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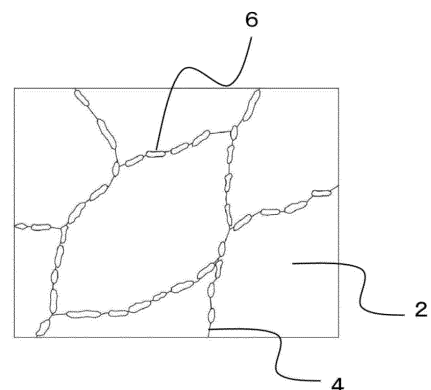
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(54) **ALUMINUM ALLOY FORGING MATERIAL AND METHOD FOR MANUFACTURING SAME**

(57) Provided are a 6000-series aluminum alloy forging material having high strength and exceptional toughness (excellent ductility), and an efficient method for manufacturing the same. This aluminum alloy forging material is characterized by being formed from a 6000-series aluminum alloy, having a Cu content of 0.2-1.0 wt.%, the composition of the 6000-series aluminum alloy satisfying relational expressions (1) and (2), and having deposits at the base metal crystal grain boundary, specifically Al-(Fe,Mn,Cr)-Si-type crystalline deposits at the base metal crystal grain boundary. (1) Si (at%)>2Mg (at%) and (2) 0.2≤surplus Si (wt%)+Mn (wt%)+Cr (wt%)≤1.7.

FIG. 1



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Description

TECHNICAL FIELD

[0001] The present invention relates to an aluminum alloy forging material and a method for manufacturing the same, and more particularly to an aluminum alloy forging material that can be suitably used for automotive underbody parts and the like, and a simple and efficient method for manufacturing the same.

PRIOR ARTS

[0002] The 6000 series aluminum alloy is an Al-Mg-Si series aluminum alloy where mainly Mg and Si are added, and, in addition to being excellent in formability and corrosion resistance, shows moderate age hardening and good strength, and thus the forging members are widely used as structural members for transportation equipment such as automobiles.

[0003] However, in recent years, there is an increasing demand for weight reduction of transportation equipment for the purpose of improving fuel efficiency and reducing CO₂ emissions, and it is strongly desirable to make the strength and toughness of the 6000 series aluminum alloy forging member higher. In particular, when a 6000 series aluminum alloy forging member is used for automotive underbody parts, and the like, it is essential to impart high reliability.

[0004] On the other hand, for example, in Patent Literature 1 (Japanese Patent Unexamined Publication No. 2017-155251), there is disclosed a forging aluminum alloy having excellent strength and ductility which is characterized by containing, by % by mass, Si: 0.7% to 1.5%, Mg: 0.6% to 1.2%, Fe: 0.01% to 0.5%, and one or more element selected from the group consisting of Mn: 0.05% to 1.0%, Cr: 0.01% to 0.5%, and Zr: 0.01% to 0.2%, with the remainder consisting of Al and inevitable impurities, and, as a structure in an observation plane at a center of the thickness in a thickest portion of the forging aluminum alloy, having a dislocation density of from 1.0×10^{14} to 5.0×10^{16} /m² on average as measured by X-ray diffractometry, including small angle grain boundaries with a tilt angle of 2° to 15° in an average proportion of 50% or more as measured by SEM-EBSD analysis, where the small angle grain boundaries are present around grains having a misorientation of 2° or more, and including precipitates measurable with a TEM at 300000-fold magnification in an average number density of 5.0×10^2 /μm³ or more.

[0005] In the aluminum alloy forging material described in Patent Literature 1, it is said that since in the case that the 6000 series aluminum alloy forging material is subjected to solution treatment and quenching treatment, and is subjected to work strain due to warm working and then subjected to artificial aging treatment, both strength and ductility are improved (higher strength and higher ductility) than in the normal case where working strain is not applied, in order to exhibit and guarantee the effects, the average dislocation density, the average ratio of low-angle grain boundaries, and the average number density of precipitates are defined as the structure at the center of the thickness of the thickest part of the forging material after the artificial aging treatment.

[0006] Further, in Patent Literature 2 (Japanese Patent Unexamined Publication No. 2008-163445), there is disclosed an automotive underbody part which is characterized in that the automotive underbody part is composed of an aluminum alloy forging material including, by % by mass, Mg: 0.5 to 1.25%, Si: 0.4 to 1.4%, Cu: 0.01 to 0.7%, Fe: 0.05 to 0.4%, Mn: 0.001 to 1.0%, Cr: 0.01 to 0.35%, Ti: 0.005 to 0.1%, Zr controlled to less than 0.15%, and the balance composed of Al and inevitable impurities, the arm portion having a substantially H-shaped width-direction sectional form including a relatively narrow and thick peripheral rib and a relatively wide central web, and in a width-direction sectional structure in a maximum stress manufacturing site of the rib, the density of crystals observed in the sectional structure of the maximum stress manufacturing site is 1.5% or less in terms of an average area ratio, and the average spacing between grain boundary precipitates observed in the sectional structure including a parting line, which is produced in forging, is 0.7 μm or more.

[0007] In the automotive underbody part described in Patent Literature 2, it is said that when the width-direction sectional structure of the specified portion in the maximum stress manufacturing site of, for example the rib, of the automotive underbody part which has a lighter weight shape is defined, and the composition is controlled and produced so that the width-direction sectional structure of the specified portion in the maximum stress manufacturing site of the rib and web of the automotive underbody part which has a lighter weight shape after the forging is to be a specific structure, coarsening of crystal grains in the rib portion and the web portion during the forging can be suppressed in the arm portion of the automotive underbody part which has a lighter weight shape, particularly in the specified site where the maximum stress is produced.

CITATION LIST

Patent Literature

[0008]

Patent Literature 1: Japanese Patent Unexamined Publication No. 2017-155251

Patent Literature 2: Japanese Patent Unexamined Publication No. 2008-163445

Summary of the Invention

Technical Problem

[0009] The mechanical properties of the 6000 series aluminum alloys are affected by precipitates in the crystal grain boundary and crystal precipitates in the crystal grains, but with respect to the aluminum alloy forging material described in Patent Literature 1, only the precipitates in the crystal grains are basically focused to Patent Document 1, and the influence of the precipitates in the crystal grain boundary which greatly contribute to toughness (ductility) is not considered.

[0010] Further, in the automotive underbody parts described in Patent Literature 2, the distance between the precipitates in the crystal grain boundary is defined, but with respect to the precipitates, there is no consideration as to the extremely important characteristics such as size and shape in terms of metal structure.

[0011] That is, with respect to the 6000 series aluminum alloy forging materials, it is difficult to say that the precipitates in the grain boundary and the crystal precipitates within the crystal grains are in a sufficiently optimal state from the viewpoint of achieving both strength and toughness at a high level.

[0012] In view of the problems in the prior art as described above, an object of the present invention is to provide a 6000 series aluminum alloy forging material having high strength and excellent toughness (good ductility), and an efficient method for manufacturing the same.

Solution to Problem

[0013] In order to achieve the above object, the present inventors have intensively studied the relationship between the composition and the microstructure of the 6000 series aluminum alloy forging material, and have found that it is extremely effective to add appropriate amounts of Mn and Cr to refine precipitates in the crystal grain boundary, in addition to forming the precipitates in the crystal grains by adding a sufficient amount of Si, and have reached the present invention.

