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(54) ALUMINUM ALLOY MATERIAL AND HYDROGEN EMBRITTLEMENT INHIBITOR FOR ALUMINUM ALLOY MATERIALS

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CPC *C22C 21/10* (2013.01)

(57) **ABSTRACT**

An aluminum alloy material having an aluminum alloy composition of the aluminum alloy compositions (1) below.

Aluminum alloy composition (1)

0.30 mass% or less of Si, more than 0.35 mass% of Fe, 0.20 mass% or less of Cu, 0.20 to 0.70 mass% of Mn, 1.0 to 2.0 mass% of Mg, 0.30 mass% or less of Cr, 4.0 to 5.0 mass% of Zn, 0.10 mass% or less of V, 0.25 mass% or less of Zr, and 0.20 mass% or less of Ti, while additionally containing Al.

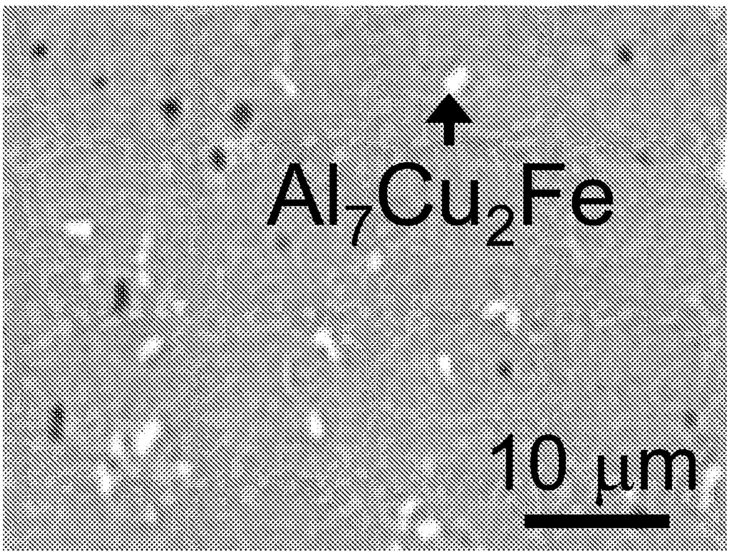


Figure 1

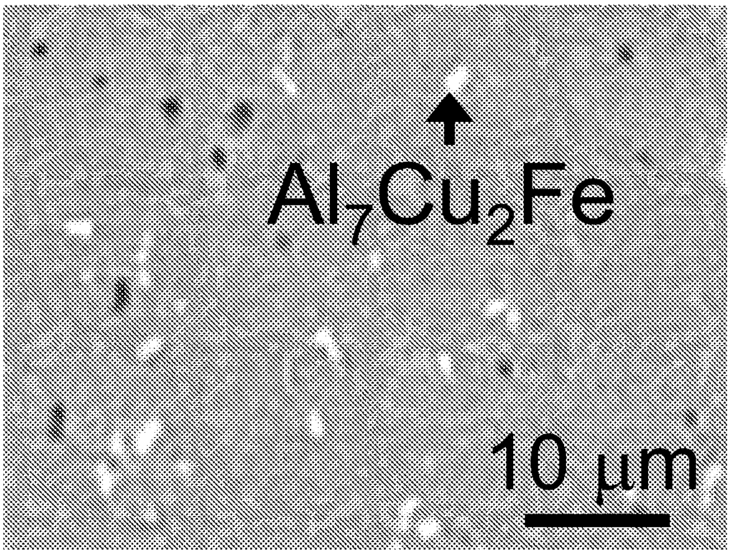


Figure 2

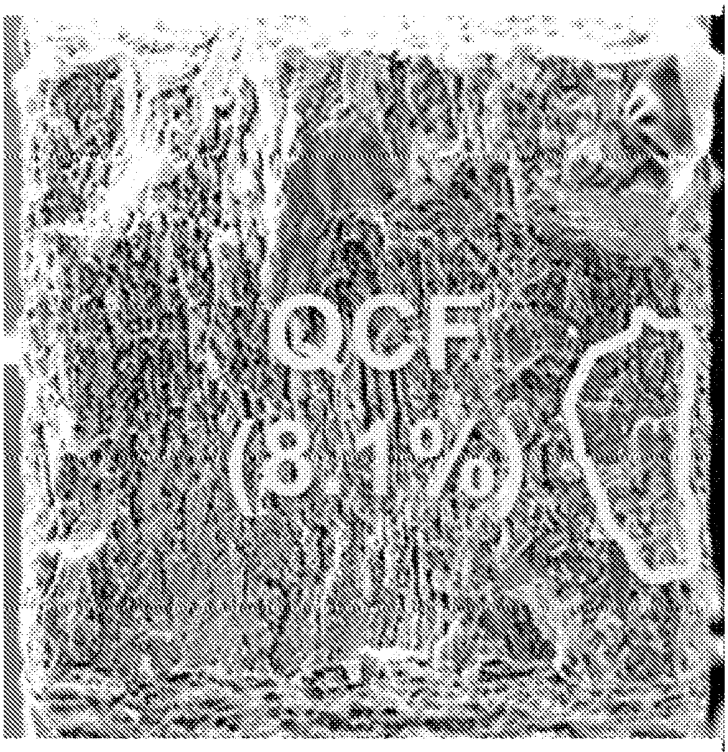


Figure 3

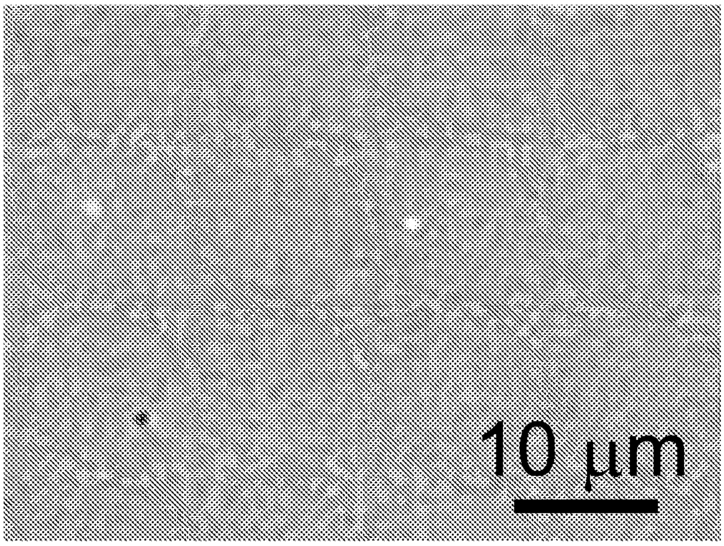


Figure 4

Figure 5

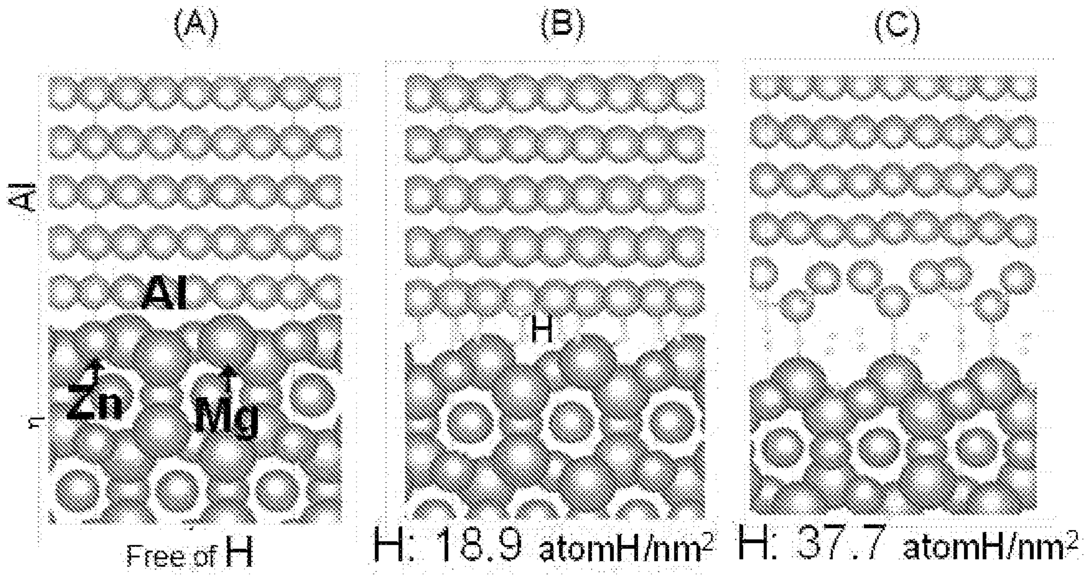


Figure 6

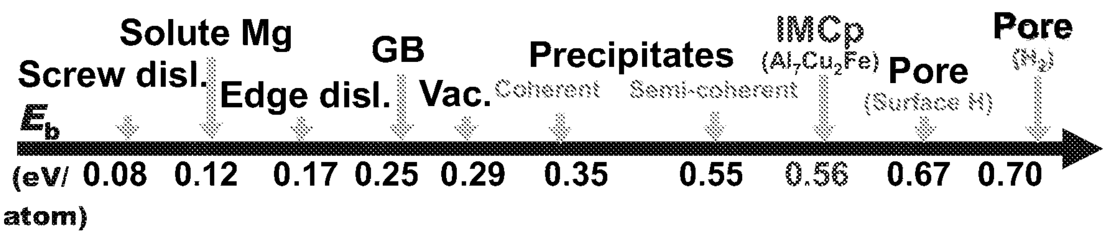


Figure 7

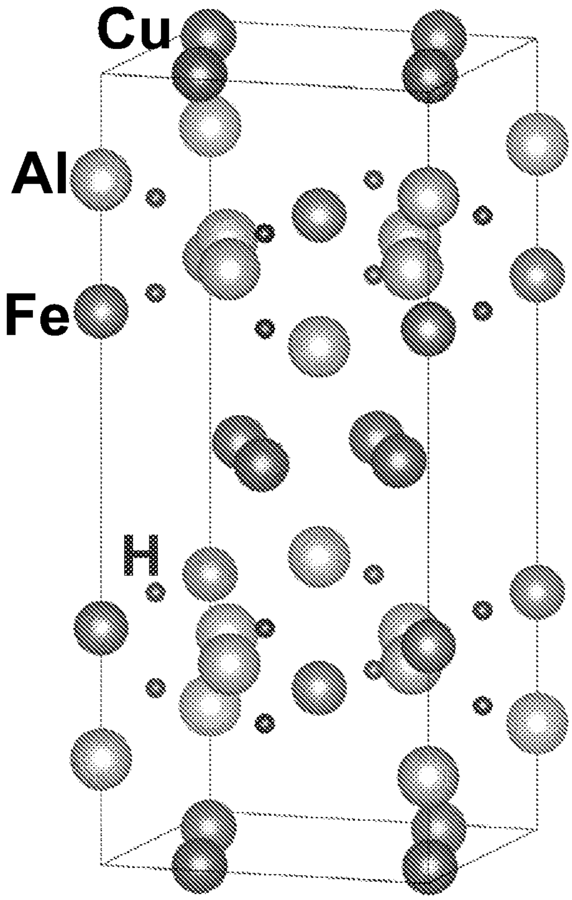
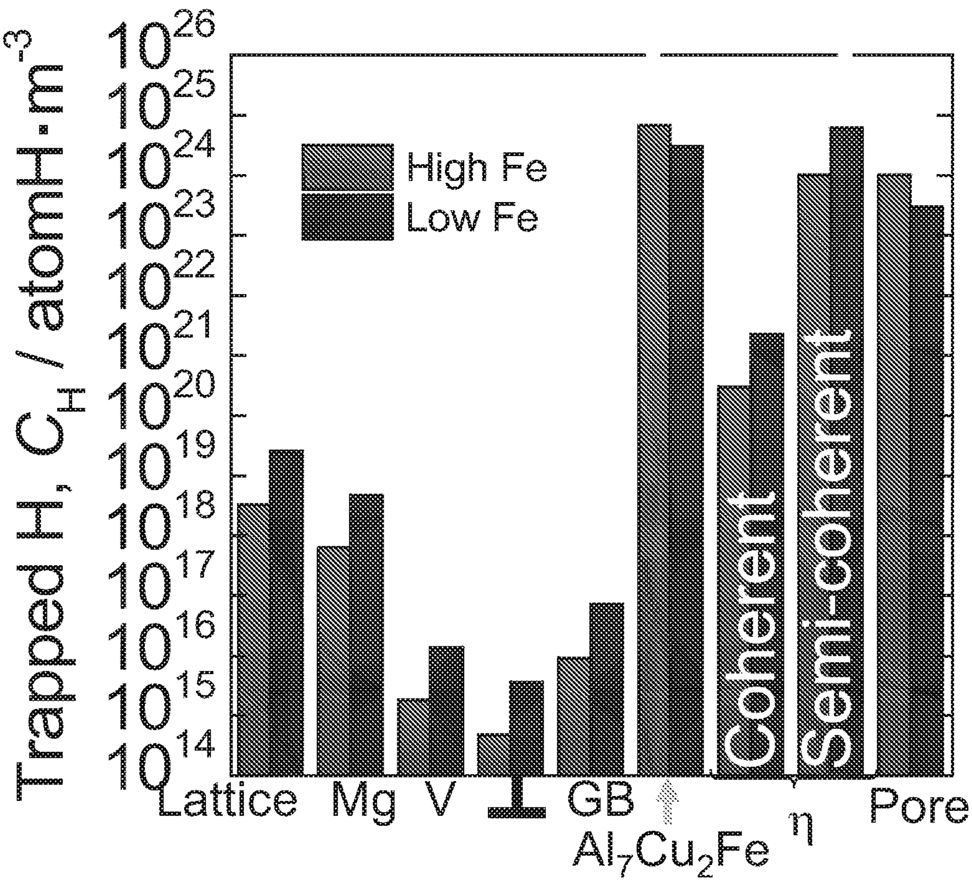
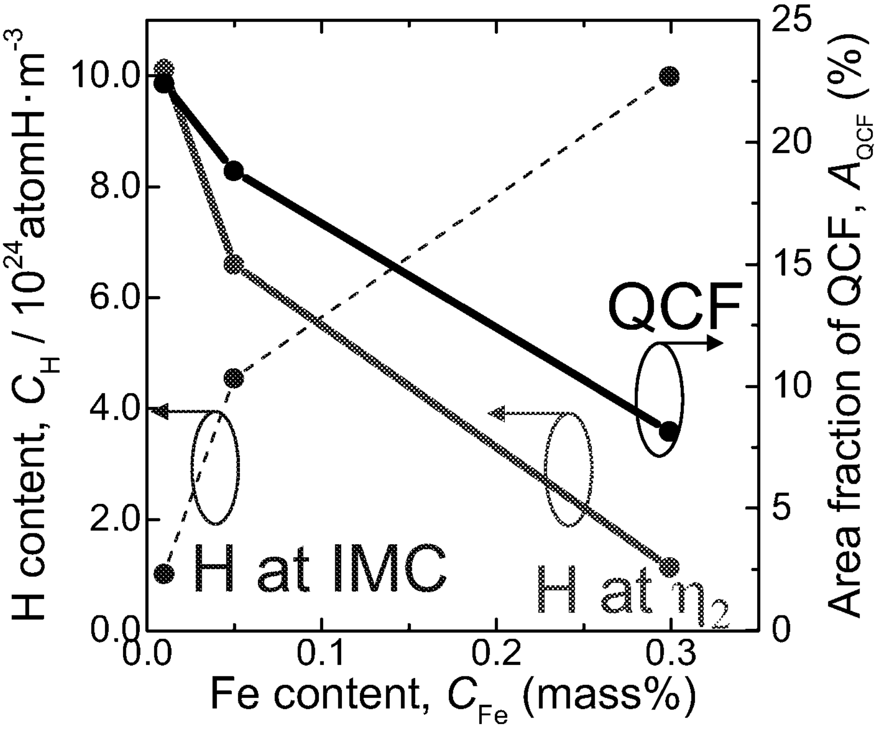


Figure 8



Trapped H, C_H / atomH·m^{-3}
10^{26}
10^{25}
10^{24}
10^{23}
10^{22}
10^{21}
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
High Fe
Low Fe
Coherent
Semi-coherent
Lattice
Mg
V
GB
Al_7Cu_2Fe
η
Pore

Figure 9


H content, C_H / 10^{24}atomH·m^{-3}
10.0
8.0
6.0
4.0
2.0
0.0
0.0
0.1
