(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 811 042 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
10.12.2014 Bulletin 2014/50

(21) Application number: **13744215.8**

(22) Date of filing: **10.01.2013**

(51) Int Cl.:
C22C 21/02 $^{(2006.01)}$
B22D 21/04 $^{(2006.01)}$
C22C 21/06 $^{(2006.01)}$
C22F 1/05 $^{(2006.01)}$
C22F 1/00 $^{(2006.01)}$

(86) International application number:
PCT/JP2013/050314

(87) International publication number:
WO 2013/114928 (08.08.2013 Gazette 2013/32)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

(30) Priority: **02.02.2012 JP 2012020956**
14.11.2012 JP 2012250374

(71) Applicant: **Kabushiki Kaisha Kobe Seiko Sho**
Chuo-ku,
Kobe-shi,
Hyogo 651-8585 (JP)

(72) Inventors:
- **INAGAKI, Yoshiya**
  Inabe-shi,
  Mie 511-0200 (JP)
- **HORI, Masayuki**
  Inabe-shi,
  Mie 511-0200 (JP)

(74) Representative: **Müller-Boré & Partner**
Patentanwälte PartG mbB
Friedenheimer Brücke 21
80639 München (DE)

(54) FORGED ALUMINUM ALLOY MATERIAL AND METHOD FOR PRODUCING SAME

(57) Provided is an aluminum alloy forged material comprising an excess amount of Si and a large quantity of a strength-increasing element such as Cu or Mn, and by which high strength and high toughness can be stably obtained even if the forged material is thinned, and also provided is a method for producing the same. A forged material constituted from an aluminum alloy which contains prescribed quantities of Mg, Si, Cu, Fe, Ti and B and further contains one or more elements selected from among Mn, Cr and Zr, with the remainder comprising A1 and inevitable impurities, wherein the electrical conductivity measured at 20 °C on the surface of the aluminum alloy is greater than 42.5 % IACS but not more than 46.0 % IACS, and the forged aluminum alloy material has 0.2% proof stress of 360 MPa or more and Charpy impact value of 6 J/cm^2 or more.

Printed by Jouve, 75001 PARIS (FR)

Description

Field of the invention

[0001] The present invention relates to an aluminum alloy forged material suitably used for strength members for transportation machines or the like, particularly chassis members of an automobile, and a method for manufacturing the same.

Background of the invention

[0002] Conventionally, aluminum alloys composed of 6000 series (Al-Mg-Si series) aluminum alloys according to the JIS standard or the AA standard, and the like, are used for structural materials or structural parts of transportation machines such as vehicles, ships, aircrafts, motorcycles, and automobiles. The 6000 series aluminum alloys have relatively excellent resistance to corrosion. The 6000 series aluminum alloys are also excellent in terms of their easy reusability of scraps as 6000 series aluminum alloy molten raw materials.

[0003] In view of decreasing production cost and workability to components of complicated structure, aluminum alloy cast materials and aluminum alloy forged materials are used for structural materials or structural parts of transportation machines. Among them, the aluminum alloy forged materials are used for structural members of automobiles, particularly for underbody parts such as upper arms and lower arms as they require mechanical properties including higher strength and toughness. Each of such aluminum alloy materials is produced by performing hot forging (die forging) such as mechanical forging or hydraulic forging after a homogenizing heat treatment of an aluminum alloy cast material, and then performing a tempering treatment including a solution-quenching treatment and an artificial aging treatment (sometime referred simply to aging treatment hereinafter). As a raw material for forging, besides the cast material mentioned above, an extruded material obtained by extruding a cast material after a homogenizing heat treatment may also be used.

[0004] In recent years, increasing requirements of further weight (thickness) reduction have been raised for strength members for the transportation machines due to higher demand of low fuel consumption and low CO_2 emission. It is difficult, however, for 6000 series aluminum alloy forged materials such as 6061 and 6151 alloys that have been conventionally used for the applications to realize the high enough strength (0.2 % proof stress) and toughness.

[0005] In order to solve the problem, the present inventors proposed an aluminum alloy forged material described in Japanese Patent No. 3766357. Disclosed in the patent literature is an aluminum alloy forged material including Mg: 0.6 - 1.8 mass%, Si: 0.8 - 1.8 mass%, Cu: 0.2 - 1.0 mass%, mass ratio of Si/Mg is 1 or more, further including one or more of Mn: 0.1 - 0.6 mass%, Cr: 0.1 - 0.2 mass% and Zr: 0.1 - 0.2 mass%, and the remainder being A1 and inevitable impurities. The aluminum alloy forged material of the composition has a thickness of the thinnest portion of 30 mm or less, electrical conductivity measured at the surface of 41.0 - 42.5 % IACS after artificial aging treatment, and 0.2 % proof stress of 350 MPa or more.

Summary of the invention

Problems to be solved by the invention

[0006] However, when one attempts to mass produce an aluminum alloy forged material having a portion whose thickness is 10 mm or less, the one faces a problem that a forged material having high mechanical strength such as 0.2 % proof stress of 360 MPa or more and high toughness cannot be obtained in a reproducible manner by using the aluminum alloy forged material disclosed in Japanese Patent No. 3766357.

[0007] In the mass production of 6000 series of aluminum alloy forged material, dispersions in various conditions of homogenizing heat treatment and hot forging can be usually accommodated to a certain extent. However, the dispersions in manufacturing conditions, which are usually accommodated, affect the 0.2 % proof stress of an aluminum forged material if the mechanical strength of the forged material is enhanced so that the 0.2 % proof stress is 360 MPa or more by containing an excess amount of Si as well as Cu and Mn which are added in an increased amount to enhance the mechanical strength of the thinned forged material. As a result, forged material of high mechanical strength and high toughness cannot be secured as the 0.2 % proof stress of the products excessively varies even if the manufacturing conditions are within the specified range.

[0008] Such a poor reproducibility of a forged material of high mechanical strength and toughness damages reliability of the material for the use of strength members, reduces the manufacturing yield of the forged material product, and increases the manufacturing cost. Excessively narrow tolerances of the manufacturing conditions aiming to stabilize the 0.2 % proof stress and toughness of the forged material also lead to increasing the manufacturing cost.

[0009] The present invention has been made in view of the above-mentioned problem. An object of the present invention is to stably provide an aluminum alloy forged material which exhibits increased mechanical strength and high toughness even if the forged aluminum alloy material is reduced in thickness, by containing an excess amount of Si and a high amount of a strength-increasing element such as Cu and Mn, and a method for manufacturing the same.

Means to solve the problem

[0010] The present invention to solve the above-mentioned problem is characterized in that the aluminum alloy forged material comprising: 0.60 - 1.80 mass% of Mg; 0.80 - 1.80 mass% of Si; 0.20 - 1.00 mass% of Cu; 0.05 - 0.40 mass% of Fe; 0.001 - 0.15 mass% of Ti; 1 - 500 ppm of B; further comprising one or more selected from 0.10 - 0.60 mass% of Mn, 0.10 - 0.40 mass% of Cr, and 0.10 - 0.20 mass% of Zr; and the remainder being A1 and inevitable impurities, and the electrical conductivity measured at the surface of the aluminum alloy forged material at 20 °C is greater than 42.5 % IACS but not more than 46.0 % IACS, the 0.2 % proof stress is 360 MPa or more, and the Charpy impact value is 6 J/cm^2 or more.