[0014] Namely, the present invention can provide an aluminum alloy forging material characterized by being formed from a 6000 series aluminum alloy, having a Cu content of 0.2 to 1.0 wt%, the composition of the 6000 series aluminum alloy satisfying the following relational equations (1) and (2), and having precipitates in the base metal crystal grain boundary, and an Al-(Fe, Mn, Cr)-Si-based crystal precipitates in the base metal crystal grain.

$$\text{Si (at\%)} \geq 2\text{Mg (at\%)} \quad (1)$$

$$0.2 \leq \text{excess Si (wt\%)} + \text{Mn (wt\%)} + \text{Cr (wt\%)} \leq 1.7 \quad (2)$$

[0015] In the aluminum alloy forging member of the present invention, a large amount of the fine crystal precipitates is produced in the crystal grain by adding a sufficient amount of Si for the production of Mg_2Si . In addition, by setting the total content of excess Si, Mn and Cr to 0.2 to 1.7 wt%, the Al-(Fe, Mn, Cr)-Si-based compound is crystallized during casting, and the Al-(Fe, Mn, Cr)-Si-based compound is precipitated during homogenizing heat treatment and preheating for forging to make the aluminum alloy forging material stronger, and in addition thereto, by consuming the excess Si, the precipitate in the crystal grain boundary is finely divided. Here, the excess Si amount (wt%) can be calculated by "Si amount (wt%) - (Mg amount (wt%) / 1.731".

[0016] In addition, in the aluminum alloy forging material of the present invention, by containing 0.2 to 1.0 wt% of Cu, an Al, Mg, Si, Cu-based quaternary precipitate (Q phase or Q' phase) is formed to provide good mechanical and fatigue strength.

[0017] Further, in the aluminum alloy forging material of the present invention, it is preferable that the Si content is 0.5 to 1.4 wt% and the Mg content is 0.6 to 1.7 wt%. Further, a more preferable Si content is 0.9 to 1.2 wt%, and a more preferable Mg content is 0.8 to 1.2 wt%.

[0018] When the content of Si is set to 0.5 wt% or more, it is possible to express the solid solution strengthening and the age hardening sufficiently, and when being set to 1.4 wt% or less, it is possible to suppress the decrease in corrosion resistance and the decrease in ductility due to coarsening the crystal precipitate and the precipitate. Further, by setting the Si content to 0.9 to 1.2 wt%, these effects can be obtained more reliably.

[0019] Further, when setting the Mg content to 0.6 wt% or more, it is possible to form a sufficient amount of Mg-Si-based precipitate and improve the strength and fatigue properties, and when setting the Mg content to 1.7 wt% or less,

it is possible to suppress the formation of a coarse compound that becomes a starting point of destruction. By setting the Mg content to 0.8 to 1.2 wt%, these effects can be obtained more reliably.

[0020] Further, in the aluminum alloy forging material of the present invention, it is preferable that an average grain size of the precipitate in the crystal grain boundary of the base material is 50 nm or less. By setting the average grain size of the precipitate in the crystal grain boundaries of the base material to 50 nm or less, it is possible to impart good ductility (toughness) to the aluminum alloy forging material. Here, the average grain size of precipitate may be calculated as a circle-equivalent diameter.

[0021] Further, in the aluminum alloy forging material of the present invention, it is preferable that an aspect ratio of the precipitate in the crystal grain boundary of the base material is 5 or less. By setting the aspect ratio of the precipitate in the crystal grain boundary of the base material to 5 or less, the ratio of the precipitate occupying the crystal grain boundary of the base material is reduced, and in addition thereto, the distance between the precipitates can be increased. As a result, it is possible to impart good ductility (toughness) to the aluminum alloy forging material.

[0022] Further, in the aluminum alloy forging material of the present invention, it is preferable that a width of the precipitation-free zone centering on the crystal grain boundary of the base material is 100 nm or less. By setting the width of the precipitation-free zone in the crystal grain boundary of the base material to 100 nm or less, it is possible to impart high strength and good ductility to the aluminum alloy forging material.

[0023] Furthermore, in the aluminum alloy forging material of the present invention, it is preferable that a 0.2% proof stress is 350 MPa or more and an elongation is 10% or more. When the aluminum alloy forging material has the 0.2% proof stress of 350 MPa or more and the elongation of 10% or more, it is possible to be suitably used for structural members that require high reliability.

[0024] The present invention also provides an automotive underbody part made of the aluminum alloy forging material of the present invention. The aluminum alloy forging material of the present invention has good strength and ductility, and the automotive underbody part of the present invention can be suitably used when high strength and reliability are required.

[0025] Furthermore, the present invention also provides a method for manufacturing the aluminum alloy forging material of the present invention, characterized by

setting the content of Cu in the aluminum alloy forging material to 0.2 to 1.0 wt%, and including a hot forging preheating step of preheating the aluminum alloy material, and a hot forging step of subjecting the preheated aluminum alloy material obtained in the hot forging preheating step to hot forging, wherein the preheating temperature in the hot forging preheating step is 300 to 550 °C and the preheating time is 1 to 3 hours, and the composition of the aluminum alloy satisfies the following relational equations (1) and (2).

$$\text{Si (at\%)} \geq 2\text{Mg (at\%)} \quad (1)$$

$$0.2 \leq \text{excess Si (wt\%)} + \text{Mn (wt\%)} + \text{Cr (wt\%)} \leq 1.7 \quad (2)$$

[0026] In the method for manufacturing an aluminum alloy forging material of the present invention, by performing the hot forging preheating step where the preheating temperature is set to 300 to 550 °C and the preheating time is set to 1 to 3 hours, the Al-(Fe, Mn, Cr)-Si-based compound is precipitated to make the aluminum alloy forging material stronger, and in addition thereto, by consuming the excess Si, the precipitate in the crystal grain boundary is finely divided.

[0027] Further, in the method for manufacturing an aluminum alloy forging material of the present invention, it is preferable that a homogenization heat treatment step of the aluminum alloy material is provided before the hot forging preheating step, and a temperature of the homogenization heat treatment step is set to 500 to 550 °C, and a retention time thereof is set to 5 to 10 hours.

[0028] By subjecting to the homogenization heat treatment at 500 to 550°C for 5 to 10 hours, the Al-(Fe, Mn, Cr)-Si-based compound is more reliably precipitated to make the aluminum alloy forging material stronger, and in addition thereto, by consuming the excess Si, the precipitate in the crystal grain boundary is finely divided.

Effects of the invention

[0029] According to this invention, it is possible to provide the 6000 series aluminum alloy forging material having high strength and excellent toughness (good ductility), and an efficient method for manufacturing the same.

Brief Explanation of the Drawings

[0030]

FIG. 1 is a schematic diagram of the microstructure of the aluminum alloy forging material of the present invention. FIG. 2 is a TEM observation result of the vicinity of the crystal grain boundary of the aluminum base material grain boundary of the aluminum alloy forging material of Example 1.

FIG. 3 is a TEM observation result inside the crystal grain of the aluminum base material of the aluminum alloy forging material of Example 1.

FIG. 4 is a TEM-EDS spectrum of the crystal precipitate shown in FIG. 3.

FIG. 5 is a TEM observation result of the vicinity of the crystal grain boundary of the aluminum base material grain boundary of the aluminum alloy forging material of Comparative Example 5.

FIG. 6 is a TEM observation result of the vicinity of the crystal grain boundary of the aluminum base material grain boundary of the aluminum alloy forging material of Comparative Example 1.

FIG. 7 is a TEM observation result of the vicinity of the crystal grain boundary of the aluminum base material grain boundary of the aluminum alloy forging material of Comparative Example 4.

FIG. 8 is a TEM observation result inside the crystal grain of the aluminum base material of the aluminum alloy forging material of Comparative Example 5.

Embodiments for achieving the invention

[0031] Hereinafter, representative embodiments of the aluminum alloy forging material and the manufacturing method thereof according to the present invention will be described in detail with reference to the drawings, but the present invention is not limited to only these examples. In the following description, the same or equivalent parts are denoted by the same numerals, and there is a case that redundant explanation may be omitted. In addition, since the drawings are for conceptually explaining the present invention, dimensions of the respective constituent elements expressed and ratios thereof may be different from actual ones.

1. Aluminum alloy forging material

(1) Composition

[0032] The aluminum alloy forging material is composed of the 6000 series aluminum alloy, and in order to impart high strength and toughness (ductility) to the aluminum alloy forging material, the contents of Si, Mg, Mn and Cr in particular are optimized. Hereinafter, the element of each characteristic component of the aluminum alloy forging material of the present invention will be described.