0.2
0.3
Fe content, C_{Fe} (mass%)
Area fraction of QCF, A_{QCF} (%)
25
20
15
10
5
0
QCF
H at IMC
H at η_2

ALUMINUM ALLOY MATERIAL AND HYDROGEN EMBRITTLEMENT INHIBITOR FOR ALUMINUM ALLOY MATERIALS

TECHNICAL FIELD

[0001] The present invention relates to an aluminum alloy material and to a hydrogen embrittlement inhibitor for aluminum alloy materials.

BACKGROUND ART

[0002] Aluminum alloy materials, which have a wide range of applications, suffer from the problem of hydrogen embrittlement cracks, and proposals have been made to solve this problem (see PTL 1 to 4).

[0003] PTL 1 discloses an aluminum alloy material for a high pressure gas vessel, which has an aluminum alloy composition that contains, in terms of mass%, 4.0 to 6.7% of Zn, 0.75 to 2.9% of Mg, 0.001 to 2.6% of Cu, 0.05 to 0.40% of Si, 0.005 to 0.20% of Ti and 0.01 to 0.5% of Fe, and contains one or two or more of 0.01 to 0.7% of Mn, 0.02 to 0.3% of Cr, 0.01 to 0.25% of Zr and 0.01 to 0.10% of V so as to satisfy the relationship $1.0\% \geq Fe+Mn+Cr+Zr+V \geq 0.1\%$, with the remainder comprising Al and unavoidable impurities, and in which the relationship between electrical conductivity (%IACS) and the total content of Fe, Mn, Cr, Zr and V satisfies the following relationship: electrical conductivity $(\%) \geq -4.9\times(Fe+Mn+Cr+Zr+V)+40.0$, and which has a 0.2% proof stress of 275 MPa or more and exhibits excellent hydrogen embrittlement resistance.