[0011] With the prescribed compositions and properties, mechanical strength and toughness of the aluminum alloy forged material are improved by containing the specific amounts of Mg, Si, Cu, Fe, Ti, and B, and further containing the specific amount of a strength-increasing element such as Mn, and by controlling the 0.2 % proof stress and the Charpy impact value to the specific value or larger. The mechanical strength and toughness of the forged material are also improved by controlling the electrical conductivity measured at the surface of the aluminium alloy forged material to the specific range because the ratio of sub-grain structure is increased while maintaining the corrosion resistance.

[0012] Mass ratio of Si/Mg is preferably 1 or more in the aluminum alloy of the present invention. If the Si/Mg mass ratio is 1 or more, the 0.2 % proof stress of the aluminum alloy forged material further increases.

[0013] Content of hydrogen gas is preferably 0.25 ml/100 g-Al or less in the aluminum alloy forged material. By controlling the content of hydrogen gas to the specified value or less, along with the aforementioned composition, forging defects such as bubbles from hydrogen are diminished. As a result of the decreased density of fracture starting points, the Charpy impact value of the aluminum alloy forged material is increased.

[0014] The method for manufacturing the aluminum alloy forged material according to the present invention is comprising: a melting step of melting the aluminum alloy into a molten metal, a casting step of casting the molten metal at a cooling rate of 10 °C/sec or more to form an ingot, a homogenizing heat treatment step of subjecting the ingot to heating at a rate of 5 °C/min or less, and to a homogenizing heat treatment at 450 - 550 °C, a forging step of subjecting the ingot having been subjected to the homogenizing heat treatment to forging at 460 - 540 °C of the forging start temperature, and after the forging step, a solution heat treatment step of subjecting the forged material to a solution heat treatment at 520 - 570 °C, and an artificial aging treatment step of subjecting the forged material to an artificial aging treatment at 170 - 200 °C for 4 - 9 hours.

[0015] According to the process described above, by conducting each of the step under the specific condition, particularly by carrying out the forging step at the starting temperature of 460 - 540 °C, precipitation of Mg_2Si is enhanced because of increase of ratio of sub-grain structure and hence the grain boundaries in the forged structure. As a result, the electrical conductivity measured at the surface of the aluminum alloy forged material after the artificial aging treatment is controlled to the specific range.

[0016] The present inventors have conceived and found that by containing an excess amount of Si and an increased amount of Cu and Mn or the like, electrical conductivity measured at the surface of the aluminum alloy (sometimes referred to as surface electrical conductivity hereinafter) is more closely correlated with the 0.2 % proof stress of the forged material in an aluminum alloy forged material which exhibits high mechanical strength of 0.2 % proof stress of 360 MPa or more, even if the forged material is reduced in thickness.

[0017] If has been generally known that the surface electrical conductivity, reflecting the structure of an aluminum alloy, is closely correlated with the 0.2 % proof stress of the aluminum alloy. It is not necessarily limited to 6000 series aluminum alloy forged material. However, in ordinary 6000 series aluminum alloy forged materials, the relation between electrical conductivity on the surface of aluminum alloy forged material and 0.2 % proof stress is moderately linear. Unless the surface electrical conductivity drastically changes, 0.2 % proof stress is not significantly influenced by the electrical conductivity in the ordinary 6000 series aluminum alloy forged materials.

[0018] On the other hand, in a 6000 series aluminum alloy forged material which is highly strengthened to the 0.2 % proof stress of 360 MPa or more by containing an excess amount of Si and an increased amount of Cu and Mn or the like, even if the forged material is reduced in thickness, the 0.2 % proof stress tends to be maximized if the surface electrical conductivity is more than 42.5 % IACS but not more than 46.0 % IACS. Moreover, the 0.2 % proof stress shows peculiar characteristics of sharp decrease if the surface electrical conductivity is out of the range.

[0019] Therefore, in the 6000 series aluminum alloy forged material in which the 0.2 % proof stress is increased to 360 MPa or more, and the thickness is reduced, the dispersions in electrical conductivity on the surface of the aluminum alloy forged material due to dispersions in manufacturing conditions more sensitively affect the 0.2 % proof stress of the forged material. As a result, a forged material with 0.2 % proof stress of 360 MPa or more is not stably produced due to the dispersion of the manufacturing conditions that are usually accommodated as described above.

[0020] According to the present invention, by utilizing the above-described phenomenon, 0.2 % proof stress of 360 MPa or more in an A1 alloy forged material can be secured and such material can be stably produced by controlling the surface electrical conductivity to more than 42.5 % IACS but not greater than 46.0 % IACS. In other words, by controlling the manufacturing condition so that the electrical conductivity is more than 42.5 % IACS but not greater than 46.0 % IACS on the surface of the aluminum alloy forge material, a forged material with 0.2 % proof stress of 360 MPa or more can be stably produced.

Effect of the invention

[0021] Provided by the present invention is an aluminum alloy forged material comprising an excess amount of Si and a large quantity of a strength-increasing element such as Cu or Mn, and by which high strength and high toughness can be stably obtained while maintaining the corrosion resistance even if the forged material is thinned, and also provided is a method for producing the same. The present invention therefore has considerable industrial significance as it expands the use of aluminum alloy forged material for transportation machines.

Brief description of the drawings

[0022]

FIG. 1 is a front view of a test specimen used for measurements of tensile strength, 0.2 % proof stress, and elongation.

FIGs. 2 are (a) a front view, (b) a side view, and (c) a magnified view of the notched part of (b) of a test specimen to be used for Charpy impact test.

FIGs. 3 show (a) a side view and (b) a front view of a test specimen used for stress corrosion test.

Description of the preferred embodiments

[0023] Firstly, the aluminum alloy forged material (referred to A1 alloy forged material hereinafter) according to the present invention is explained. In the A1 alloy forged material, electrical conductivity measured at 20 °C at the surface of the material after an artificial aging treatment which is described later is controlled to a range of greater than 42.5 % IACS but not more than 46.0 % IACS in order to secure and stably obtain 0.2 % proof stress of 360 MPa or more.

(Electrical conductivity at 20 °C of greater than 42.5 % IACS but not more than 46.0 % IACS)

[0024] In a highly-strengthened A1 alloy forged material in which the 0.2 % proof stress is enhanced to 360 MPa or more even if the thickness of the material is reduced, by containing excess amount of Si and an increased amount of Cu and Mn or the like as for the present invention, 0.2 % proof stress of 360 MPa or more can not be attained if the electrical conductivity at 20 °C measured at the surface is either 42.5 % IACS or less, or more than 46.0 % IACS.

[0025] The electrical conductivity of the A1 alloy forged material shows a similar behavior not only at the surface but also within the bulk including the center portion. Because of convenience in measurement, the electrical conductivity at the surface of the A1 alloy forged material is selected in the present invention.