Cu: 0.2-1.0 wt%

[0033] The content of Cu is 0.2-1.0 wt%. Cu has the effect of increasing mechanical strength and fatigue strength by forming the Al, Mg, Si, and Cu-based quaternary precipitate (Q phase or Q' phase). When the Cu content is less than 0.2 wt%, these effects cannot be sufficiently obtained, and the proof stress of the aluminum alloy forging material cannot be increased to 350 MPa or more. On the other hand, when the Cu content exceeds 1.0 wt%, there is a possibility that the corrosion resistance is lowered.

Si: 0.5 to 1.4 wt%

[0034] It is preferable that the content of Si is set to 0.5 to 1.4 wt%. When the content of Si is set to 0.5 wt% or more, it is possible to express the solid solution strengthening and the age hardening sufficiently, and when being set to 1.4 wt% or less, it is possible to suppress the decrease in corrosion resistance and the decrease in ductility due to coarsening the crystal precipitate and the precipitate. Further, more preferable content of Si is 0.9 to 1.2 wt%. Further, by setting the Si content to 0.9 to 1.2 wt%, these effects can be obtained more reliably.

Mg: 0.6-1.7 wt%

[0035] It is preferable that the content of Mg is set to 0.6-1.7 wt%. When setting the content of Mg to 0.6 wt% or more, it is possible to form a sufficient amount of the Mg-Si-based precipitate and improve the strength and fatigue properties, and when setting the content of Mg to 1.7 wt% or less, it is possible to suppress the formation of a coarse compound

that becomes a starting point of destruction. Further, more preferable content of Mg is 0.8 to 1.2 wt%. By setting the content of Mg to 0.8 to 1.2 wt%, these effects can be obtained more reliably.

Mn: 0.1 to 0.8 wt%

[0036] It is preferable that the content of Mn is set to 0.1 to 0.8 wt%. When the content of Mn is set to 0.1 wt % or more, the strength of the aluminum alloy forging material can be increased by forming the Al-(Fe, Mn, Cr)-Si-based compound. Further, when setting the content of Mn to 0.8 wt % or less, it is possible to suppress the formation of coarse Al-(Fe, Mn, Cr)-Si-based compound that reduce toughness and ductility.

Cr: 0.1 to 0.8 wt%

[0037] It is preferable that the content of Cr is set to 0.1 to 0.8 wt%. When the content of Cr is set to 0.1 wt % or more, the strength of the aluminum alloy forging material can be increased by forming the Al-(Fe, Mn, Cr)-Si-based compound. Further, when setting the content of Cr to 0.8 wt % or less, it is possible to suppress the formation of coarse Al-(Fe, Mn, Cr)-Si-based compound that reduce toughness and ductility.

Fe: 0.05 to 0.3 wt%

[0038] It is preferable that the content of Fe is set to 0.05 to 0.3 wt%. When the content of Fe is set to 0.05 wt % or more, the strength of the aluminum alloy forging material can be increased by forming the Al-(Fe, Mn, Cr)-Si compound. Further, when setting the content of Fe to 0.3 wt % or less, it is possible to suppress the formation of coarse Al-(Fe, Mn, Cr)-Si compound that reduce toughness and ductility.

[0039] Other than those, Cu, Zn, Ti and the like can be contained within the composition range specified for various 6000 series aluminum alloys (Al-Mg-Si alloys).

[0040] Further, with respect to the elements of the component of the aluminum alloy forging material of the present invention, it is necessary to meet the following two requirements.

(1) $\text{Si (at\%)} \geq 2\text{Mg (at\%)}$

[0041] When Si and Mg satisfy $\text{Si (at\%)} \geq 2\text{Mg (at\%)}$, sufficient Si exists for the yield of Mg_2Si , and a large amount of the fine crystal precipitates can be formed in the crystal grain.

(2) $0.2 \leq \text{excess Si (wt\%)} + \text{Mn (wt\%)} + \text{Cr (wt\%)} \leq 1.7$

[0042] When setting the total content of excess Si, Mn and Cr to 0.2 to 1.7 wt%, the Al-(Fe, Mn, Cr)-Si-based compound is crystallized during casting, and the Al-(Fe, Mn, Cr)-Si-based compound is precipitated during homogenizing heat treatment and preheating for forging to make the aluminum alloy forging material stronger, and in addition thereto, by consuming the excess Si, the precipitate in the crystal grain boundary is finely divided.

(2) Structure

[0043] Fig. 1 shows a schematic diagram of the microstructure of the aluminum alloy forging material of the present invention. In the aluminum alloy forging material of the present invention, the precipitate 6 is formed in the crystal grain boundary 4 of the aluminum base material 2. Further, extremely fine Al-(Fe, Mn, Cr)-Si-based crystal precipitates are dispersed in the crystal grains of the aluminum base material 2. What is present in the crystal grains is not limited to the Al-(Fe, Mn, Cr)-Si-based crystal precipitates, but, for example, precipitation phases known as an aging precipitation phase of an Al-Mg-Si-based alloy such as a general 6 phase and its precursor phase, a Q phase and its precursor phase, and the like may be dispersed.

[0044] It is preferable that an average grain size of the precipitate 6 in the crystal grain boundary 4 is 50 nm or less. By setting the average grain size of the precipitate 6 in the crystal grain boundary 4 to 50 nm or less, it is possible to impart good ductility (toughness) to the aluminum alloy forging material. The average grain size of the precipitate 6 is more preferably 40 nm or less, most preferably 30 nm or less.

[0045] It is preferable that an aspect ratio of the precipitate 6 in the crystal grain boundary 4 is 5 or less. By setting the aspect ratio of the precipitate 6 in the crystal grain boundary 4 to 5 or less, the ratio of the precipitate 6 occupying the crystal grain boundary 4 is reduced, and in addition thereto, the distance between the precipitates 6 can be increased. As a result, it is possible to suppress the propagation of the precipitates 6 and the propagation of cracks, and to impart good ductility (toughness) to the aluminum alloy forging material. A more preferable aspect ratio of the precipitates 6 is

4 or less, and the most preferable aspect ratio is 3 or less.

[0046] It is preferable that a width of the precipitation-free zone centering on the crystal grain boundary 4 is 100 nm or less. By setting the width of the precipitation-free zone in the crystal grain boundary 4 to 100 nm or less, it is possible to impart high strength and good ductility to the aluminum alloy forging material. A more preferable width of the precipitation-free zone is 90 nm or less, and the most preferable width is 80 nm or less.

[0047] The aluminum alloy forging material has excellent tensile properties by having the aforementioned composition and the composition. In the aluminum alloy forging material of the present invention, it is preferable that a 0.2% proof stress is 350 MPa or more and an elongation is 10% or more. When the aluminum alloy forging material 2 has the 0.2% proof stress of 350 MPa or more and the elongation of 10% or more, it is possible to be suitably used for structural members that require high reliability. A more preferable 0.2% proof stress of the aluminum alloy forging 2 is 360 MPa or more, and the most preferable 0.2% proof stress is 370 MPa or more. Further, a more preferable elongation of the aluminum alloy forging 2 is 12% or more, and the most preferable elongation is 14% or more.

2. Automotive underbody part

[0048] The automotive underbody part of the present invention is an automobile underbody part made of the aluminum alloy forging material of the present invention.

[0049] Specific examples of automotive underbody part include, for example, suspension parts for automobiles such as an upper arm, a lower arm, and a transverse link.

3. Method for manufacturing aluminum alloy forging material

[0050] The method for manufacturing the aluminum alloy forging material of the present invention provides an effective method for manufacturing the aluminum alloy forging material of the present invention. The method for manufacturing the aluminum alloy forging material of the present invention sets the content of Cu of the aluminum alloy forging material to 0.2 to 1.0 wt%, and includes the hot forging preheating step of preheating the aluminum alloy material and the hot forging step of hot forging the preheated aluminum alloy material obtained in the hot forging preheating step. Further, other steps are not particularly limited as long as the effect of the invention is not impaired, and if necessary, various conventionally known steps used for manufacturing the forging materials of 6000 series aluminum alloys may be used. Hereinafter, the characteristic steps of the method for manufacturing the aluminum alloy forging material of the present invention will be described.