[0004] PTL 2 discloses a method for producing a thick aluminum alloy thick plate having excellent strength and ductility, in which a thick plate in which the total area ratio of intermetallic compounds having an equivalent circle diameter of more than 5 μm is controlled to 2% or less is obtained by using an Al-Zn-Mg-Cu-based aluminum alloy, which contains 5.0 to 7.0% of Zn, 1.0 to 3.0% of Mg and 1.0 to 3.0% of Cu, also contains a total of 0.05 to 0.5% of one or two or more of 0.05 to 0.3% of Cr, 0.05 to 0.25% of Zr, 0.05 to 0.40% of Mn and 0.05 to 0.35% of Sc, and further contains 0.25% or less of Si and 0.25% or less of Fe as impurities, with the remainder comprising Al and unavoidable impurities, subjecting an ingot of this alloy to a homogenizing treatment by holding the ingot at a temperature of 450 to 520° C. for 1 hour or longer, then regulating the average cooling rate at least to 400° C. to 100° C./hr or more in a step for cooling the ingot, then carrying out hot rolling to a plate thickness of 50 mm or more at a temperature within the range 300 to 440° C., and then carrying out a solution treatment, quenching and an artificial aging treatment.

[0005] PTL 3 discloses a method for producing a high strength Al-Zn-Mg-based aluminum alloy forging material having excellent resistance to stress corrosion cracking by regulating the Fe content in the alloy to 0.15 wt% or less when an aluminum alloy, which contains 4.5 to 8.5 wt% of Zn, 1.5 to 3.5 wt% of Mg and 0.8 to 2.6 wt% of Cu and further contains at least one of Mn, Cr, Zr, V and Ti, with the remainder comprising Al and impurities, is molded into a forging material having an H-section by forging.

[0006] PTL 4 discloses a high strength aluminum alloy for welded structures, which exhibits excellent stress corrosion cracking resistance and which contains 5 to 8 wt% of Zn, 1.2 to 4.0 wt% of Mg, more than 1.5 wt% and not more than 4.0 wt% of Cu, 0.03 to 1.0 wt% of Ag, 0.01 to 1.0 wt% of Fe, 0.005 to 0.2 wt% of Ti and 0.01 to 0.2 wt% of V, and further contains one or two or more of 0.01 to 1.5 wt% of Mn, 0.01 to 0.6 wt% of Cr, 0.01 to 0.25 wt% of Zr, 0.0001 to 0.08 wt% of B and 0.03 to 0.5 wt% of Mo, with the remainder comprising aluminum and unavoidable impurities.

CITATION LIST

Patent Literature

[0007] PTL 1: Japanese Patent Application Publication No. 2009-221566

[0008] PTL 2: Japanese Patent Application Publication No. 2011-058047

[0009] PTL 3: Japanese Examined Patent Publication No. H01-025386

[0010] PTL 4: Japanese Patent No. 2915487

SUMMARY OF INVENTION

Technical Problem

[0011] However, no aluminum alloy materials are known that can effectively prevent or inhibit hydrogen embrittlement to the extent required in the aerospace industry.

[0012] The problem to be solved by the present invention is to provide: an aluminum alloy material that can effectively prevent or inhibit hydrogen embrittlement; and a hydrogen embrittlement inhibitor for aluminum alloy materials.

Solution to Problem

[0013] According to the present invention, it was found that hydrogen embrittlement could be prevented or inhibited by an aluminum alloy material having a specific alloy composition and by a hydrogen embrittlement inhibitor for aluminum alloy materials which comprises specific second phase particles, and the problem mentioned above was thereby solved.

[0014] This type of alloy is novel. In PTL 1 to 4, the amount of Fe is higher than that specified in Alloy No. 7050 in JIS H 4100: 2014 “Aluminum and Aluminum Alloy Plates and Strips”, but all of these fall outside the range of the aluminum alloy material of the present invention.

[0015] For example, the composition of invention example 6 in table 1 in PTL 1 contains 0.21 mass% of Si, 0.28 mass% of Fe, and the like, the composition of alloy A in table 1 on page 11 of PTL 2 contains 0.21 mass% of Si, 0.28 mass% of Fe, and the like, the composition of sample 4 in table 1 on page 4 of PTL 3 contains 0.10 mass% of Si, 0.19 mass% of Fe, and the like, and the composition of comparative alloy 10 in table 1 on page 4 of PTL 4 contains 0.10 mass% of Si, 0.20 mass% of Fe, and the like, but these compositions all fall outside the scope of the aluminum alloy material of the present invention.

[0016] The constitution of the present invention, which is a specific means for solving the problem mentioned above, and a preferred constitution of the present invention will now be described.

[0017] [1] An aluminum alloy material which has an aluminum alloy composition of any one of aluminum alloy compositions (1) to (7) below.

Aluminum Alloy Composition (1)

[0018] 0.30 mass% or less of Si, more than 0.35 mass% of Fe, 0.20 mass% or less of Cu, 0.20 to 0.70 mass% of Mn, 1.0 to 2.0 mass% of Mg, 0.30 mass% or less of Cr, 4.0 to 5.0 mass% of Zn, 0.10 mass% or less of V, 0.25 mass% or less of Zr, and 0.20 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (2)

[0019] 0.12 mass% or less of Si, more than 0.15 mass% of Fe, 1.5 to 2.0 mass% of Cu, 0.10 mass% or less of Mn, 2.1 to 2.6 mass% of Mg, 0.05 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.05 mass% or less of Ni, 0.10 to 0.16 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (3)

[0020] 0.12 mass% or less of Si, more than 0.25 mass% of Fe, 2.0 to 2.6 mass% of Cu, 0.10 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (4)

[0021] 0.40 mass% or less of Si, more than 0.50 mass% of Fe, 1.2 to 2.0 mass% of Cu, 0.30 mass% or less of Mn, 2.1 to 2.9 mass% of Mg, 0.18 to 0.26 mass% of Cr, 5.1 to 6.1 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (5)

[0022] More than 0.7 mass% of Si+Fe, 0.10 mass% or less of Cu, 0.10 mass% or less of Mn, 0.10 mass% or less of Mg, and 0.8 to 1.3 mass% of Zn, while additionally containing Al.

Aluminum Alloy Composition (6)

[0023] 0.12 mass% or less of Si, more than 0.12 mass% of Fe, 2.0 to 2.6 mass% of Cu, 0.06 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.05 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (7)

[0024] 0.40 mass% or less of Si, more than 0.50 mass% of Fe, 1.6 to 2.4 mass% of Cu, 0.30 mass% or less of Mn, 2.4 to 3.1 mass% of Mg, 0.18 to 0.28 mass% of Cr, 6.3 to 7.3 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al.

[0025] The aluminum alloy material set forth in [1] in which the aluminum alloy composition is aluminum alloy composition (3).

[0026] The aluminum alloy material set forth in [1] or [2], which includes second phase particles having a higher hydrogen trapping energy than that of a semi-coherent precipitate interface.

[0027] The aluminum alloy material set forth in [3], wherein the second phase particles are Al_7Cu_2Fe particles.

[0028] A hydrogen embrittlement inhibitor for aluminum alloy materials, which comprises Al_7Cu_2Fe particles and can prevent hydrogen embrittlement of aluminum alloy materials.

[0029] The hydrogen embrittlement inhibitor set forth in [5], which can prevent hydrogen embrittlement of an aluminum alloy material having aluminum alloy composition (A) below.

Aluminum Alloy Composition (A)

[0030] 0.40 mass% or less of Si, 2.6 mass% or less of Cu, 0.70 mass% or less of Mn, 3.1 mass% or less of Mg, 0.30 mass% or less of Cr, 7.3 mass% or less of Zn, and 0.20 mass% or less of Ti, while additionally containing Fe and Al.

[0031] The hydrogen embrittlement inhibitor set forth in [5] or [6], which can prevent hydrogen embrittlement of an aluminum alloy material having any one of aluminum alloy compositions (1) to (7) below.

Aluminum Alloy Composition (1)

[0032] 0.30 mass% or less of Si, more than 0.35 mass% of Fe, 0.20 mass% or less of Cu, 0.20 to 0.70 mass% of Mn, 1.0 to 2.0 mass% of Mg, 0.30 mass% or less of Cr, 4.0 to 5.0 mass% of Zn, 0.10 mass% or less of V, 0.25 mass% or less of Zr, and 0.20 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (2)

[0033] 0.12 mass% or less of Si, more than 0.15 mass% of Fe, 1.5 to 2.0 mass% of Cu, 0.10 mass% or less of Mn, 2.1 to 2.6 mass% of Mg, 0.05 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.05 mass% or less of Ni, 0.10 to 0.16 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (3)

[0034] 0.12 mass% or less of Si, more than 0.25 mass% of Fe, 2.0 to 2.6 mass% of Cu, 0.10 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (4)

[0035] 0.40 mass% or less of Si, more than 0.50 mass% of Fe, 1.2 to 2.0 mass% of Cu, 0.30 mass% or less of Mn, 2.1 to 2.9 mass% of Mg, 0.18 to 0.26 mass% of Cr, 5.1 to 6.1 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (5)

[0036] More than 0.7 mass% of Si+Fe, 0.10 mass% or less of Cu, 0.10 mass% or less of Mn, 0.10 mass% or less of Mg, and 0.8 to 1.3 mass% of Zn, while additionally containing Al.