[0026] Each of test specimen of A1 alloy forged material for measurement of electrical conductivity is prepared from an A1 alloy forged material after an artificial aging treatment by mechanical grinding the surface about 0.05 to 0.1 mm or by etching the surface about a few micrometers. The electrical conductivity at the surface is measured by using, for example, an Eddy current type electrical conductivity meter (AutoSigma 3000DL, manufactured by GE Inspection Technologies Japan). By leaving the meter with a probe, a standard specimen, and the A1 alloy forged material specimen for measurement in the same inspection area so that temperature of the all are equal, it is confirmed prior to the measurement that temperature of the specimens is within a range of ± 1 °C of the ambient temperature by a contact thermometer. In the present invention, a measured value at 20 °C or a conversion value is used to represent electrical conductivity of A1 alloy forged material. Hereinafter, "electrical conductivity at 20 °C" is simply referred to as "electrical conductivity".

[0027] The electrical conductivity on the surface of A1 alloy forged material comprehensively reflects the contents of each of alloy elements as well as structure of the material including their dispersion and degree of crystallization. Further, in addition to these material factors, the electrical conductivity also reflects total metallurgical state of the material including factors in manufacturing conditions.

[0028] In an A1 alloy forged material which is highly-strengthened to 0.2 % proof stress of 360 MPa or more, even if the forged material is reduced in thickness, by containing an excess amount of Si and an increased amount of Cu and Mn or the like, the surface electrical conductivity is not necessarily the same even if the content of each alloying element or the process conditions such as temperature of homogenizing heat treatment and starting temperature of hot forging are roughly in accord with each other.

[0029] Influencing factors of manufacturing condition, which affect surface electrical conductivity of the A1 alloy forged material after the artificial aging treatment include; in addition to the above-described temperature conditions, details of the cooling rate in the casting step, the heating rate, the holding temperature, and the cooling rate of ingot in the homogenizing heat treatment step, type of hot forging apparatus such as mechanical forging and hydraulic forging, number of times of the forging, working ratio in each of the forging steps, the condition of forging finish temperature, the temperature and time conditions of the solution heat treatment, the quenching treatment, and the artificial aging treatment.

[0030] This is because the surface electrical conductivity is significantly affected by slight difference in the process condition in an A1 alloy forged material even if it is reduced in thickness as the forged material is highly-strengthened to 0.2 % proof stress of 360 MPa or more by containing an excess amount of Si and an increased amount of Cu and Mn or the like.

[0031] Thus, if the conditions of material and manufacturing are roughly in accord and the surface electrical conductivities of the Al alloy forged materials are similar, then the problem to be solved by the present invention, the dispersion in the 0.2 % proof stress in the mass-produced materials, would not arise.

[0032] According to the present invention, 0.2 % proof stress is controlled to 360 MPa or more and Charpy impact value is controlled to 6 J/cm^2 or more in the A1 alloy forged material.

(0.2 % proof stress: 360 MPa or more, and Charpy impact value: 6 J/cm^2)

[0033] By controlling the 0.2 % proof stress to 360 MPa or more and the Charpy impact value to 6 J/cm^2 or more in the A1 alloy forged material to possess high enough mechanical strength and toughness, it becomes possible to use the A1 alloy forged material for structural material or parts for transportation machines such as an automobile and a ship.

[0034] Chemical components in the A1 alloy forged material of the present invention are explained hereinafter. The A1 alloy forged material of the present invention comprises Al-Mg-Si series (6000 series) A1 alloy, and the chemical components are specified to secure high mechanical strength, high toughness, and high durability such as stress corrosion cracking resistance for the material to be used for structural material or structural parts for transportation machines such as an automobile and a ship. The chemical components in the Al alloy forged material of the present invention are ones of main factors to govern the electrical conductivity on the surface of the forged material.

[0035] The chemical composition of the aluminum alloy forged material of the present invention includes Mg: 0.60 - 1.80 mass%, Si: 0.80 - 1.80 mass%, Cu: 0.20 - 1.00 mass%, Fe: 0.05 - 0.40 mass%, Ti: 0.001 - 0.15 mass%, B: 1 - 500 ppm; further comprising one or more element selected from Mn: 0.10 - 0.60 mass%, Cr: 0.10 - 0.40 mass% and Zr: 0.10 - 0.20 mass%; and the remainder being Al and inevitable impurities, accordingly.

[0036] It is to be noted here that the chemical composition of the aluminum alloy forged material of the present invention may not necessarily be in accord with a standard component of 6000 series A1 alloy of the JIS standard or the like. For the purpose of further improvement or additional properties, other kinds of element are allowed to be contained appropriately within a range which does not inhibit the characteristics of the present invention. In addition, inevitable impurities which are inevitably mixed from molten raw material scraps are also allowed within a range which does not inhibit the qualities of the forged material of the present invention.

[0037] Next, critical significance and preferred ranges of each element constituting the Al alloy forged material of the present invention are explained.

(Mg: 0.60 - 1.80 mass%)

[0038] Mg is precipitated as Mg_2Si (6' phase) in crystal grains together with Si by artificial aging treatment, and is an essential element for imparting the high 0.2 % proof stress to the aluminum alloy forged material. When the content of Mg is less than 0.60 mass%, the amount of age hardening during the artificial aging treatment is decreased, resulting in deterioration of Charpy impact value (referred to as an index of toughness hereinbelow) and corrosion resistance which are essential properties for an Al alloy forged material as for the high 0.2 % proof stress. On the other hand, when the content of Mg exceeds 1.80 mass%, the 0.2 % proof stress is excessively increased to inhibit forging properties. Further, a large amount of Mg_2Si is liable to precipitate in the middle of a quenching step after a solution heat treatment as explained below. It hinders decrease of average grain size of the Mg_2Si and Al-Fe-Si-(Mn,Cr,Zr)-based crystallized and precipitated products residing on grain boundaries, which are formed by selective chemical bonding of Al, Si, Mn, Cr, Zr, and Fe, and suppresses average distance between the crystallized and precipitated products. As a result, the corrosion resistance of the A1 alloy forged material is deteriorated. Moreover, when the content of Mg exceeds the specified range, it becomes difficult to control the electrical conductivity of the surface of the Al alloy forged materials to the range of greater than 42.5 % IACS but not more than 46.0 % IACS by adjusting the manufacturing conditions. Accordingly, the content of Mg is adjusted to the range from 0.60 to 1.80 mass%.

(Si: 0.80 - 1.80 mass%)

[0039] Si is combined with Mg to form Mg_2Si (β' phase) which precipitates during the artificial aging treatment. The precipitation of Mg_2Si crystals contributes to increasing 0.2 % proof stress of the aluminum alloy forged material. When the Si content is less than 0.80 mass%, the amount of temper hardening decreases, and 0.2 % proof stress and corrosion resistance of the A1 alloy forged material are deteriorated. On the other hand, when the Si content exceeds 1.80 mass%, coarse single body Si particles are crystallized and precipitated in casting and in the middle of quenching after the solution heat treatment. Further, too much amount of the excessive Si prevents average grain size of the Al-Fe-Si-(Mn, Cr,Zr)-based crystallized and precipitated products residing on grain boundaries from decreasing, and suppresses average distance between the crystallized and precipitated products, resulting in deterioration of corrosion resistance and toughness of the A1 alloy forged material, as for Mg. Furthermore, the excessive Si deteriorates the workability of the A1 alloy forged material by lowering its elongation. Moreover, when the content of Si exceeds the specified range, it becomes difficult to control the electrical conductivity of the surface of the Al alloy forged materials to the range of greater than 42.5 % IACS but not more than 46.0 % IACS by adjusting the manufacturing conditions. The content of Si is to be 0.80 - 1.80 mass%, accordingly.