(1) Homogenization heat treatment step

[0051] As a pretreatment for the hot forging step including the hot forging preheating step, it is preferable that the aluminum alloy material to be forged is subjected to the homogenization heat treatment. Further, it is preferable that the temperature of the homogenization heat treatment step is set to 500 to 550 °C, and a retention time thereof is set to 5 to 10 hours.

[0052] By subjecting to the homogenization heat treatment at 500 to 550°C for 5 to 10 hours, the Al-(Fe, Mn, Cr)-Si-based compound can be more reliably precipitated in the crystal grain of the aluminum base material 2 to make the aluminum alloy forging material stronger, and in addition thereto, by consuming the excess Si, the precipitate 6 in the crystal grain boundary 4 can be finely divided. Further, as a result, the aspect ratio of the precipitate 6 can be reduced.

(2) Hot forging preheating step

[0053] This is a treatment to perform as a pretreatment for the hot forging step. By subjecting the aluminum base material to the heat treatment at a preheating temperature of 300 to 550°C for a preheating time of 1 to 3 hours, the Al-(Fe, Mn, Cr)-Si-based compound can be more reliably precipitated in the crystal grain of the aluminum base material 2 to make the aluminum alloy forging material stronger, and in addition thereto, by consuming the excess Si, the precipitate 6 in the crystal grain boundary 4 can be finely divided. Further, as a result, the aspect ratio of the precipitate 6 can be reduced.

(3) Hot forging step

[0054] By subjecting the aluminum alloy material which is preheated according to various conventionally known forging methods, it is possible to form into a desired shape. Further, by forming the final shape into the suspension parts for automobiles such as an upper arm, a lower arm, and a transverse link, it is possible to obtain the automotive underbody part of the present invention.

(4) Solution treatment and aging treatment

[0055] By subjecting the forged parts that have been finalized by the hot forging to appropriate solution treatment and aging treatment, it is possible to improve the strength of the entire forged part.

[0056] The conditions for the solution treatment and the aging treatment are not particularly limited, and conventionally known various solution treatments and aging treatments can be used as long as the effects of the present invention are not impaired. Since these optimum conditions depend on the kind of aluminum alloy and the shape and size of the forged parts, it is preferable to select conditions by observing the structure of the forged parts after the solution treatment and the aging treatment and evaluating the mechanical properties.

[0057] Although the typical embodiments of the present invention have been described above, the present invention is not limited to these, and various design changes are possible, and all of these design changes are included in the technical scope of the present invention.

EXAMPLE

<<Example>>

[0058] An aluminum alloy slabs having the compositions shown in Table 1 as Examples were obtained by the DC continuous casting method. The components in Table 1 are indicated by wt%. Here, the "excess Si (wt%)" value related to the relational equation (1) and the relational equation (2) and the "excess Si (wt%) + Mn (wt%) + Cr (wt%)" value related to the relational equation (2) are also shown in Table 1. All of the aluminum alloys according to the Examples have excess Si and 0.2 to 1.0 wt% of Cu, and in addition thereto, satisfy the relational equation of $0.2 \leq \text{excess Si (wt\%)} + \text{Mn (wt\%)} + \text{Cr (wt\%)} \leq 1.7$.

[Table 1]

	Si	Mg	Mn	Cr	Cu	Fe	Ti	Al	Excess Si	Excess Si + Mn + Cr
Ex. 1	1.20	0.89	0.40	0.40	0.30	0.18	0.01	bal.	0.7	1.50
Ex. 2	1.07	1.19	0.39	0.41	0.29	0.17	0.03	bal.	0.4	1.20
Ex. 3	0.99	0.87	0.87	0.28	0.41	0.19	0.01	bal.	0.5	1.65
Ex. 4	0.99	0.86	0.86	0.29	0.42	0.19	0.01	bal.	0.5	1.65
Ex. 5	1.01	0.88	0.88	-	0.40	0.19	0.01	bal.	0.5	1.38
Ex. 6	1.01	0.87	0.87	-	0.41	0.20	0.01	bal.	0.5	1.37
Ex. 7	1.21	1.01	0.41	0.36	0.83	0.18	0.01	bal.	0.6	1.37
Ex. 8	0.69	1.19	0.38	0.39	0.98	0.16	0.01	bal.	-	0.77
Com. Ex. 1	0.68	1.17	-	-	0.29	0.17	0.01	bal.	-	0.00
Com. Ex. 2	0.68	1.15	-	0.40	0.29	0.17	0.01	bal.	-	0.40
Com. Ex. 3	0.69	1.17	0.40	-	0.29	0.17	0.01	bal.	-	0.40
Com. Ex. 4	0.68	1.18	0.39	0.39	0.30	0.17	0.01	bal.	-	0.78
Com. Ex. 5	1.19	0.86	-	-	0.28	0.17	0.01	bal.	0.7	0.70
Com. Ex. 6	0.69	1.57	0.40	0.40	0.30	0.17	0.01	bal.	-	0.80
Com. Ex. 7	1.02	0.90	0.50	0.08	0.01	0.20	0.01	bal.	0.5	1.08

[0059] Next, the obtained slab was cut, subjected to the hot forging preheating step at 350 °C or 500 °C for 2 hours, and then forged at a forging rate of 60% to obtain aluminum alloy forging material. Here, a case where the homogenization heat treatment was performed at 510 °C for 6 hours or 550 °C for 10 hours before the hot forging preheating step and a case where the homogenization heat treatment was not performed were investigated.

[0060] Next, the obtained aluminum alloy forging material was subjected to the solution treatment at 550 °C for 2 hours, the water cooling, and the aging treatment at 180 °C for 8 hours.

[0061] Table 2 shows the tensile properties and the manufacturing conditions of each aluminum alloy forging material obtained. No. 14 A test piece described in JIS Z 2241 was used as the tensile test piece, and the tensile speed was 2

mm/min up to 0.2% proof stress and 5 mm / min after 0.2% proof stress in accordance with JIS Z 2241. As shown in Table 2, the aluminum alloy forging material of the present invention has both a 0.2% proof stress of 350 MPa and an elongation of 10% or more.

[0062] Further, with respect to several aluminum alloy forging materials, the average a circle-equivalent diameter and the aspect ratio of the precipitates present in the crystal grain boundary of the aluminum base material were determined. Specifically, regarding the TEM observation photograph, the circle-equivalent diameter and the aspect ratio of the precipitates were calculated by using the image processing software (Image-Pro Premier V9.0 available from Media Cybernetic, USA). The thus obtained results are shown in Table 2. It can be seen that in the aluminum alloy forging material of the present invention, the average circle-equivalent diameter of the precipitate present in crystal grain boundary is 50 μm or less, and the aspect ratio is 5 or less.