Aluminum Alloy Composition (6)

[0037] 0.12 mass% or less of Si, more than 0.12 mass% of Fe, 2.0 to 2.6 mass% of Cu, 0.06 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to

6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.05 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (7)

[0038] 0.40 mass% or less of Si, more than 0.50 mass% of Fe, 1.6 to 2.4 mass% of Cu, 0.30 mass% or less of Mn, 2.4 to 3.1 mass% of Mg, 0.18 to 0.28 mass% of Cr, 6.3 to 7.3 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al.

[0039] The hydrogen embrittlement inhibitor set forth in [5] or [6], which can prevent hydrogen embrittlement of an aluminum alloy material having any one of aluminum alloy compositions (A1) to (A7) below.

Aluminum Alloy Composition (A1)

[0040] 0.30 mass% or less of Si, 0.35 mass% or less of Fe, 0.20 mass% or less of Cu, 0.20 to 0.70 mass% of Mn, 1.0 to 2.0 mass% of Mg, 0.30 mass% or less of Cr, 4.0 to 5.0 mass% of Zn, 0.10 mass% or less of V, 0.25 mass% or less of Zr, and 0.20 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (A2)

[0041] 0.12 mass% or less of Si, 0.15 mass% or less of Fe, 1.5 to 2.0 mass% of Cu, 0.10 mass% or less of Mn, 2.1 to 2.6 mass% of Mg, 0.05 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.05 mass% or less of Ni, 0.10 to 0.16 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (A3)

[0042] 0.12 mass% or less of Si, 0.15 mass% or less of Fe, 2.0 to 2.6 mass% of Cu, 0.10 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (A4)

[0043] 0.40 mass% or less of Si, 0.50 mass% or less of Fe, 1.2 to 2.0 mass% of Cu, 0.30 mass% or less of Mn, 2.1 to 2.9 mass% of Mg, 0.18 to 0.26 mass% of Cr, 5.1 to 6.1 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al. Aluminum alloy composition (A5)

[0044] 0.7 mass% or less of Si+Fe, 0.10 mass% or less of Cu, 0.10 mass% or less of Mn, 0.10 mass% or less of Mg, and 0.8 to 1.3 mass% of Zn, while additionally containing Al.

Aluminum Alloy Composition (A6)

[0045] 0.12 mass% or less of Si, 0.12 mass% or less of Fe, 2.0 to 2.6 mass% of Cu, 0.06 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.05 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (A7)

[0046] 0.40 mass% or less of Si, 0.50 mass% or less of Fe, 1.6 to 2.4 mass% of Cu, 0.30 mass% or less of Mn, 2.4 to 3.1 mass% of Mg, 0.18 to 0.28 mass% of Cr, 6.3 to 7.3 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al.

Advantageous Effects of Invention

[0047] The present invention is capable of providing: an aluminum alloy material that can effectively prevent or inhibit hydrogen embrittlement; and a hydrogen embrittlement inhibitor for aluminum alloy materials.

BRIEF DESCRIPTION OF DRAWINGS

[0048] FIG. **1** is a virtual cross section of a tomographic image of a microstructure of a (High Fe) aluminum alloy material of Working Example 1.

[0049] FIG. **2** is a virtual cross section of a tomographic image of a fracture surface of the (High Fe) aluminum alloy material of Working Example 1.

[0050] FIG. **3** is a virtual cross section of a tomographic image of a (Low Fe) aluminum alloy material of Reference Example 2.

[0051] FIG. **4** is a virtual cross section of a tomographic image of a fracture surface of the (Low Fe) aluminum alloy material of Reference Example 2.

[0052] FIG. **5** is a schematic diagram of separation at η/Al interfaces as a result of hydrogen trapping.

[0053] FIG. **6** is a number line diagram of hydrogen trapping energies of microstructures in an aluminum alloy material.

[0054] FIG. **7** is a schematic diagram of the crystal structure (space group P4/mnc) of Al_7Cu_2Fe particles.

[0055] FIG. **8** is a bar chart showing trapped hydrogen amounts at sites in the aluminum alloy materials of Working Example 1 (High Fe) and Reference Example 2 (Low Fe).

[0056] FIG. **9** is a graph that shows the relationship between hydrogen distribution to IMC (Al_7Cu_2Fe) particles (H at IMC), hydrogen distribution to a semi-coherent precipitate interface (H at η_2), and hydrogen embrittlement (quasi-cleavage creak) area fraction QCF.

DESCRIPTION OF EMBODIMENTS

[0057] The present invention will now be explained in detail. Explanations of the constituent features described below are based on representative embodiments and specific examples, but it should be understood that the present invention is not limited to such embodiments. Moreover, numerical ranges expressed using the symbol "-" mean ranges that include the numerical values before and after the "-" as lower and upper limits of the range.

Aluminum Alloy Material

[0058] In the aluminum alloy material of the present invention, the aluminum alloy composition is any one of aluminum alloy compositions (1) to (7) below.

Aluminum Alloy Composition (1)

[0059] 0.30 mass% or less of Si, more than 0.35 mass% of Fe, 0.20 mass% or less of Cu, 0.20 to 0.70 mass% of Mn, 1.0 to 2.0 mass% of Mg, 0.30 mass% or less of Cr, 4.0 to 5.0 mass% of Zn, 0.10 mass% or less of V, 0.25 mass% or less of Zr, and 0.20 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (2)

[0060] 0.12 mass% or less of Si, more than 0.15 mass% of Fe, 1.5 to 2.0 mass% of Cu, 0.10 mass% or less of Mn, 2.1 to 2.6 mass% of Mg, 0.05 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.05 mass% or less of Ni, 0.10 to 0.16 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (3)

[0061] 0.12 mass% or less of Si, more than 0.25 mass% of Fe, 2.0 to 2.6 mass% of Cu, 0.10 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (4)

[0062] 0.40 mass% or less of Si, more than 0.50 mass% of Fe, 1.2 to 2.0 mass% of Cu, 0.30 mass% or less of Mn, 2.1 to 2.9 mass% of Mg, 0.18 to 0.26 mass% of Cr, 5.1 to 6.1 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (5)

[0063] More than 0.7 mass% of Si+Fe, 0.10 mass% or less of Cu, 0.10 mass% or less of Mn, 0.10 mass% or less of Mg, and 0.8 to 1.3 mass% of Zn, while additionally containing Al.

Aluminum Alloy Composition (6)

[0064] 0.12 mass% or less of Si, more than 0.12 mass% of Fe, 2.0 to 2.6 mass% of Cu, 0.06 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.05 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (7)

[0065] 0.40 mass% or less of Si, more than 0.50 mass% of Fe, 1.6 to 2.4 mass% of Cu, 0.30 mass% or less of Mn, 2.4 to 3.1 mass% of Mg, 0.18 to 0.28 mass% of Cr, 6.3 to 7.3 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al.

[0066] By having such features, the aluminum alloy material of the present invention can effectively prevent or inhibit hydrogen embrittlement. In particular, it is possible to effectively prevent or inhibit hydrogen embrittlement to the extent required in the aerospace industry.

[0067] In the past, there have been a variety of discussions regarding the relationship between metal structures and hydrogen embrittlement. As means for preventing hydrogen embrittlement, three types of microstructure control methods have been proposed, namely (i) making the distribution of precipitates at grain boundaries low density and coarse, (ii) making the grain boundary tilt angle (twist angle) small (a structure is not recrystallized), and (iii) refining crystal grains (for example, see Goro ITOH, Takehiko ETOH, Yoshimitsu MIYAGI, Mikihiro KANNO, “Al-Zn-Mg-based alloy”, Light Metals, 38 (1988), pages 818 to 839. Moreover, in the table on page 822, a tetragonal Al_7Cu_2Fe crystal is described as a stable phase). However, the effectiveness of these means is unclear, and specific mechanisms are also unclear. Although the effectiveness thereof is insufficient, addition of alloying elements such as zirconium and chromium, which is actually carried out as a method for preventing hydrogen embrittlement, was based on method (ii) or (iii) above.

[0068] In the present invention, however, attention was paid to the fact that local distribution behavior and accumulation behavior of hydrogen in the aluminum alloy material govern hydrogen embrittlement cracks. Particular attention was paid to the fact that a controlling factor responsible for hydrogen embrittlement was hydrogen trapped in precipitates (see Engineering Fracture Mechanics 216 (2019) 106503). In addition, the amount of hydrogen at hydrogen trapping sites that causes hydrogen embrittlement was grasped by determining the binding energy between aluminum microstructures and hydrogen and calculating the hydrogen distribution in the aluminum alloy material. An aluminum alloy material having a specific alloy composition was found that can effectively prevent or inhibit hydrogen embrittlement in an aluminum alloy by concentrating hydrogen at sites that can strongly trap hydrogen. In addition, it was found that second phase particles having a higher hydrogen trapping energy than that of a semi-coherent precipitate interface are used as the hydrogen trapping site.

[0069] In addition, the hydrogen embrittlement inhibitor for aluminum alloy materials of the present invention, which is described later, comprises Al_7Cu_2Fe particles having the hydrogen trapping sites mentioned above.

[0070] Moreover, hydrogen embrittlement cracks include grain boundary cracks and quasi-cleavage cracks, and quasi-cleavage cracks in particular can be effectively prevented or inhibited in the present invention.

[0071] Preferred aspects of the present invention will now be explained.