(Cu: 0.20 - 1.00 mass%)

[0040] Cu contributes to enhancement of 0.2 % proof stress for the material by solid solution strengthening. Furthermore, Cu has an effect to significantly promote age hardening of A1 alloy forged material in the step of the artificial aging treatment. When the content of Cu is less than 0.20 mass%, these effects cannot be expected and 0.2 % proof stress cannot be obtained. In order to secure these effects, the content of Cu is preferably controlled to 0.30 mass% or more. On the other hand, when the content of Cu exceeds 1.00 mass%, it extremely increases the sensitivity of stress corrosion cracking and intergranular corrosion of the structure of the aluminum alloy forged material, and deteriorates the corrosion resistance of the aluminum alloy forged material. Further, when the content of Cu exceeds the specified range, it becomes difficult to control the electrical conductivity of the surface of the Al alloy forged materials to the range of more than 42.5 % IACS and 46.0 % IACS or less by adjusting the manufacturing conditions. Therefore, the content of Cu is to be in the range of 0.20 - 1.00 mass%, and preferably 0.30 - 1.00 mass%.

(Fe: 0.05 - 0.40 mass%)

[0041] Fe is added to improve the toughness of the A1 alloy forged material. Fe forms Al_7Cu_2Fe, $Al_{12}(Fe,Mn)_3Cu_2$, $(Fe,Mn)Al_6$, and coarse Al-Fe-Si-(Mn,Cr,Zr)-based crystallized and precipitated products which is a problem to be solved by the present invention. These crystallized and precipitated products provide the start point of fracture and deteriorate the fracture toughness, fatigue properties and the like. In particular, if the content of Fe is more than 0.40 mass%, more strictly 0.35 mass%, then the Al-Fe-Si-(Mn,Cr,Zr)-based crystallized and precipitated products residing on grain boundaries become coarse, and average distance between the crystallized and precipitated products decreases, resulting in decrease of the toughness. If the content of Fe is less than 0.05 mass%, on the other hand, cracking during the casting step and abnormal material structure are induced. The content of Fe is to be in a range of 0.05 - 0.40 mass%, accordingly. The content of Fe is preferably to be in a range of 0.05 - 0.35 mass%.

(Ti: 0.001 - 0.15 mass%)

[0042] Ti is added to the aluminum alloy to make crystal grains in the ingot finer to improve the workability of the material in the extrusion, rolling, and forging steps. If a content of Ti is less than 0.001 mass%, the effect of improved workability is not obtained. On the other hand, if the content of Ti is higher than 0.15 mass%, coarse precipitated crystalline particles are formed and the workability is deteriorated. The content of Ti is to be in a range of 0.001 - 0.15 mass%, accordingly.

(B: 1 - 500 ppm)

[0043] Like Ti, B is added to the aluminum alloy to make crystal grains in the ingot finer to improve the workability of the material in the extrusion, rolling, and forging steps. If a content of B is less than 1 ppm, the effect is not obtained. On the other hand, if the content of B is higher than 500 ppm, coarse precipitated crystalline particles are formed and the workability is deteriorated. The content of B is to be in a range of 1 - 500 ppm, accordingly.

(At least one element of Mn: 0.10 - 0.60 mass%, Cr: 0.10 - 0.40 mass%, and Zr: 0.10-0.20 mass%)

[0044] These elements forms dispersed particles (dispersed phase) collectively known as $(Fe,Mn,Cr,Zr)_3SiAl_{12}$ system of Al-Mn, Al-Cr, and Al-Zr intermetallic compounds which precipitate by selective chemical bonding of Fe, Mn, Cr, Zr, Si, and A1 or others according to their contents during the homogenizing heat treatment step and subsequent the hot forging step.

[0045] Since these dispersed particles have an effect of preventing grain boundaries from moving after recrystallization, coarsening of average crystal size in ST direction of parting line structure in the forging step is prevented. Fine crystal grains or fine sub grains are obtained as well throughout the A1 alloy forged material according to the present invention. Further, enhancement of 0.2 % proof stress is also expected by solid solution of Mn, Cr, and Zr.

[0046] The aluminum alloy according to the present invention contains one or more elements selected from Mn, Cr and Zr, within the range of the contents. If the content of Mn, Cr and Zr is too low, the effect cannot be expected. On the other hand, if an excessive amount of these elements is contained, coarse Al-Fe-Si-(Mn,Cr,Zr)-based intermetallic compounds or crystallized and precipitated products are liable to be formed in the middle of melting and casting steps. They behave as fracture starting points and are factors to deteriorate at least one of electrical conductivity, 0.2 % proof stress, toughness, and corrosion resistance of the Al alloy forged material. Accordingly, the content of each of the elements is adjusted to the range of Mn: 0.10 - 0.60 mass%, Cr: 0.10 - 0.40 mass% and Zr: 0.10 - 0.20 mass%, and one or more kinds of them are to be contained.

(Inevitably contained impurities)

[0047] Elements such as Zn, Be, and V may be assumed inevitably contained in the aluminum alloy. Each of these elements may be contained as long as the amount is low enough not to affect the feature of the present invention. Specifically, an amount of each of these elements is to be 0.05 mass% or less and a total amount of these elements is to be 0.15 mass%.

(Si/Mg mass ratio: 1 or more)

[0048] Mass ratio of Si/Mg is preferably 1 or more in the aluminum alloy of the present invention. By controlling the Si/Mg mass ratio to 1 or more within the content of the elements the 0.2 % proof stress further increases. If the Si/Mg mass ratio is less than 1, such enhancement of the 0.2 % proof stress cannot be realized.

[0049] Further, the content of hydrogen in the A1 alloy forged material of the present invention is preferably to be regulated to a range shown below.

(Hydrogen: 0.25 ml/100 g-Al or less)

[0050] Especially when the working ratio of an A1 alloy forged material is small, hydrogen (H_2) is liable to cause forging defects such as blow holes and the like caused by hydrogen, provides starting points of fracture, and therefore is liable to significantly deteriorate the toughness and fatigue properties of the forged material. The effect of hydrogen particularly becomes significant for the highly strengthened structural material of transportation devices. The content of hydrogen, therefore, is to be regulated to 0.25 ml/100 g-Al or less, and preferably as low as possible.