[Table 2]

	Homogenization heat treatment	hot forging preheating step	Tensile strength (MPa)	0.2% proof stress (MPa)	Elongation (%)	Circle- equivalent diameter (mm)	Aspect ratio
Ex. 1	-	500 °C , 2h	410	388	17.0	-	-
		350 °C , 2h	410	381	13.5	-	-
	510 °C , 6h	500 °C , 2h	411	387	15.9	26	1.7
		350 °C , 2h	408	379	11.6	-	-
	550 °C , 10h	500 °C , 2h	413	388	16.2	-	-
		350 °C , 2h	398	375	11.5	-	-
Ex. 2	-	500 °C , 2h	409	379	12.7	-	-
		350 °C , 2h	405	371	12.2	-	-
	510 °C , 6h	500 °C , 2h	411	380	14.4	-	-
		350 °C , 2h	408	374	12.7	-	-
	550 °C , 10h	500 °C , 2h	411	382	15.3	-	-
		350 °C , 2h	397	363	12.1	-	-
Ex. 3	510 °C , 6h	500 °C , 2h	413	389	13.4	20	1.4
Ex. 4	510 °C , 6h	500 °C , 2h	418	387	12.4	20	1.6
Ex. 5	510 °C , 6h	500 °C , 2h	405	374	10.6	-	-
Ex. 6	510 °C , 6h	500 °C , 2h	414	388	12.6	38	2.8
Ex. 7	510 °C , 6h	500 °C , 2h	428	373	17.3	-	-
Ex. 8	510 °C , 6h	500 °C , 2h	427	375	16.9	-	-

[0063] FIG. 2 shows the TEM observation result of the aluminum alloy forging material of Example 1 (homogenization heat treatment: 510 °C, 6 hours, hot forging preheating step: 500 °C, 2 hours) in the vicinity of the crystal grain boundary of the aluminum base material. For the TEM observation, Tecnai series G2-F20 available from FEI was used. Precipitate in the crystal grain boundary of the aluminum base material can be confirmed, and the precipitate is found to be fine and granular. In addition, the precipitates are not in close contact with each other, and there is ideal conditions for imparting good toughness and ductility to aluminum alloy forging material. In addition, the width of the precipitation-free zone is 100 nm or less.

[0064] FIG. 3 shows the TEM observation result of the aluminum alloy forging material of Example 1 (homogenization

heat treatment: 510 °C, 6 hours, hot forging preheating step: 500 °C, 2 hours) inside the crystal grain boundary of the aluminum base material. It can be confirmed that a large amount of fine crystal precipitates are dispersed in the crystal grain of the aluminum base material. A TEM-EDS spectrum of the crystal precipitate is shown in FIG. 4, and it was confirmed that the crystal precipitate contained Al-(Fe, Mn, Cr)-Si-based crystal precipitates.

<<Comparative Example>>

[0065] An aluminum alloy forging material was obtained in the same manner as in Examples except that an aluminum alloy slab having the composition shown in Table 1 as a comparative example was used. Further, the obtained aluminum alloy forging materials were evaluated in the same manner as in Example.

[0066] Table 3 shows information on the manufacturing conditions, tensile properties, and precipitates present in the grain boundary of the aluminum base material of the aluminum alloy forging material obtained as a comparative example. Further, Table 3 also shows the average equivalent circle diameter and the aspect ratio of precipitate present in grain boundaries of the aluminum base material for several aluminum alloy forging materials.

[Table 3]

	Homogenization heat treatment	hot forging preheating step	Tensile strength (MPa)	0.2% proof stress (MPa)	Elongation (%)	Circle- equivalent diameter (mm)	Aspect ratio
Com. Ex. 1	-	500 °C , 2h	364	326	16.2	-	-
		350 °C , 2h	363	326	16.5	-	-
	510 °C , 6h	500 °C , 2h	362	324	17.5	22	1.9
		350 °C , 2h	371	329	17.3	-	-
	550 °C , 10h	500 °C , 2h	361	324	16.4	-	-
		350 °C , 2h	370	327	17.5	-	-
Com. Ex. 2	-	500 °C , 2h	375	337	15.6	-	-
		350 °C , 2h	373	331	18.9	-	-
	510 °C , 6h	500 °C , 2h	384	346	14.2	-	-
		350 °C , 2h	371	328	15.6	-	-
	550 °C , 10h	500 °C , 2h	378	349	11.1	-	-
		350 °C , 2h	369	325	17.1	-	-
Com. Ex. 3	-	500 °C , 2h	357	342	8.8	-	-
		350 °C , 2h	366	326	17.6	-	-
	510 °C , 6h	500 °C , 2h	367	329	8.2	-	-
		350 °C , 2h	372	328	16.4	-	-
	550 °C , 10h	500 °C , 2h	358	317	9.3	-	-
		350 °C , 2h	372	327	16.0	-	-
Com. Ex. 4	-	500 °C , 2h	380	333	13.5	-	-
		350 °C , 2h	376	325	14.4	-	-
	510 °C , 6h	500 °C , 2h	384	339	16.8	18	2.3
		350 °C , 2h	379	328	16.8	-	-
	550 °C , 10h	500 °C , 2h	384	336	16.1	-	-
		350 °C , 2h	369	316	15.7	-	-

(continued)

	Homogenization heat treatment	hot forging preheating step	Tensile strength (MPa)	0.2% proof stress (MPa)	Elongation (%)	Circle- equivalent diameter (mm)	Aspect ratio
5	-	500 °C , 2h	384	360	7.8	-	-
		350 °C , 2h	382	355	11.9	-	-
10	Com. Ex. 5	510 °C , 6h	500 °C , 2h	379	353	7.5	97
			350 °C , 2h	389	359	7.4	-
15	550 °C , 10h	500 °C , 2h	377	353	4.6	-	-
			350 °C , 2h	388	358	7.0	-
20	Com. Ex. 6	-	500 °C , 2h	361	306	14.4	-
			350 °C , 2h	355	295	14.2	-
		510 °C , 6h	500 °C , 2h	363	308	17.4	-
			350 °C , 2h	356	295	15.4	-
		550 °C , 10h	500 °C , 2h	365	306	17.0	-
			350 °C , 2h	353	288	17.7	-
25	Com. Ex. 7	510 °C , 6h	500 °C , 2h	324	296	8.7	-

[0067] As shown in Table 3, the aluminum alloy forging materials of Comparative Examples cannot achieve both strength and ductility at high levels. With respect to Comparative Example 1 to Comparative Example 4, which do not contain excess Si, the absolute strength is insufficient, and the 0.2% proof stress is less than 350 MPa in all cases. On the other hand, with respect to Comparative Example 5, which has excess Si but does not contain Mn and/or Cr, the ductility is poor, and the elongation is less than 10% in all cases. Furthermore, with respect to Comparative Example 6, which contains Mn and Cr but does not have excess Si, the absolute strength is insufficient, and the 0.2% proof stress is less than 350 MPa in all cases.

[0068] With respect to the precipitate present in the crystal grain boundary of the aluminum base material, no coarsening and an increase in the aspect ratio are observed in the case of no excess Si, but in the case of excess Si (Comparative Example 5), the average equivalent circle diameter is greater than 50 nm and the aspect ratio is also greater than 5.

[0069] FIG. 5 shows the TEM observation result of the aluminum alloy forging material of Comparative Example 5 (homogenization heat treatment: 510 °C, 6 hours, hot forging preheating step: 500 °C, 2 hours) in the vicinity of the crystal grain boundary of the aluminum base material. Precipitate in the crystal grain boundary of the aluminum base material can be confirmed, and the precipitate is found to be coarse and acicular.

In addition, the width of the precipitation-free zone is larger than that of the aluminum alloy forging materials obtained in the Examples.

[0070] FIG. 6 shows the TEM observation result of the aluminum alloy forging material of Comparative Example 1 (homogenization heat treatment: 510 °C, 6 hours, hot forging preheating step: 500 °C, 2 hours) in the vicinity of the crystal grain boundary of the aluminum base material. Precipitate in the crystal grain boundary of the aluminum base material can be confirmed, and it can be seen that the amount of the precipitate is smaller in comparison with those in the case of the aluminum alloy forging materials obtained in the Examples.

[0071] FIG. 7 shows the TEM observation result of the aluminum alloy forging material of Comparative Example 4 (homogenization heat treatment: 510 °C, 6 hours, hot forging preheating step: 500 °C, 2 hours) in the vicinity of the crystal grain boundary of the aluminum base material. Precipitate in the crystal grain boundary of the aluminum base material can be confirmed, and it can be seen that the precipitate is fine in comparison with that in the case of Comparative Example 1.

[0072] FIG. 8 shows the TEM observation result of the aluminum alloy forging material of Comparative Example 5 (homogenization heat treatment: 510 °C, 6 hours, hot forging preheating step: 500 °C, 2 hours) inside the crystal grain boundary of the aluminum base material. It can be confirmed that no crystal precipitate is clearly dispersed in the crystal grains of the aluminum base material.