<Aluminum Alloy Composition>

[0072] In the aluminum alloy material of the present invention, the aluminum alloy composition is any one of aluminum alloy compositions (1) to (7) above.

[0073] Among these aluminum alloy compositions, the aluminum alloy composition is preferably aluminum alloy composition (3) above in the present invention.

[0074] The aluminum alloy material of the present invention preferably has an Fe content of more than 0.12 mass%, more preferably more than 0.15 mass%, particularly preferably more than 0.25 mass%, and yet more preferably 0.30 mass% or more, relative to the entire aluminum alloy material. As the amount of Fe increases, the volume ratio of the second phase particles (preferably Al_7Cu_2Fe particles), the number density of the second phase particles, and the particle diameter of the second phase particles can also be increased.

[0075] However, the upper limit of the amount of Fe is not particularly limited. For example, the amount of Fe relative to the entire aluminum alloy material can be, for example, 1.0 mass% or less, 0.8 mass% or less, or 0.6 mass% or less. If the amount of Fe is less than these upper limits, the volume ratio, number density and particle size of the second phase particles are reduced to a certain extent, meaning that it is easier to inhibit deterioration of material properties caused by aggregation and localization of second phase particles.

[0076] The aluminum alloy material of the present invention contains aluminum as a primary component, and preferably contains 0.50 mass% or more of aluminum.

[0077] More preferred ranges for the aluminum alloy composition will be described in order.

[0078] Aluminum alloy composition (1) is as shown below.

[0079] 0.30 mass% or less of Si, more than 0.35 mass% of Fe, 0.20 mass% or less of Cu, 0.20 to 0.70 mass% of Mn, 1.0 to 2.0 mass% of Mg, 0.30 mass% or less of Cr, 4.0 to 5.0 mass% of Zn, 0.10 mass% or less of V, 0.25 mass% or less of Zr, and 0.20 mass% or less of Ti, while additionally containing Al.

[0080] In aluminum alloy composition (1), the content of Fe is preferably more than 0.35 mass% and not more than 1.0 mass%, and more preferably more than 0.35 mass% and not more than 0.6 mass%.

[0081] Aluminum alloy composition (2) is as shown below.

[0082] 0.12 mass% or less of Si, more than 0.15 mass% of Fe, 1.5 to 2.0 mass% of Cu, 0.10 mass% or less of Mn, 2.1 to 2.6 mass% of Mg, 0.05 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.05 mass% or less of Ni, 0.10 to 0.16 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

[0083] In aluminum alloy composition (2), the content of Fe is preferably more than 0.15 mass% and not more than 1.0 mass%, and more preferably more than 0.15 mass% and not more than 0.6 mass%.

[0084] Aluminum alloy composition (3) is as shown below.

[0085] 0.12 mass% or less of Si, more than 0.25 mass% of Fe, 2.0 to 2.6 mass% of Cu, 0.10 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

[0086] In aluminum alloy composition (3), the content of Fe is preferably more than 0.25 mass% and not more than 1.0 mass%, and more preferably more than 0.25 mass% and not more than 0.6 mass%.

[0087] Aluminum alloy composition (4) is as shown below.

[0088] 0.40 mass% or less of Si, more than 0.50 mass% of Fe, 1.2 to 2.0 mass% of Cu, 0.30 mass% or less of Mn, 2.1 to 2.9 mass% of Mg, 0.18 to 0.26 mass% of Cr, 5.1 to 6.1 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al.

[0089] In aluminum alloy composition (4), the content of Fe is preferably more than 0.55 mass% and not more than 1.0 mass%, and more preferably more than 0.55 mass% and not more than 0.6 mass%.

[0090] Aluminum alloy composition (5) is as shown below.

[0091] More than 0.7 mass% of Si+Fe, 0.10 mass% or less of Cu, 0.10 mass% or less of Mn, 0.10 mass% or less of Mg, and 0.8 to 1.3 mass% of Zn, while additionally containing Al.

[0092] In aluminum alloy composition (5), it is preferable for 0.7 mass%<Si+Fe ≤ 1.0 mass%. In addition, the content of Fe is preferably more than 0.35 mass% and not more than 1.0 mass%, and more preferably more than 0.35 mass% and not more than 0.6 mass%.

[0093] Aluminum alloy composition (6) is as shown below.

[0094] 0.12 mass% or less of Si, more than 0.12 mass% of Fe, 2.0 to 2.6 mass% of Cu, 0.06 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.05 mass% or less of Ti, while additionally containing Al.

[0095] In aluminum alloy composition (6), the content of Fe is preferably more than 0.12 mass% and not more than 1.0 mass%, and more preferably more than 0.12 mass% and not more than 0.6 mass%.

[0096] Aluminum alloy composition (7) is as shown below.

[0097] 0.40 mass% or less of Si, more than 0.50 mass% of Fe, 1.6 to 2.4 mass% of Cu, 0.30 mass% or less of Mn, 2.4 to 3.1 mass% of Mg, 0.18 to 0.28 mass% of Cr, 6.3 to 7.3 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al.

[0098] In aluminum alloy composition (7), the content of Fe is preferably more than 0.50 mass% and not more than 1.0 mass%, and more preferably more than 0.50 mass% and not more than 0.6 mass%.

<Shape of Alloy Material>

[0099] The shape of the aluminum alloy material of the present invention is not particularly limited. The aluminum alloy material may be bulky or particulate, but is preferably bulky.

<Second Phase Particles>

[0100] The aluminum alloy material of the present invention preferably contains second phase particles having a higher hydrogen trapping energy than that of a semi-coherent precipitate interface.

[0101] The term second phase particles means particles having a composition that is different from the constituent composition of a parent phase. The second phase particles in the aluminum alloy material are particles having a composition that is different from that of Al or the aluminum alloy material.

[0102] Second phase particles having a higher hydrogen trapping energy than that of a semi-coherent precipitate interface are not particularly limited. Second phase particles having a higher hydrogen trapping energy than that of a semi-coherent precipitate interface can be determined using first principle calculations. The term "first principle calculations" means theoretically representing an electronic state by mathematically solving the Schrodinger equation (without using experimental data or empirical parameters). The distribution of hydrogen at each trapping site can be calculated from the density of other hydrogen trapping sites, such as grain boundaries, precipitates and lattices, and the binding energy with hydrogen. Moreover, by observing the deformation process of the aluminum alloy material by radiation tomography and carrying out 3D or 4D image processing, a large number of second phase particles dispersed in the aluminum alloy material can be traced, and the internal plastic strain distribution can be determined by means of 3D mapping. From the 3D strain distribution, geometrically required dislocations, statistically required dislocations, and concentration distributions of atomic vacancies can be calculated.

[0103] In the present invention, second phase particles having a hydrogen trapping energy higher than that of a semi-coherent precipitate interface are preferably Al_7Cu_2Fe

particles. Moreover, similar effects can be expected from particles having an Al:Cu:Fe atomic ratio that deviates from the stoichiometric composition of 7:2:1 by approximately 30% (for example, $Al_7Cu_2Fe_{0.7}$ particles). Of the hydrogen trapping energies of the microstructures in the aluminum alloy material, that of Al_7Cu_2Fe particles is 0.56 eV. However, preferred second phase particles or microstructures other than Al_7Cu_2Fe particles having hydrogen trapping energies that are higher than that of a semi-coherent precipitate interface (0.55 eV) are not yet known.

[0104] The shape of the second phase particles includes a variety of shapes, such as spherical, elliptical, square cylinder-shaped, cylindrical, cubic, rectangular parallelepiped-shaped and scaly, but is preferably spherical or elliptical.

[0105] The volume ratio of the second phase particles is preferably 0.05 to 10.0%, more preferably 0.1 to 5.0%, and particularly preferably 0.5 to 2.0%. The volume ratio of the second phase particles can be calculated as the volume of the second phase particles relative to the volume of the aluminum alloy material by means of, for example, 3D analysis using X-Ray tomography (CT).

[0106] The number density of the second phase particles is preferably $6.5\times10^{12}/m^3$ to $100\times10^{12}/m^3$, more preferably $10\times10^{12}/m^3$ to $50\times10^{12}/m^3$, and particularly preferably $20\times10^{12}/m^3$ to $40\times10^{12}/m^3$. The number density of the second phase particles can be calculated by means of, for example, 3D analysis using high resolution X-Ray tomography (CT) having a spatial resolution of up to 1 μm.

[0107] The average particle diameter of the second phase particles is preferably 0.5 to 20 μm. The upper limit of the average particle diameter of the second phase particles is preferably 10 μm or less, and particularly preferably 5.0 μm or less. The average particle diameter of the second phase particles can be calculated as an arithmetic mean value by means of, for example, 3D analysis using X-Ray tomography (CT).

<Method for Producing Aluminum Alloy Material>

[0108] The method for producing the aluminum alloy material is not particularity limited.

[0109] By forming the hydrogen embrittlement inhibitor for aluminum alloy materials, which comprises Al_7Cu_2Fe particles, inside a raw material aluminum alloy material, it is possible to prevent hydrogen embrittlement in the aluminum alloy material.

[0110] It is possible to add Al_7Cu_2Fe particles to the raw material aluminum alloy material, or to add Fe at the time of production to form Al_7Cu_2Fe particles, and ultimately use the Al_7Cu_2Fe particles as a hydrogen embrittlement inhibitor.