[0051] Next, the method for manufacturing the aluminum alloy forged material in relation with the present invention is explained. The manufacturing method in relation with the present invention includes a melting step, a casting step, a homogenizing heat treatment step, a forging step, and a tempering step. The Al alloy forged material of the present invention may be manufactured in a usual manner, other than controlling the surface electrical conductivity to the range of more than 42.5 % IACS but not more than 46.0 % IACS, the 0.2 % proof stress, and the toughness of the A1 alloy forged material. Explained hereinafter are conditions of each of the steps to improve the characteristics of the A1 alloy forged material such as controlling the electrical conductivity within the specified range.

(Melting step)

[0052] The melting step is a step to dissolve an aluminum alloy having the above-described composition into a molten metal.

(Casting step)

[0053] The casting step is a step to cast the molten metal having the above-described composition into an ingot. Ordinal melting and casting method, such as continuous casting and rolling method, semi-continuous casting method (direct chill casting process), hot-top casting method, or the like is suitably selected and the ingot is casted. Shape of ingot is not particularly limited. It may be a round bar or a slab shape.

[0054] The molten alloy is cast to an ingot at a cooling rate of 10 °C/sec or more for the purpose of refinement of crystal grains in the ingot, decreasing the mean crystal grain size of the Al-Fe-Si-(Mn,Cr,Zr)-based crystallized and precipitated products residing on grain boundaries, and increasing the average distance between the crystallized and precipitated products. If the cooling rate is low, the mean crystal grain size of the Al-Fe-Si-(Mn,Cr,Zr)-based crystallized and precipitated products residing on grain boundaries increases, and the average distance between the crystallized and precipitated products decreases, resulting in decrease of the 0.2 % proof stress of the A1 alloy forged material after an artificial aging treatment. It is noted that that the cooling rate of the molten alloy is defined as a mean cooling rate from the liquidus temperature to the solidus temperature.

(Homogenizing heat treatment step)

[0055] The homogenizing heat treatment step is a step of subjecting the ingot to homogenizing heat treatment. The treatment is conducted at a heating rate of 5 °C/min or less and at a holding temperature ranging from 450 to 550 °C.

[0056] When the homogenizing heat treatment temperature is too high exceeding 550 °C, the $(Fe,Mn,Cr,Zr)_3SiAl_{12}$ dispersed particles become coarse and the density decreases, failing to disperse relatively high density of fine dispersed crystals among the crystal grains and to obtaining fine crystal grains. As a result, the 0.2 % proof stress of the A1 alloy forged material is decreased after the homogenizing heat treatment.

[0057] On the other hand, of the holding temperature is too low, i.e., less than 450 °C, the number of the $(Fe,Mn,Cr,Zr)_3SiAl_{12}$ dispersed precipitates decreases, causing a shortage of density of the dispersed grains. Further, sufficient solid solution of the Al-Fe-Si-(Mn,Cr,Zr)-based crystallized and precipitated products cannot be realized. It becomes difficult to decrease the mean grain size of Mg_2Si and Al-Fe-Si-(Mn,Cr,Zr)-based crystallized and precipitated products residing on grain boundaries in the A1 alloy forged material after a tempering step explained later, and to increase the average distance between the crystallized and precipitated products. As a result, it becomes difficult to control the electrical conductivity of the surface of the A1 alloy forged materials to the range of more than 42.5 % IACS but not more than 46.0 % IACS (hereinafter referred to the range of the present invention) after the artificial aging treatment.

[0058] The heating rate to the holding temperature is suppressed low as to 5 °C/min. or less in order to maintain the 0.2 % proof stress of the Al alloy forged material after the artificial aging treatment. Holding duration at the holding temperature is preferably 2 hours or more. For the homogenizing heat treatment, the air furnace, the induction heating furnace, a niter furnace, or the like is used appropriately. The heating rate of an ingot is defined as a mean heating rate from room temperature to the holding temperature.

(Forging step)

[0059] The forging step is a step of using the above-mentioned ingot subjected to the homogenizing heat treatment as a forging raw material, and performing predetermined hot forging by forging using a mechanical press or by forging using a hydraulic press. For the hot forging, starting temperature of the forging raw material is adjusted to 460 - 540 °C. If the starting temperature is less than 460 °C, precipitation of Mg_2Si is suppressed because a ratio of sub- grain and the density of grain boundaries in the forged structure are decreased. As a result, the 0.2 % proof stress is deteriorated as the electrical conductivity on the surface of the A1 alloy forged material after the artificial aging treatment cannot be controlled within the range of the present invention. On the other hand, of the starting temperature is more than 540 °C, there are cases in which a portion of the material melts because of heat generated during the forging step. As a result, the 0.2 % proof stress and the corrosion resistance are deteriorated as the electrical conductivity cannot be controlled within the range of the present invention.

[0060] The finishing temperature of the forging raw material in the hot forging step is preferably to be 350 - 540 °C from a point of view to control the electrical conductivity to the range of the present invention. For the purpose of diminishing residual forged structure in the A1 alloy forged material and further improvement of 0.2 % proof stress and toughness, an ingot which has been extruded and/or rolled after a homogenizing heat treatment may also be used as a forging raw material.

[0061] In order to control the hot-forging finishing temperature to 350 - 540 °C, it is necessary to exercise ingenuity such as reheating prior to hot forging and using a die which can be held at high temperatures.

[0062] For the purpose of facilitating to control the electrical conductivity on the surface of the A1 alloy forged material after the artificial aging treatment to the range of the present invention, it is preferred to perform the hot forging by a mechanical forging method, and to perform the forging not more than three times. The shape of the A1 alloy forged material is not particularly limited, and may be near net shape which is close to that of a final product.

(Heat treatment step)

[0063] A heat treatment step is a step of performing a solution treatment and an artificial aging treatment after the forging step, in order to obtain 0.2 % proof stress, corrosion resistance, and toughness necessary for an A1 alloy forged material. Specifically, the heat treatment step includes T6 (an artificial aging treatment for obtaining the maximum strength after the solution treatment at 520 - 570 °C), T7 (excessive artificial aging treatment (over-aging treatment) surpassing the conditions of the artificial aging treatment for obtaining the maximum strength after the solution treatment), T8 (an artificial aging treatment for obtaining the maximum strength, in addition to a cold forging after the solution treatment) or the like.

[0064] The solution heat treatment is conducted at a temperature range of 520 - 570 °C. If the treatment temperature is excessively low, insufficient solutionizing prevents the solid solution of Mg_2Si, controlling the electrical conductivity to the specified range of the present invention, which results in decrease of 0.2 % proof stress. If the treatment temperature is excessively high, localized melting and coarsening of crystal grains are induced, resulting in decrease of 0.2 % proof stress. The holding duration and heating rate of the solution heat treatment are preferably 20 minutes to 20 hours and 100 °C/hr or more, respectively, in order to secure the 0.2 % proof stress. The heating rate of the A1 alloy forged material is defined as a mean heating rate from the temperature of the material immersed in the solution to the holding temperature in the present invention.

[0065] A quenching step may be conducted after the solution heat treatment. The quenching treatment may be conducted by cooling in either cold or hot water. The cooling rate is preferably 40 °C/sec or more in order to prevent degradation of toughness and fatigue property of the forged material. An air furnace, an induction heating furnace, a niter furnace, or the like is used appropriately.