[0073] Further, the aluminum alloy forging material of Comparative Example 7 has sufficient Si and satisfies the relationship of $0.2 \leq \text{excess Si (wt\%)} + \text{Mn (wt\%)} + \text{Cr (wt\%)} \leq 1.7$, but has the Cu content of less than 0.2 wt%, and thus, the tensile strength and 0.2% proof stress are low.

[0074] From the above results, in the aluminum alloy forging material of the present invention, it can be seen that a large amount of fine Al-(Fe, Mn, Cr)-Si-based crystal precipitates are dispersed in the crystal grains of the aluminum base material, and the precipitate in the crystal grains is fine and has a shape of near granular, resulting in high strength and excellent toughness (good ductility).

Explanation of symbols

[0075]

2 Aluminum base material,

4 Crystal grain boundary,

6 Precipitate.

Claims

1. An aluminum alloy forging material **characterized by** being formed from a 6000 series aluminum alloy, having a Cu content of 0.2 to 1.0 wt%, the composition of the 6000 series aluminum alloy satisfying the following relational equations (1) and (2), and having precipitates in the base metal crystal grain boundary, and an Al-(Fe, Mn, Cr)-Si-based crystal precipitates in the base metal crystal grain.

$$\text{Si (at\%)} \geq 2\text{Mg (at\%)} \quad (1)$$

$$0.2 \leq \text{excess Si (wt\%)} + \text{Mn (wt\%)} + \text{Cr (wt\%)} \leq 1.7 \quad (2)$$

2. The aluminum alloy forging material according to claim 1, wherein the content of Si is 0.5 to 1.4 wt%, and the content of Mg is 0.6 to 1.7 wt%.

3. The aluminum alloy forging material according to claim 1, wherein the content of Si is 0.9 to 1.2 wt%, and the content of Mg is 0.8 to 1.2 wt%.

4. The aluminum alloy forging material according to any one of claims 1 to 3, wherein the average grain size of the precipitate in the crystal grain boundary of the base material is 50 nm or less.

5. The aluminum alloy forging material according to any one of claims 1 to 4, wherein the aspect ratio of the precipitate in the crystal grain boundary of the base material is 5 or less.

6. The aluminum alloy forging material according to any one of claims 1 to 5, wherein the width of the precipitation-free zone centering on the crystal grain boundary of the base material is 100 nm or less.

7. The aluminum alloy forging material according to any one of claims 1 to 6, wherein the 0.2% proof stress is 350 MPa or more and the elongation is 10% or more.

8. An automotive underbody part **characterized by** comprising the aluminum alloy forging material according to any one of claims 1 to 7.

9. A method for manufacturing the aluminum alloy forging material according to any one of claims 1 to 7, **characterized by**

setting the content of Cu in the aluminum alloy forging material to 0.2 to 1.0 wt%, and including a hot forging preheating step of preheating the aluminum alloy material, and a hot forging step of subjecting the preheated aluminum alloy material obtained in the hot forging preheating step to hot forging,

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wherein the preheating temperature in the hot forging preheating step is 300 to 550 °C and the preheating time is 1 to 3 hours, and
the composition of the aluminum alloy satisfies the following relational equations (1) and (2).

$$\text{Si (at\%)} \geq 2\text{Mg (at\%)} \quad (1)$$

$$0.2 \leq \text{excess Si (wt\%)} + \text{Mn (wt\%)} + \text{Cr (wt\%)} \leq 1.7 \quad (2)$$

- 10.** The method for manufacturing the aluminum alloy according to claim 9, wherein, a homogenization heat treatment step for the aluminum alloy material before the hot forging preheating step, and
the temperature in the homogenization heat treatment step is 500 to 550 °C and the holding time is 5 to 10 hours.