[0111] The raw material aluminum alloy material may be a raw material mixture before a metal such as Al or a metal compound is alloyed.

[0112] The aluminum alloy material can be produced by subjecting the raw material aluminum alloy material (which may be a raw material mixture) to a well-known process such as a heat treatment, rolling, forging and/or casting. In the present invention, it is preferable to cast the raw material aluminum alloy material to produce the aluminum alloy material from the perspective of inhibiting hydrogen trapping in precipitates, that is, inhibiting quasi-cleavage creak. In particular, it is preferable to actively form Al_7Cu_2Fe particles by adding Fe at the time of casting to the raw material mixture before each metal or metal compound is alloyed, at a higher quantity than in a case where a conventional aluminum alloy material is produced. In addition, it is possible to not carry out a heat treatment, rolling or forging.

[0113] As other production methods, the method described in paragraphs [0034] to [0042] of Japanese Patent Application Publication No. 2009-221556 can be appropriated, and the contents of this publication are incorporated herein by reference.

Hydrogen Embrittlement Inhibitor for Aluminum Alloy Materials

[0114] The hydrogen embrittlement inhibitor for aluminum alloy materials of the present invention comprises Al_7Cu_2Fe particles and can prevent hydrogen embrittlement of aluminum alloy materials.

[0115] Al_7Cu_2Fe particles may be contained in an existing aluminum alloy material, but such a product was not known to be a hydrogen embrittlement inhibitor for aluminum alloy materials.

<Raw Material Aluminum Alloy Material>

[0116] The raw material aluminum alloy material in which hydrogen embrittlement is to be prevented may be the aluminum alloy material of the present invention or a conventional aluminum alloy material.

[0117] It is preferable for the hydrogen embrittlement inhibitor for aluminum alloy materials of the present invention to be able to prevent hydrogen embrittlement of an aluminum alloy material having aluminum alloy composition (A) below.

Aluminum Alloy Composition (A)

[0118] 0.40 mass% or less of Si, 2.6 mass% or less of Cu, 0.70 mass% or less of Mn, 3.1 mass% or less of Mg, 0.30 mass% or less of Cr, 7.3 mass% or less of Zn, and 0.20 mass% or less of Ti, while additionally containing Fe and Al.

[0119] In a case where a raw material aluminum alloy material in which hydrogen embrittlement is to be prevented is the aluminum alloy material of the present invention, it is preferable for the hydrogen embrittlement inhibitor for aluminum alloy materials of the present invention to be able to prevent hydrogen embrittlement in an aluminum alloy material having any one of aluminum alloy compositions (1) to (7) above.

[0120] In a case where a raw material aluminum alloy material in which hydrogen embrittlement is to be prevented is a conventional aluminum alloy material, it is preferable for the hydrogen embrittlement inhibitor for aluminum alloy materials of the present invention to be able to prevent hydrogen embrittlement in an aluminum alloy material having any one of aluminum alloy compositions (A1) to (A7) below. However, in a case where a raw material aluminum alloy material in which hydrogen embrittlement is to be prevented is a conventional aluminum alloy material, it is preferable to reduce the particle diameter of second phase particles to lower than in the past and disperse these second phase particles so as to more readily prevent hydrogen embrittlement.

Aluminum Alloy Composition (A1)

[0121] 0.30 mass% or less of Si, 0.35 mass% or less of Fe, 0.20 mass% or less of Cu, 0.20 to 0.70 mass% of Mn, 1.0 to 2.0 mass% of Mg, 0.30 mass% or less of Cr, 4.0 to 5.0 mass% of Zn, 0.10 mass% or less of V, 0.25 mass% or less of Zr, and 0.20 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (A2)

[0122] 0.12 mass% or less of Si, 0.15 mass% or less of Fe, 1.5 to 2.0 mass% of Cu, 0.10 mass% or less of Mn, 2.1 to 2.6 mass% of Mg, 0.05 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.05 mass% or less of Ni, 0.10 to 0.16 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (A3)

[0123] 0.12 mass% or less of Si, 0.15 mass% or less of Fe, 2.0 to 2.6 mass% of Cu, 0.10 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (A4)

[0124] 0.40 mass% or less of Si, 0.50 mass% or less of Fe, 1.2 to 2.0 mass% of Cu, 0.30 mass% or less of Mn, 2.1 to 2.9 mass% of Mg, 0.18 to 0.26 mass% of Cr, 5.1 to 6.1 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al. Aluminum alloy composition (A5)

[0125] 0.7 mass% or less of Si+Fe, 0.10 mass% or less of Cu, 0.10 mass% or less of Mn, 0.10 mass% or less of Mg, and 0.8 to 1.3 mass% of Zn, while additionally containing Al.

Aluminum Alloy Composition (A6)

[0126] 0.12 mass% or less of Si, 0.12 mass% or less of Fe, 2.0 to 2.6 mass% of Cu, 0.06 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.05 mass% or less of Ti, while additionally containing Al.

Aluminum Alloy Composition (A7)

[0127] 0.40 mass% or less of Si, 0.50 mass% or less of Fe, 1.6 to 2.4 mass% of Cu, 0.30 mass% or less of Mn, 2.4 to 3.1 mass% of Mg, 0.18 to 0.28 mass% of Cr, 6.3 to 7.3 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al.

[0128] Aluminum alloy compositions (A1) to (A7) are summarized in Table 1 below. “Alloy number” in Table 1 means the alloy number in JIS H 4100: 2014 “Aluminum and aluminum alloy plates and strips”.

TABLE 1

Alloy Composition	Alloy No.	Laminated sheet	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ga, V, Ni, B, Zr etc.	Ti	Others Each	Others Total	Al
(A1)	7204 (7N01)		≤0.30	≤0.35	≤0.20	0.20-0.7	1.0-2.0	≤0.30	4.0-5.0	V: ≤0.10, Zr: ≤0.25	≤0.20	≤0.05	≤0.15	Balance
(A2)	7010		≤0.12	≤0.15	1.5-2.0	≤0.10	2.1-2.6	≤0.05	5.7-6.7	Ni: ≤0.05, Zr: 0.10-0.16	≤0.06	≤0.05	≤0.15	Balance
(A3)	7050		≤0.12	≤0.15	2.0-2.6	≤0.10	1.9-2.6	≤0.04	5.7-6.7	Zr: 0.08-0.15	≤0.06	≤0.05	≤0.15	Balance
(A4)	7075		≤0.40	≤0.50	1.2-2.0	≤0.30	2.1-2.9	0.18-0.28	5.1-6.1	-	≤0.20	≤0.05	≤0.15	Balance
	7075 Laminated sheet	Core material (7075)	≤0.40	≤0.50	1.2-2.0	≤0.30	2.1-2.9	0.18-0.28	5.1-6.1	-	≤0.20	≤0.05	≤0.15	Balance
(A5)		Skin material (7072)	Si+Fe: ≤0.7		≤0.10	≤0.10	≤0.10	-	0.8-1.3	-	-	≤0.05	≤0.15	Balance
(A6)	7475		≤0.10	≤0.12	1.2-1.9	≤0.06	1.9-2.6	0.18-0.25	5.2-6.2	-	≤0.06	≤0.05	≤0.15	Balance
(A7)	7178		≤0.40	≤0.50	1.6-2.4	≤0.30	2.4-3.1	0.18-0.28	6.3-7.3	-	≤0.20	≤0.05	≤0.15	Balance

WORKING EXAMPLES

[0129] The present invention will now be explained in greater detail by means of working examples and comparative examples. The materials, usage quantities, ratios, treatment details, treatment procedures, and so on, shown in the working examples below can be changed as appropriate as long as these do not deviate from the gist of the present invention. Therefore, the scope of the present invention should not be interpreted as being limited by the specific examples given below.

Working Example 1

[0130] Using the method described below, an aluminum alloy material (High Fe) of Working Example 1, in which content of Fe was 0.30 mass%, was prepared as an aluminum alloy material that satisfies aluminum alloy composition (3). This aluminum alloy material is an Al-Zn-Cu alloy which contains 50 mass% or more of Al as a primary component, with the component having the next highest content being Zn, followed by Cu.

[0131] Fe was further added to a melting column for the composition of Alloy No. 7050 in JIS H 4100: 2014 "Aluminum and Aluminum Alloy Plates and Strips", that is, a material for casting an aluminum alloy material that satisfies the aluminum alloy composition (A3), and Al_7Cu_2Fe particles were formed inside the material as second phase particles.

Reference Examples 1 and 2

[0132] An aluminum alloy (Mid Fe) of Reference Example 1, in which the content of Fe was 0.05 mass%, and an aluminum alloy material (Low Fe) of Reference Example 2, in which the content of Fe was 0.01 mass%, were prepared as aluminum alloy materials that satisfy the composition of Alloy No. 7050 in JIS H 4100: 2014 "Aluminum and Aluminum Alloy Plates and Strips", that is, aluminum alloy composition (A3).

[Evaluations]

<3D Analysis>

[0133] The aluminum alloy materials of Working Example 1 and Reference Examples 1 and 2 were subjected to 3D analysis by means of X-Ray tomography. The obtained results are shown in Table 2 below. In Table 2 below, "Particles" means Al_7Cu_2Fe particles.