[0066] Temperature and duration of the artificial aging step significantly affect the electrical conductivity on the surface of the Al alloy forged material after the artificial aging step. It is thus necessary to select appropriate conditions in the step by considering the process hysteresis of the material in order to secure the 0.2 % proof stress by controlling the electrical conductivity within the range of the present invention as well as to secure the essential toughness and corrosion resistance. Depending on the amount of alloy elements and process hysteresis (manufacturing conditions) before the artificial aging treatment step, it is necessary to confirm in each of the processing step and manufacturing apparatus. In order to control the electrical conductivity on the surface of the Al alloy forged material after the artificial aging treatment into the range of the present invention, processing condition of the artificial aging treatment is selected from a range of temperature of 170 to 200 °C and a duration of 4 to 9 hours, considering the conditions aiming for the material having the maximum strength by the tempering treatments of T6, T7, and T8 steps. For the artificial aging treatment, the air furnace, the induction heating furnace, an oil bath, or the like is used appropriately.

[0067] Further, the manufacturing method according to the present invention preferably includes a degassing step between the melting step and the casting step.

(Degassing step)

[0068] The degassing step is a step of removing a hydrogen gas (degassing treatment) from the above-mentioned molten metal of the aluminum alloy melted in the melting step, and controlling a hydrogen gas concentration in 100 g of the aluminum alloy to 0.25 ml or less. The removal of the hydrogen gas is performed in a holding furnace for adjusting the components of the molten metal, and removing inclusions by fluxing, chlorine refining, or in-line refining of the molten metal. Preferably, the hydrogen gas is removed by blowing an inert gas of argon or the like into the molten metal using SNIF (Spinning Nozzle Inert Floatation) or porous plugs (Japanese Unexamined Patent Application Publication No. 2002-146447) in an apparatus for removing the hydrogen gas.

[0069] Here, the determination of the hydrogen gas concentration is performed by measuring a hydrogen gas concentration in an ingot produced in the casting step described later or in a forging produced in the forging step, which is described later. The hydrogen gas concentration in the ingot can be obtained by, e.g., cutting a sample out of the ingot prior to the homogenizing heat treatment, subjecting the sample to ultrasonic cleaning using alcohol and acetone, and measuring the hydrogen gas concentration in the sample by, e g., the inert gas flow fusion-thermal conductivity method (LIS A06-1993). On the other hand, the hydrogen gas concentration in the forged material can be obtained by, e.g., cutting a sample out of the forging, immersing the sample in a NaOH solution, removing an oxide coating on the surface thereof with a nitric acid, subjecting the sample to ultrasonic cleaning using alcohol and acetone, and measuring the hydrogen gas concentration in the sample by the vacuum heating extraction volumetric method (LIS A06-1993).

[0070] In the manufacturing method of the present invention, a pre-forming step by forging roll or the like may be included prior to the forging step.

Examples

[0071] Next, the present invention is specifically described based on examples. A1 alloy ingots of compositions shown in Table 1 were casted at a cooling rate of 20 °C/sec by a hot-top casting method into a round bar of 68 mm in diameter and 580 mm in length. The ingots were then subjected to a homogenizing heat treatment at a heating rate of 5 °C/min and a holding temperature of 550 °C for 4 hours.

[0072] Further, a hot forging was performed three times so that the total forging working ratio reaches 75 % by a mechanical forging method using an upper and a lower dies at the forging start temperature and forging finish temperature shown in Table 2. Manufactured was an A1 alloy forged material in a shape of chassis members of an automobile. The thinnest part of the forged material was 6 mm in thickness.

[0073] Next, the A1 alloy forged material was subjected to a solution heat treatment at 550 °C for 1 hour in an air furnace, followed by a water cooling (water quenching) step. The forged material was subsequently subjected to an artificial aging treatment at 190 °C for 5 hours in an air furnace.

[0074] Three test pieces were collected from each of the specimens, and subjected to evaluations on electrical conductivity at the surface, tensile properties such as tensile strength, 0.2 % proof stress, elongation, which are measures of mechanical strength, and Charpy impact value (mechanical property) which is a measure of toughness. Each of the values shown in Table 2 is an average value of those collected from the three test pieces. The measurements of tensile strength, 0.2 % proof stress, elongation were conducted using test specimens S1 collected from each of the A1 alloy forged material as shown in FIG. 1 and by a test method according to the provisions of JIS-Z-2241. The measurement of Charpy impact value was performed using test specimens S2 collected from each of the Al alloy forged material as shown in FIG. 2 and by a test method according to the provisions of JIS-Z-2242. The test pieces having 0.2 % proof stress of 360 MPa or more and Charpy impact values of 6 J/cm^2 or more were each evaluated as excellent.

[0075] Test pieces S3 of a C-ring shape illustrated in FIG. 3 were also collected from each of the A1 alloy forged material, and subjected to a stress corrosion cracking resistance test. The stress corrosion cracking resistance test was performed using the test pieces S3 in the C-ring shape and the alternate immersion test method according to the provisions of ASTMG47. Under added stress of 75 % of the yield stress in LT direction of the test pieces S3, the C-ring shape test pieces were repeatedly subjected to a cycle of immersion and pulling into and out of a salt water during a test period of 90 days. Then presence/absence of stress corrosion cracking in each of the test pieces was examined. The test pieces which did not undergo cracking nor grain boundary corrosion including whole-surface corrosion on the surface were each provided with "good" representing excellent stress corrosion cracking resistance, and evaluated as having excellent corrosion resistance. The test pieces without stress corrosion cracking but with grain boundary corrosion which could potentially leads to stress corrosion cracking were each provided with "not very good" representing not very good stress corrosion cracking resistance, and evaluated as having not very good corrosion resistance. The test pieces which underwent cracking were each provided with "poor" representing poor stress corrosion cracking resistance, and evaluated as having poor corrosion resistance. The results are shown in Table 2.

[Table 1]

Alloy No.	Al alloy composition (In mass%. Contents of B and H_2 are in ppm and ml/100g-Al, respectively. The remainder bering Al)											
	Mg	Si	Cu	Fe	Ti	B	Mn	Cr	Zr	Zn	H_2	Si/Mg
1	1.00	1.10	0.50	0.20	0.03	50	0.5	0.15	0.10	0.01	0.15	1.10
2	0.60	0.80	0.20	0.20	0.03	50	0.5	0.15	0.10	0.01	0.15	1.33
3	0.60	0.80	0.20	0.20	0.03	50	0.5	0.15	0.10	0.01	0.15	1.33
4	1.80	1.80	1.00	0.20	0.03	50	0.5	0.15	0.10	0.01	0.15	1.00
5	1.80	1.80	1.00	0.20	0.03	50	0.5	0.15	0.10	0.01	0.15	1.00
6	1.00	1.10	0.50	0.20	0.03	50	0.5	-	-	0.01	0.15	1.10
7	1.00	1.10	0.50	0.20	0.03	50	-	0.15	-	0.01	0.15	1.10
8	1.00	1.10	0.50	0.20	0.03	50	-	-	0.10	0.01	0.15	1.10
9	1.00	1.10	0.50	0.20	0.03	50	0.5	0.15	-	0.01	0.15	1.10
10	1.00	1.10	0.50	0.20	0.03	50	-	0.15	0.10	0.01	0.15	1.10
1A	1.00	0.80	0.50	0.20	0.03	50	0.5	0.15	0.10	0.01	0.15	0.80

