alloy extrudate excellent in bending crush resistance and corrosion resistance according to claim **1**, wherein the aluminum alloy extrudate has such bending crush resistance as to have a critical bending radius (R) of 3.0 mm or less without cracking in a 180-degree bending test according to a press-bending method prescribed in Japanese Industrial Standards (JIS) Z2248 in which a plate-shaped specimen is bent in an extrusion direction.

4. A method for manufacturing an aluminum alloy extrudate excellent in bending crush resistance and corrosion resistance, the method comprising the steps of soaking a cast billet of an Al—Mg—Si aluminum alloy at a temperature of 560° C. or higher, the aluminum alloy having the chemical composition as defined in claim **1**; forcedly cooling the soaked cast billet to a temperature of 400° C. or lower at an average cooling rate of 100° C./hr or more; reheating the cooled cast billet to a temperature of 500° C. or higher and subjecting the reheated billet to hot extrusion so that an extrudate reaches a solid solution temperature of 575° C. or higher at an extruder exit; immediately forcedly cooling the extrudate from the extruder exit at an average cooling rate of 5° C./second or more; and subjecting the cooled extrudate to aging so as to have a 0.2% yield strength of 280 MPa or more.

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