TABLE 2

Material	Amount of Fe (mass%)	Volume ratio of particles (%)	Number density of particles ($10^{12}/m^3$)	Particle diameter (μm)
High Fe	0.30	1.0	35.2	4.6
Mid Fe	0.05	0.1	6.7	1.7
Low Fe	0.01	0.05	6.3	1.7

[0134] From Table 2 above, it was understood that the volume ratio of Al_7Cu_2Fe particles also increased as the amount of Fe increased.

<Tomographic Images>

[0135] Next, tomographic images were taken of the aluminum alloy materials of Working Example 1 and Reference Examples 1 and 2.

[0136] FIG. **1** shows a virtual cross section of a tomographic image of a microstructure of the (High Fe) aluminum alloy material of Working Example 1. In addition, FIG. **2** shows a virtual cross section of a tomographic image of a fracture surface of the (High Fe) aluminum alloy material of Working Example 1. In FIG. **2** and FIG. **4**, QCF means Area fraction of Quasi-cleavage creak.

[0137] FIG. **3** shows a virtual cross section of a tomographic image of the (Low Fe) aluminum alloy material of Reference Example 2. In addition, FIG. **4** shows a virtual cross section of a tomographic image of a fracture surface of the (Low Fe) aluminum alloy material of Reference Example 2.

[0138] Diagrams are not shown for Reference Example 1.

[0139] From FIG. **1**, it was understood that in the (High Fe) aluminum alloy material of Working Example 1, second phase particles, namely Al_7Cu_2Fe particles, were formed inside the material. It was also understood that the Al_7Cu_2Fe particles were present at the micron level, and were dispersed at a high density.

[0140] However, in the (Low Fe) aluminum alloy material of Reference Example 2 shown in FIG. **3**, it was understood that the second phase particles were hardly formed inside the material.

[0141] Furthermore, from FIG. **2** and FIG. **4** and the results of Reference Example 1 (not shown), the area fraction of quasi-cleavage creak (QCF) at fracture surfaces was determined for Working Example 1 (High Fe), Reference Example 1 (Mid Fe) and Reference Example 2 (Low Fe). The obtained results are shown in Table 3 below.

TABLE 3

	Area fraction of quasi-cleavage creak QCF (%)
High Fe (0.30 mass%)	8.1
Mid Fe (0.05 mass%)	18.8
Low Fe (0.01 mass%)	22.4

[0142] In view of Table 3 above, hydrogen embrittlement can be reduced. It was understood that when the amount of Fe increases from 0.01 mass% to 0.3 mass%, the area fraction of quasi-cleavage creak (QCF) decreases from 22.4% to 8.1%. The area fraction of quasi-cleavage creak QCF corresponds to the hydrogen embrittlement fracture surface ratio. It was thus understood that hydrogen embrittlement can be reduced by increasing the amount of Fe in comparison with conventional aluminum alloy materials, to form and disperse at the micron level at a high density Al_7Cu_2Fe particles as second phase particles inside the material. In addition, it was found that Al_7Cu_2Fe particles can effectively prevent or inhibit quasi-cleavage creak of the aluminum alloy material, and are extremely effective as a hydrogen embrittlement inhibitor for aluminum alloy materials.

<Analysis of Hydrogen Distribution State>

[0143] For the aluminum alloy materials of Working Example 1, Reference Example 1 and Reference Example

2, the hydrogen amount (H at IMC) in a microstructure and the hydrogen amount (H at η_2) in a semi-coherent precipitate (η_2, semi-coherent) were determined using a calculation process.

Semi-Spontaneous Separation of Semi-coherent Precipitate Interface By Hydrogen

[0144] Separation of a η/Al interface by hydrogen trapping was calculated using first principle calculations. The obtained results are shown in FIG. **5**.

[0145] From FIG. **5**, it was understood that when hydrogen was concentrated at a semi-coherent precipitate interface (η_2, semi-coherent), the interface semi-spontaneously separated, and this separation became a starting point for hydrogen embrittlement. This result is a new hydrogen embrittlement mechanism in aluminum alloy materials.

Hydrogen Trapping Energies of Microstructures

[0146] The hydrogen trapping energies of microstructures in the aluminum alloy material were calculated using first principle calculations. The obtained results are shown in FIG. **6**. In FIG. **6**, spiral dislocations (Screw disl.), solute Mg atoms (Solute Mg), edge dislocations (Edge disl.), grain boundaries (GB), vacancies (Vac.), coherent precipitate interfaces (η_1, coherent), semi-coherent precipitate interfaces (η_2, semi-coherent), Al_7Cu_2Fe particles (IMCp), pore surface (Pore (surface H), and molecular hydrogen in the pore (Pore (H_2)) are shown in order from the left.

[0147] From FIG. **6**, it was understood that in the control of hydrogen embrittlement, microstructure control by heat treatment or rolling is not effective for inhibiting hydrogen trapping in precipitates, that is, is not effective for suppressing quasi-cleavage creak. It was understood that the binding energy between a precipitate and hydrogen was the second highest after a pore, and the trapping site density of hydrogen was also high. It was understood that in order to inhibit quasi-cleavage creak based on hydrogen distribution control, it is necessary to provide a site in the material which has a higher binding energy with hydrogen than a precipitate and a sufficiently high trapping site density. From FIG. **6**, it was understood that among the hydrogen trapping energies of the microstructures, that of Al_7Cu_2Fe particles was 0.56 eV, which was higher than 0.35 eV for a coherent precipitate interface (η_1, coherent) and 0.55 eV for a semi-coherent precipitate interface (η_2, semi-coherent). That is, the Al_7Cu_2Fe particles have a higher hydrogen trapping energy than that of a semi-coherent precipitate interface, and this is effective for preventing hydrogen embrittlement.

[0148] The crystal structure (space group P4/mnc) of the Al_7Cu_2Fe particles is shown in FIG. **7** (see Bown et al., Acta Cryst., 9 (1956), 911). From FIG. **7**, it can be confirmed that there is a hydrogen trapping site that can strongly trap H inside the Al_7Cu_2Fe particles.

Calculation of Hydrogen Distribution State

[0149] The hydrogen distribution state in the aluminum alloy material was analyzed.

[0150] Based on the relationships of Numerical Formulae 1 to 3 below, the distribution state of hydrogen in a state of thermal equilibrium was calculated using hydrogen trapping energies determined using first principle calculations. Specific calculations were carried out using a method according to Engineering Fracture Mechanics 216 (2019) 106503.

[Math. 1]

[0151] Formula 1: Thermal equilibrium

Occupancy (trapping sites)
Binding E

$$\frac{\theta_{Ti}}{1-\theta_{Ti}} = \theta_L \exp\left(\frac{E_{bi}}{RT}\right)$$

Occupancy (lattices)

[Math. 2]

[0152] Formula 2: Distribution of hydrogen at trapping sites

Trapping site density (trapping sites)
Surface E

$$C_H^T = \theta_L N_L + \sum \theta_{Ti} N_{Ti} + 2N_A \frac{4\gamma V}{dRT}$$

Trapping site density (lattices)
Pore surface H

[Math. 3]

[0153] Formula 3: Reduction in surface E (surface energy) of pore due to hydrogen adsorption

$$\gamma = \gamma_0 - \left(E_S + RT\ln(\theta_L)\right)\frac{N_S\theta_S}{N_A A} + \frac{N_s}{N_A A}RT\{\theta_s \ln(\theta_s) + (1-\theta_s)\ln(1-\theta_s)\}$$

Surface E
Binding E and chemical potential of hydrogen in lattices
Configurational entropy of adsorbed hydrogen

[0154] The obtained results are shown in FIG. **8**. In FIG. **8**, amounts of hydrogen trapped in microstructures of lattices (Lattice), solute Mg atoms (Mg), pores (V), grain boundaries (⊥), Al_7Cu_2Fe particles (IMCp), coherent precipitate interfaces (coherent), semi-coherent precipitate interfaces (semi-coherent) and pores (Pore), respectively, are shown in order from the left. In the two bar charts for each microstructure, the left hand bar shows a case where the amount of Fe is 0.30 mass% (High Fe), which corresponds to Working Example 1, and the right hand bar shows a case where the amount of Fe is 0.01 mass% (Low Fe), which corresponds to Reference Example 2. However, results for a case where the amount of Fe is 0.05 mass% (Mid Fe), which corresponds to Reference Example 1, are not shown in FIG. **8**.

[0155] As shown in FIG. **8**, it can be understood that hydrogen in the aluminum alloy material is distributed at each microstructure according to the trapping energy thereof.

[0156] In an aluminum alloy material having a low Fe amount of 0.01 mass% (Low Fe), which is similar to that of Reference Example 1, hydrogen is most strongly distributed at a semi-coherent precipitate interface (η_2, semi-coherent). This is a starting point for hydrogen embrittlement (see FIG. **5** above).

[0157] On the other hand, in an aluminum alloy having a high Fe amount of 0.30 mass% (High Fe), which is similar to Working Example 1, hydrogen is most strongly distributed at Al_7Cu_2Fe particles (IMCp). As a result, it was understood that the hydrogen concentration at a precipitate interface such as a semi-coherent precipitate (η_2, semi-coherent) interface was reduced, and hydrogen embrittlement could be prevented.