(continued)

Alloy No.	Al alloy composition (In mass%. Contents of B and H_2 are in ppm and ml/100g-Al, respectively. The remainder bering Al)										
	Mg	Si	Cu	Fe	Ti	B	Mn	Cr	Zr	Zn	H_2	Si/Mg
1B	1.00	0.90	0.50	0.20	0.03	50	0.5	0.15	0.10	0.01	0.15	0.90
1C	1.00	0.80	0.50	0.20	0.03	50	0.5	0.15	0.10	0.01	0.26	0.80
1D	1.00	1.10	0.50	0.20	0.03	50	0.5	0.15	0.10	0.01	0.26	1.10
13	0.50	1.80	1.00	0.20	0.03	50	0.5	0.15	0.10	0.01	0.15	3.60
14	2.00	1.80	1.00	0.20	0.03	50	0.5	0.15	0.10	0.01	0.15	0.90
15	1.80	0.70	1.00	0.20	0.03	50	0.5	0.15	0.10	0.01	0.15	0.39
16	1.80	2.00	1.00	0.20	0.03	50	0.5	0.15	0.10	0.01	0.15	1.11
17	1.80	1.80	0.10	0.20	0.03	50	0.5	0.15	0.10	0.01	0.15	1.00
18	1.80	1.80	1.20	0.20	0.03	50	0.5	0.15	0.10	0.01	0.15	1.00
19	1.90	1.90	1.10	0.20	0.03	50	0.5	0.15	0.10	0.01	0.15	1.00
20	1.00	1.10	0.50	0.20	0.03	50	-	-	-	0.01	0.15	1.10
21	1.00	1.10	0.50	0.20	0.03	50	0.7	0.15	0.10	0.01	0.15	1.10
22	1.00	1.10	0.50	0.20	0.03	50	0.5	0.42	0.10	0.01	0.15	1.10
23	1.00	1.10	0.50	0.20	0.03	50	0.5	0.15	0.22	0.01	0.15	1.10
24	1.00	1.10	0.50	0.20	0.03	50	0.7	0.42	0.30	0.01	0.15	1.10
25	1.00	1.10	0.50	0.45	0.03	50	0.5	0.15	0.10	0.01	0.15	1.10
26	1.00	1.10	0.50	0.03	0.03	50	0.5	0.15	0.10	0.01	0.15	1.10
27	1.00	1.10	0.50	0.20	0.17	50	0.5	0.15	0.10	0.01	0.15	1.10
28	1.00	1.10	0.50	0.20	0.03	600	0.5	0.15	0.10	0.01	0.15	1.10
29	1.00	1.10	0.50	0.20	-	-	0.5	0.15	0.10	0.01	0.15	1.10

Note that underlined values indicate that they are out of the claimed range specified in Claim 1. " - " represents the element is not contained in the alloy specimen.

[Table 2]

No.		Alloy No. in Table 1	Casting step	Homogenizing heat treatment step			Forging step		Tempering step				Properties of Al alloy forged material					
			Cooling rate (°C/sec)	Heating rate (°C/min)	Holding temp. (°C)	Heat treatment time (hr)	Starting temp. (°C)	Finishing temp. (°C)	Solution heat treatment temp. (°C)	Solution heat treatment time (hr)	Artificial aging treatment temp. (°C)	Artificial aging treatment time (hr)	Surface electrical conductivity (% IACS)	Tensile stress (MPa)	0.2 % proof stress (MPa)	Elongation (%)	Charpy impact value (J/cm²)	Stress corrosion cracking resistance
Examples	1	1	20	5	550	4	500	420	550	1	190	5	44.0	400	380	14	15	good
	2	2	20	5	550	4	540	460	550	1	190	5	45.5	395	368	16	20	good
	3	3	20	5	550	4	460	380	550	1	190	5	45.0	386	363	15	18	good
	4	4	20	5	550	4	540	460	550	1	190	5	43.0	425	400	12	11	good
	5	5	20	5	550	4	460	380	550	1	190	5	42.7	420	395	10	10	good
	6	6	20	5	550	4	500	420	550	1	190	5	44.5	400	375	12	13	good
	7	7	20	5	550	4	500	420	550	1	190	5	45.0	390	370	12	13	good
	8	8	20	5	550	4	500	420	550	1	190	5	44.5	395	375	12	13	good
	9	9	20	5	550	4	500	420	550	1	190	5	44.5	393	375	13	14	good
	10	10	20	5	550	4	500	420	550	1	190	5	44.5	396	375	13	14	good
	10A	1	20	5	550	4	500	420	550	1	170	4	42.9	397	378	15	16	good
	10B	1	20	5	550	4	500	420	550	1	180	4	43.0	402	383	15	15	good
	10C	1	20	5	550	4	500	420	570	1	190	5	42.6	410	380	13	14	good
	10D	5	20	5	550	4	460	380	550	1	170	4	42.6	418	393	11	10	good
	10E	1A	20	5	550	4	500	420	550	1	190	5	44.7	385	365	15	17	good
	10F	1B	20	5	550	4	500	420	550	1	190	5	44.3	390	373	14	16	good
	10G	1C	20	5	550	4	500	420	550	1	190	5	44.7	380	362	10	7	good
	10H	1D	20	5	550	4	500	420	550	1	190	5	44.0	395	375	10	8	good
Comparative examples	11	13	20	5	550	4	500	420	550	1	190	5	43.5	400	380	8	5	not very good
	12	14	20	5	550	4	500	420	550	1	190	5	41.4	435	415	7	6	poor
	13	15	20	5	550	4	500	420	550	1	190	5	43.5	375	358	9	6	not very good
	14	16	20	5	550	4	500	420	550	1	190	5	41.5	430	410	6	5	poor
	15	17	20	5	550	4	500	420	550	1	190	5	43.5	375	350	10	10	good
	16	18	20	5	550	4	500	420	550	1	190	5	41.6	440	425	6	6	poor

17	19	20	5	550	4	500	420	550	1	190	5	41.5	440	420	6	5	poor
18	20	20	5	550	4	500	420	550	1	190	5	45.0	370	345	9	9	good
19	21	20	5	550	4	500	420	550	1	190	5	42.0	375	355	10	9	good
20	22	20	5	550	4	500	420	550	1	190	5	44.5	370	340	12	10	not very good
21	23	20	5	550	4	500	420	550	1	190	5	44.5	365	330	10	9	not very good
22	24	20	5	550	4	500	420	550	1	190	5	42.0	360	325	8	7	good
23	1	5	5	550	4	500	420	550	1	190	5	45.0	370	340	9	13	good
24	1	20	10	550	4	500	420	550	1	190	5	43.0	370	340	9	12	good
25	1	20	5	560	4	500	420	550	1	190	5	45.0	370	345	9	12	good
26	1	20	5	550	4	420	350	550	1	190	5	42.4	375	355	10	9	good
27	1	20	5	550	4	550	470	550	1	190	5	46.6	320	300	4	7	not very good
28	1	20	5	550	4	500	420	510	1	190	5	46.5	350	320	13	12	good
29	1	20	5	550	4	500	420	550	1	220	5	46.5	350	320	7	9	good
30	25	20	5	550	4	500	420	550	1	190	5	43.0	390	370	9	5	good
31	26	20	5	550	4	Forging could not be conducted due to cracking in the casting step.											
32	27	20	5	550	4	500	420	550	1	190	5	43.0	400	380	10	5	good
33	28	20	5	550	4	500	420	550	1	190	5	43.5	400	380	11	5	good
34	29	20	5	550	4	Cracking occurred in the forging step due to coarsening of the casted structure.											