FIG. 1

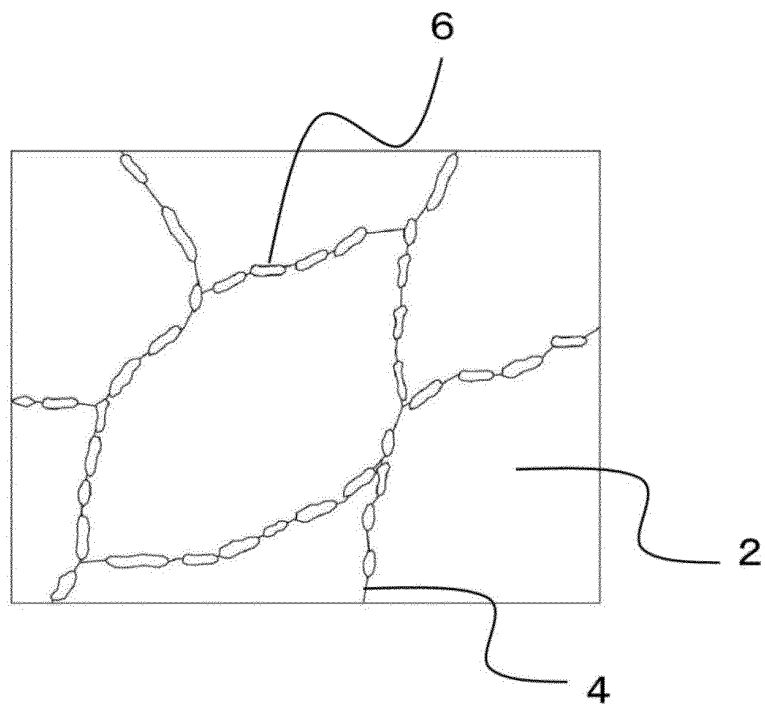


FIG. 2

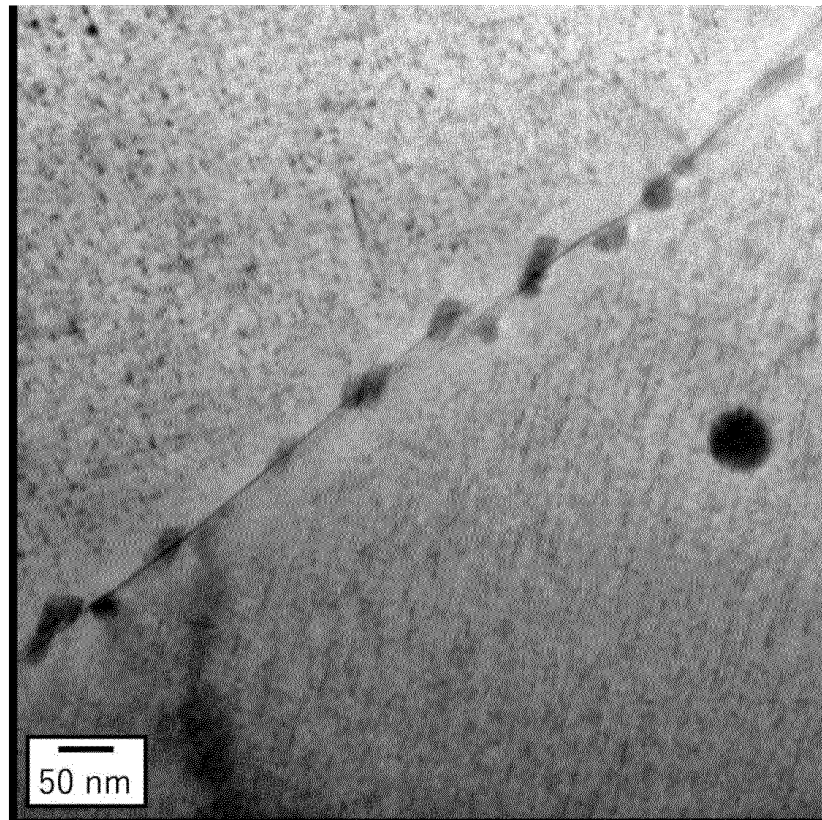


FIG. 3

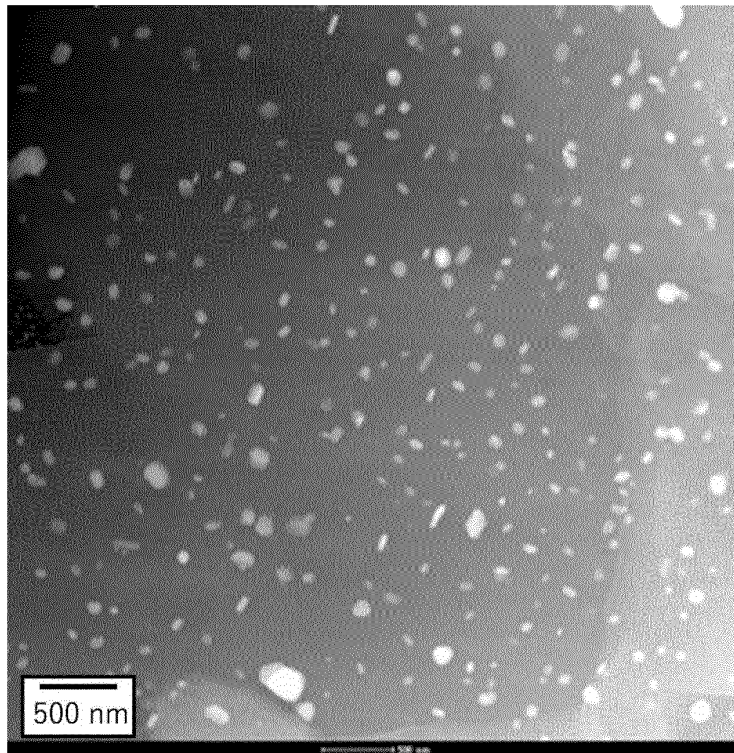


FIG. 4

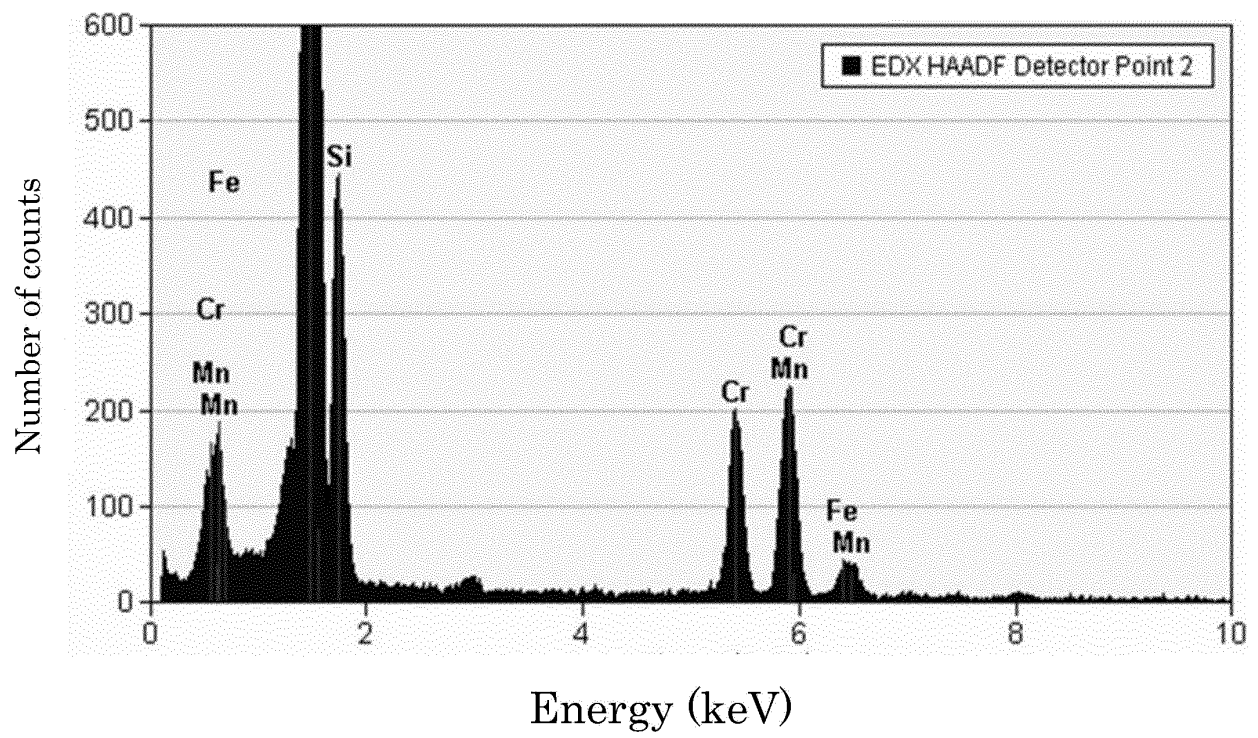


FIG. 5

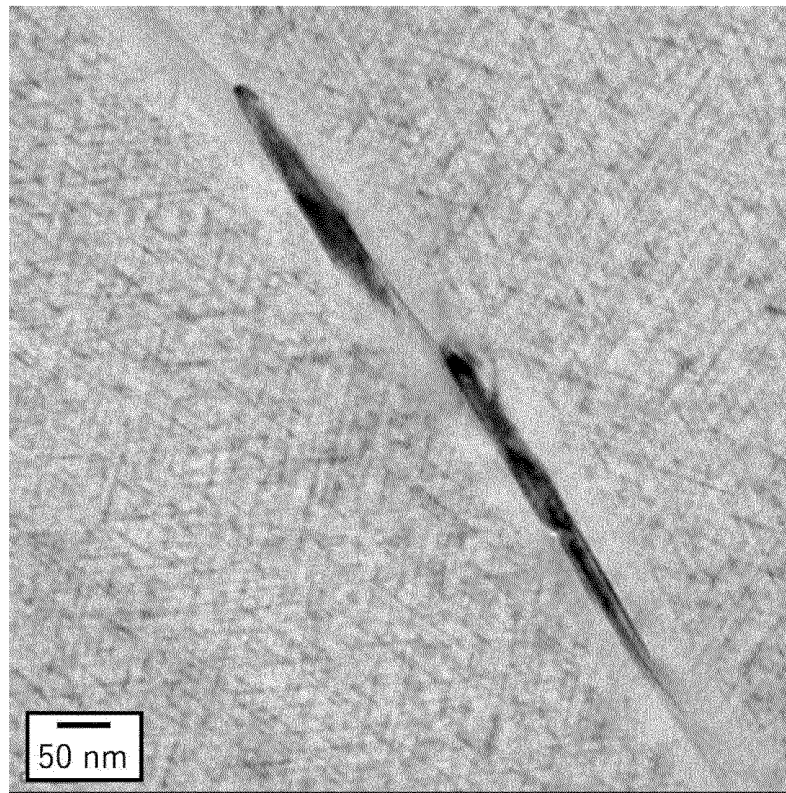


FIG. 6

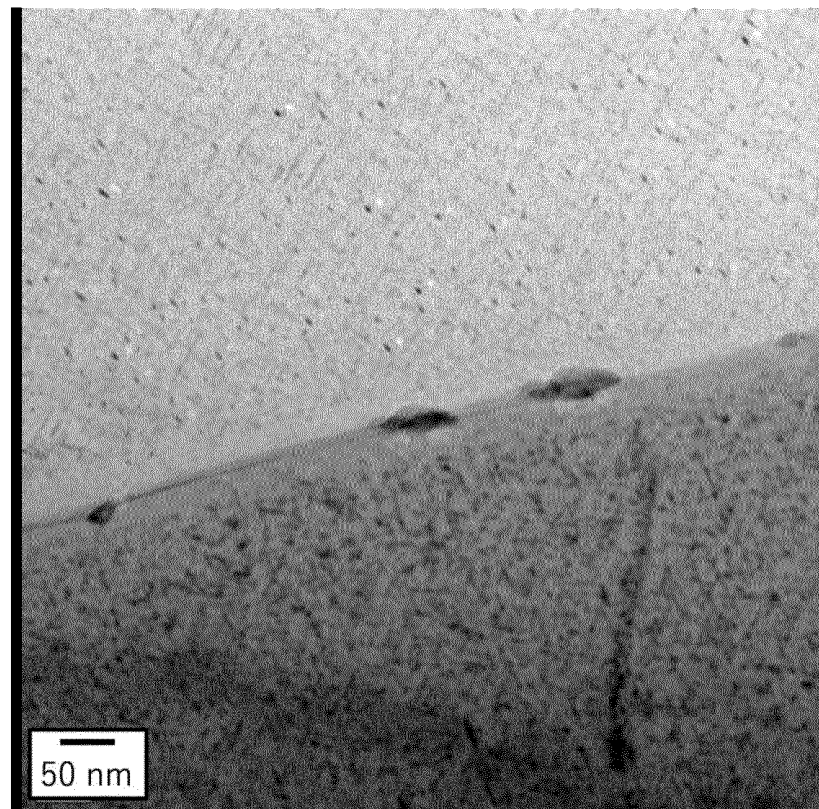


FIG. 7

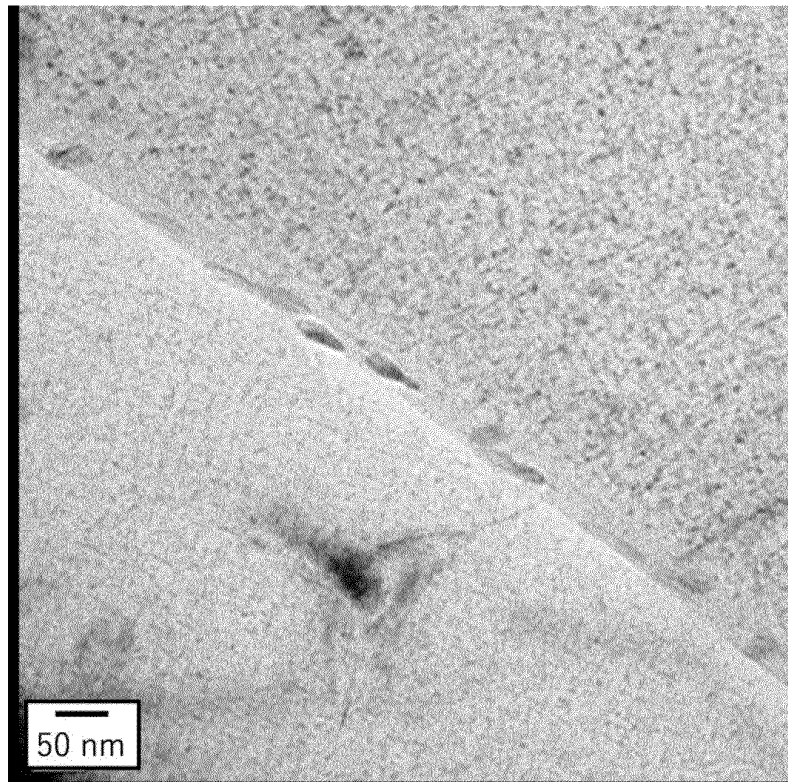
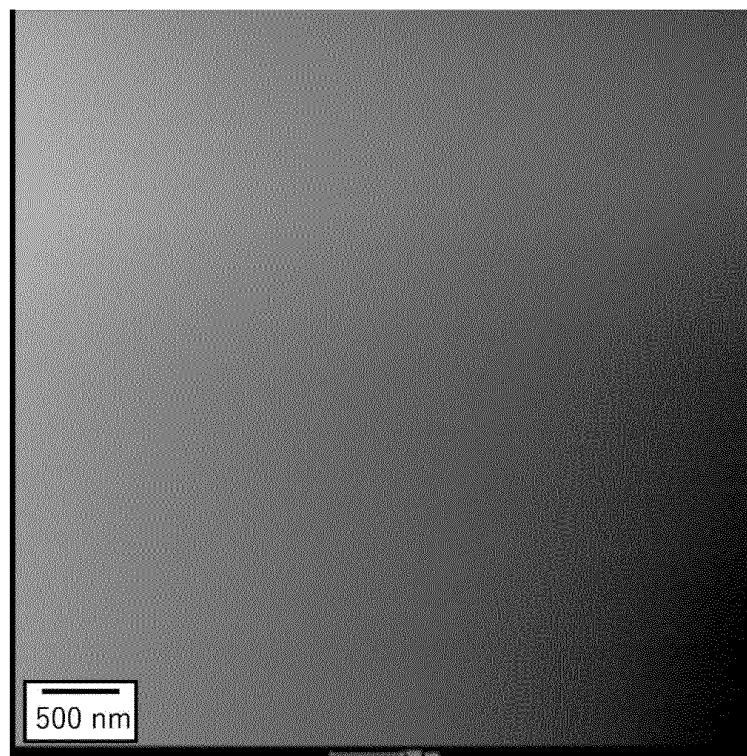


FIG. 8



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2021/016908

A. CLASSIFICATION OF SUBJECT MATTER

C22C 21/02(2006.01)i; C22C 21/06(2006.01)i; C22F 1/00(2006.01)i; C22F 1/05(2006.01)i

FI: C22C21/02; C22C21/06; C22F1/00 601; C22F1/00 602; C22F1/00 630A;
 C22F1/00 630K; C22F1/00 631Z; C22F1/00 682; C22F1/00 683;
 C22F1/00 684C; C22F1/00 691B; C22F1/00 691C; C22F1/00 694A;
 C22F1/00 694B; C22F1/05

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
 C22C21/00-21/18; C22F1/04-1/057

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2021
Registered utility model specifications of Japan	1996-2021
Published registered utility model applications of Japan	1994-2021

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2016/129127 A1 (SHOWA DENKO KABUSHIKI KAISHA) 18 August 2016 (2016-08-18) claims, page 21, line 3 to page 22, line 12, tables 1-2	1-10
X	WO 2013/114928 A1 (KOBE STEEL, LTD.) 08 August 2013 (2013-08-08) claims, paragraphs [0001], [0068]-[0071], tables 1-2	1-10
X	WO 2007/114078 A1 (KOBE STEEL, LTD.) 11 October 2007 (2007-10-11) claims, paragraphs [0099]-[0104], tables 1-4	1-10