[0158] The evaluation results above are summarized in FIG. **9**. FIG. **9** is a graph that shows the relationship between hydrogen distribution to IMC (Al_7Cu_2Fe) particles (H at IMC), hydrogen distribution to a semi-coherent precipitate interface (H at η_2), and hydrogen embrittlement (quasi-cleavage creak) area fraction QCF. The horizontal axis shows the amount of Fe in the aluminum alloy materials of Working Example 1, Reference Example 1 and Reference Example 2.

[0159] From Table 1 above, it was understood that the volume ratio of the Al_7Cu_2Fe particles increases as the amount of Fe in the aluminum alloy material increases.

[0160] From the results in Table 1 and FIG. **9**, it was understood that as the amount of Fe in the aluminum alloy material increases, the amount of hydrogen trapped by Al_7Cu_2Fe particles increases (dashed line; H at IMC), the amount of hydrogen in the precipitate decreases (H at η_2), and hydrogen embrittlement (quasi-cleavage creak) can be effectively prevented or inhibited (QCF).

[0161] In addition, it was understood that the aluminum alloy material effectively functions as a hydrogen brittle inhibitor even in a case where a material for casting an aluminum alloy material having a conventional well-known composition specified in JIS H 4100: 2014 is used, because Al_7Cu_2Fe particles are formed inside the material as second phase particles.

1. An aluminum alloy material which has an aluminum alloy composition of any one of aluminum alloy compositions (1) to (7) below.

Aluminum alloy composition (1)

0.30 mass% or less of Si, more than 0.35 mass% of Fe, 0.20 mass% or less of Cu, 0.20 to 0.70 mass% of Mn, 1.0 to 2.0 mass% of Mg, 0.30 mass% or less of Cr, 4.0 to 5.0 mass% of Zn, 0.10 mass% or less of V, 0.25 mass% or less of Zr, and 0.20 mass% or less of Ti, while additionally containing Al.

Aluminum alloy composition (2)

0.12 mass% or less of Si, more than 0.15 mass% of Fe, 1.5 to 2.0 mass% of Cu, 0.10 mass% or less of Mn, 2.1 to 2.6 mass% of Mg, 0.05 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.05 mass% or less of Ni, 0.10 to 0.16 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

Aluminum alloy composition (3)

0.12 mass% or less of Si, more than 0.25 mass% of Fe, 2.0 to 2.6 mass% of Cu, 0.10 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

Aluminum alloy composition (4)

0.40 mass% or less of Si, more than 0.50 mass% of Fe, 1.2 to 2.0 mass% of Cu, 0.30 mass% or less of Mn, 2.1 to 2.9 mass% of Mg, 0.18 to 0.26 mass% of Cr, 5.1 to 6.1 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al.

Aluminum alloy composition (5)

More than 0.7 mass% of Si+Fe, 0.10 mass% or less of Cu, 0.10 mass% or less of Mn, 0.10 mass% or less of Mg, and 0.8 to 1.3 mass% of Zn, while additionally containing Al.

Aluminum alloy composition (6)

0.12 mass% or less of Si, more than 0.12 mass% of Fe, 2.0 to 2.6 mass% of Cu, 0.06 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.05 mass% or less of Ti, while additionally containing Al.

Aluminum alloy composition (7)

0.40 mass% or less of Si, more than 0.50 mass% of Fe, 1.6 to 2.4 mass% of Cu, 0.30 mass% or less of Mn, 2.4 to 3.1 mass% of Mg, 0.18 to 0.28 mass% of Cr, 6.3 to 7.3 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al.

2. The aluminum alloy material set forth in claim **1** in which the aluminum alloy composition is aluminum alloy composition (3).

3. The aluminum alloy material set forth in claim **1**, which includes second phase particles having a higher hydrogen trapping energy than that of a semi-coherent precipitate interface.

4. The aluminum alloy material set forth in claim **3**, wherein the second phase particles are Al_7Cu_2Fe particles.

5. A hydrogen embrittlement inhibitor for aluminum alloy materials, which comprises Al_7Cu_2Fe particles and can prevent hydrogen embrittlement of aluminum alloy materials.

6. The hydrogen embrittlement inhibitor set forth in claim **5**, which can prevent hydrogen embrittlement of an aluminum alloy material having aluminum alloy composition (A) below.

Aluminum alloy composition (A)

0.40 mass% or less of Si, 2.6 mass% or less of Cu, 0.70 mass% or less of Mn, 3.1 mass% or less of Mg, 0.30 mass% or less of Cr, 7.3 mass% or less of Zn, and 0.20 mass% or less of Ti, while additionally containing Fe and Al.

7. The hydrogen embrittlement inhibitor set forth in claim **5**, which can prevent hydrogen embrittlement of an aluminum alloy material having any one of aluminum alloy compositions (1) to (7) below.

Aluminum alloy composition (1)

0.30 mass% or less of Si, more than 0.35 mass% of Fe, 0.20 mass% or less of Cu, 0.20 to 0.70 mass% of Mn, 1.0 to 2.0 mass% of Mg, 0.30 mass% or less of Cr, 4.0 to 5.0 mass% of Zn, 0.10 mass% or less of V, 0.25 mass% or less of Zr, and 0.20 mass% or less of Ti, while additionally containing Al.

Aluminum alloy composition (2)

0.12 mass% or less of Si, more than 0.15 mass% of Fe, 1.5 to 2.0 mass% of Cu, 0.10 mass% or less of Mn, 2.1 to 2.6 mass% of Mg, 0.05 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.05 mass% or less of Ni, 0.10 to 0.16 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

Aluminum alloy composition (3)

0.12 mass% or less of Si, more than 0.25 mass% of Fe, 2.0 to 2.6 mass% of Cu, 0.10 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

Aluminum alloy composition (4)

0.40 mass% or less of Si, more than 0.50 mass% of Fe, 1.2 to 2.0 mass% of Cu, 0.30 mass% or less of Mn, 2.1 to 2.9 mass% of Mg, 0.18 to 0.26 mass% of Cr, 5.1 to 6.1 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al.

Aluminum alloy composition (5)

More than 0.7 mass% of Si+Fe, 0.10 mass% or less of Cu, 0.10 mass% or less of Mn, 0.10 mass% or less of Mg, and 0.8 to 1.3 mass% of Zn, while additionally containing Al.

Aluminum alloy composition (6)

0.12 mass% or less of Si, more than 0.12 mass% of Fe, 2.0 to 2.6 mass% of Cu, 0.06 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.05 mass% or less of Ti, while additionally containing Al.

Aluminum alloy composition (7)

0.40 mass% or less of Si, more than 0.50 mass% of Fe, 1.6 to 2.4 mass% of Cu, 0.30 mass% or less of Mn, 2.4 to 3.1 mass% of Mg, 0.18 to 0.28 mass% of Cr, 6.3 to 7.3 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al.

8. The hydrogen embrittlement inhibitor set forth in claim **5**, which can prevent hydrogen embrittlement of an aluminum alloy material having any one of aluminum alloy compositions (A1) to (A7) below.

Aluminum alloy composition (A1)

0.30 mass% or less of Si, 0.35 mass% or less of Fe, 0.20 mass% or less of Cu, 0.20 to 0.70 mass% of Mn, 1.0 to 2.0 mass% of Mg, 0.30 mass% or less of Cr, 4.0 to 5.0 mass% of Zn, 0.10 mass% or less of V, 0.25 mass% or less of Zr, and 0.20 mass% or less of Ti, while additionally containing Al.

Aluminum alloy composition (A2)

0.12 mass% or less of Si, 0.15 mass% or less of Fe, 1.5 to 2.0 mass% of Cu, 0.10 mass% or less of Mn, 2.1 to 2.6 mass% of Mg, 0.05 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.05 mass% or less of Ni, 0.10 to 0.16 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

Aluminum alloy composition (A3)

0.12 mass% or less of Si, 0.15 mass% or less of Fe, 2.0 to 2.6 mass% of Cu, 0.10 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.06 mass% or less of Ti, while additionally containing Al.

Aluminum alloy composition (A4)

0.40 mass% or less of Si, 0.50 mass% or less of Fe, 1.2 to 2.0 mass% of Cu, 0.30 mass% or less of Mn, 2.1 to 2.9 mass% of Mg, 0.18 to 0.26 mass% of Cr, 5.1 to 6.1 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al.

Aluminum alloy composition (A5)

0.7 mass% or less of Si+Fe, 0.10 mass% or less of Cu, 0.10 mass% or less of Mn, 0.10 mass% or less of Mg, and 0.8 to 1.3 mass% of Zn, while additionally containing Al.

Aluminum alloy composition (A6)

0.12 mass% or less of Si, 0.12 mass% or less of Fe, 2.0 to 2.6 mass% of Cu, 0.06 mass% or less of Mn, 1.9 to 2.6 mass% of Mg, 0.04 mass% or less of Cr, 5.7 to 6.7 mass% of Zn, 0.08 to 0.15 mass% of Zr, and 0.05 mass% or less of Ti, while additionally containing Al.

Aluminum alloy composition (A7)

0.40 mass% or less of Si, 0.50 mass% or less of Fe, 1.6 to 2.4 mass% of Cu, 0.30 mass% or less of Mn, 2.4 to 3.1 mass% of Mg, 0.18 to 0.28 mass% of Cr, 6.3 to 7.3 mass% of Zn, and 0.20 mass% or less of Ti, while additionally containing Al.

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