X	JP 2004-292937 A (KOBE STEEL, LTD.) 21 October 2004 (2004-10-21) claims, paragraphs [0057]-[0063], tables 1-3	1-10



Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search
 09 July 2021 (09.07.2021)

Date of mailing of the international search report
 27 July 2021 (27.07.2021)

Name and mailing address of the ISA/
 Japan Patent Office
 3-4-3, Kasumigaseki, Chiyoda-ku,
 Tokyo 100-8915, Japan

Authorized officer

Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2021/016908

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	JP 2000-144296 A (KOBE STEEL, LTD.) 26 May 2000 (2000-05-26) claims, paragraphs [0048]-[0050], tables 1-3	1-10
X	JP 5-59477 A (NIPPON LIGHT METAL CO., LTD.) 09 March 1993 (1993-03-09) claims, paragraphs [0005]-[0007], [0027]-[0029], tables 1-2	1-10
X	CN 102337429 A (SUZHOU INSTITUTE FOR NONFERROUS METALS RESEARCH CO., LTD.) 01 February 2012 (2012-02-01) claims, paragraphs [0004]-[0005], [0019]-[0022], table 1	1-10
A	JP 8-3675 A (NIPPON LIGHT METAL CO., LTD.) 09 January 1996 (1996-01-09) claims, paragraphs [0001], [0017], tables 1-7	1-10

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/JP2021/016908

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WO 2013/114928 A1	08 Aug. 2013	claims, paragraphs [0001], [0071]- [0072], tables 1-2 US 2014/0367001 A1 CN 103975085 A JP 2013-177672 A EP 2003219 A2	
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CN 102337429 A	01 Feb. 2012	(Family: none)	
JP 8-3675 A	09 Jan. 1996	(Family: none)	

REFERENCES CITED IN THE DESCRIPTION

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