Note that underlined values indicate that they are out of the claimed range specified in Claims 1 and 4.

[0076] As shown in Tables 1 and 2, A1 alloy forged material examples Nos. 1 - 10, 10A - 10H were excellent in terms of 0.2 % proof stress, Charpy impact value, and stress corrosion cracking resistance, satisfying the scope of claims of the present invention. On the other hand, A1 alloy forged material comparative examples Nos. 11-34 did not satisfy the scope of claims of the present invention, and are inferior in terms of either 0.2 % proof stress, Charpy impact value, or stress corrosion cracking resistance.

[0077] Specifically, comparative example No. 11 was inferior in terms of the Charpy impact value and the stress corrosion crack resistance because the content of Mg was less than the lower limit. Comparative example No. 12 was inferior in terms of the stress corrosion crack resistance and the electrical conductivity was less than the lower limit because the content of Mg was more than the upper limit. Comparative example No. 13 was inferior in terms of the 0.2 % proof stress and the stress corrosion crack resistance because the content of Si was less than the lower limit. Comparative example No. 14 was inferior in terms of the Charpy impact value and the stress corrosion crack resistance and the electrical conductivity was less than the lower limit because the content of Si was more than the upper limit. Comparative example No. 15 was inferior in terms of the 0.2 % proof stress because the content of Cu was less than the lower limit. Comparative example No. 16 was inferior in terms of the stress corrosion crack resistance and the electrical conductivity was less than the lower limit because the content of Cu was more than the upper limit. Comparative example No. 17 was inferior in terms of the Charpy impact value and the stress corrosion crack resistance and the electrical conductivity was less than the lower limit because the contents of Mg, Si, and Cu were more than each of the upper limit.

[0078] Comparative example No. 18 was inferior in terms of the 0.2 % proof stress because it did not contain either Mn or Cr or Zr. Comparative example No. 19 was inferior in terms of the 0.2 % proof stress and the electrical conductivity was less than the lower limit because the content of Mn was more than the upper limit. Comparative example No. 20 was inferior in terms of the 0.2 % proof stress and the stress corrosion crack resistance because the content of Cr was more than the upper limit. Comparative example No. 21 was inferior in terms of the 0.2 % proof stress and the stress corrosion crack resistance because the content of Zr was more than the upper limit. Comparative example No. 22 was inferior in terms of the 0.2 % proof stress and the electrical conductivity was less than the lower limit because the contents of Mn, Cr, and Zr were more than each of the upper limit.

[0079] Although the chemical components satisfy the claimed range, comparative example No. 23 was inferior in terms of the 0.2 % proof stress because the cooling rate was less than the lower limit. Although the chemical components satisfy the claimed range, comparative example No. 24 was inferior in terms of the 0.2 % proof stress because the heating rate was more than the upper limit. Although the chemical components satisfy the claimed range, comparative example No. 25 was inferior in terms of the 0.2 % proof stress because the duration in the homogenizing heat treatment step was more than the upper limit. Although the chemical components satisfy the claimed range, comparative example No. 26, which is the A1 alloy forged material according to the invention of Japanese Patent No. 3766357, was inferior in terms of the 0.2 % proof stress because the forging start temperature was less than the lower limit and hence the electrical conductivity became less than the lower limit. Although the chemical components satisfy the claimed range, comparative example No. 27 was inferior in terms of the 0.2 % proof stress and the resistance to stress corrosion cracking because the forging start temperature was more than the upper limit and hence the electrical conductivity became more than the upper limit. Although the chemical components satisfy the claimed range, comparative example No. 28 was inferior in terms of the 0.2 % proof stress because the temperature of the solution heat treatment was less than the lower limit and hence the electrical conductivity became more than the upper limit. Although the chemical components satisfy the claimed range, comparative example No. 29 was inferior in terms of the 0.2 % proof stress because the temperature of the artificial aging treatment was more than the upper limit and hence the electrical conductivity became more than the upper limit.

[0080] Comparative example No. 30 was inferior in terms of the Charpy impact value because the content of Fe was more than the upper limit. Cracking occurred and comparative example No. 31 could not be forged because the content of Fe was less than the lower limit. Comparative example No. 32 was inferior in terms of the Charpy impact value because the content of Ti was more than the upper limit. Comparative example No. 33 was inferior in terms of the Charpy impact value because the content of B was more than the upper limit. Comparative example No. 34 cracked during the forging step because the cast structure became coarse as it did not contain Ti and B.

Claims

1. An aluminum alloy forged material comprising:

Mg: 0.60 - 1.80 mass%;
Si: 0.80 - 1.80 mass%;
Cu: 0.20 - 1.00 mass%;

Fe: 0.05 - 0.40 mass%;
Ti: 0.001 - 0.15 mass%;
B: 1 - 500 ppm;
further comprising at least one element selected from Mn: 0.10 - 0.60 mass%, Cr: 0.10 - 0.40 mass% and Zr: 0.10 - 0.20 mass%;
the remainder being A1 and inevitable impurities, wherein
the electrical conductivity measured at the surface of the aluminum alloy forged material at 20 °C is more than 42.5 % IACS but not more than 46.0 % IACS,
the 0.2 % proof stress is 360 MPa or more, and
the Charpy impact value is 6 J/cm^2 or more.

2. The aluminum alloy forged material according to claim 1, wherein the mass ratio of Si/Mg is 1 or more in the aluminum alloy.

3. The aluminum alloy forged material according to claim 1 or claim 2, wherein a hydrogen concentration is 0.25 ml/100 g-Al or less.

4. A method for manufacturing the aluminum alloy forged material according to claim 1 or claim 2, comprising:

a melting step of melting the aluminum alloy into a molten metal,
a casting step of casting the molten metal at a cooling rate of 10 °C/sec or more to form an ingot,
a homogenizing heat treatment step of subjecting the ingot to heating at a rate of 5 °C/min or less, and to a homogenizing heat treatment at 450 - 550 °C,
a forging step of subjecting the ingot having been subjected to the homogenizing heat treatment to forging at 460 - 540 °C of the forging start temperature, and
after the forging step,
a solution heat treatment step of subjecting the forged material to a solution heat treatment at 520 - 570 °C, and
an artificial aging treatment step of subjecting the forged material to an artificial aging treatment at 170 - 200 °C for 4 - 9 hours.

FIG. 1

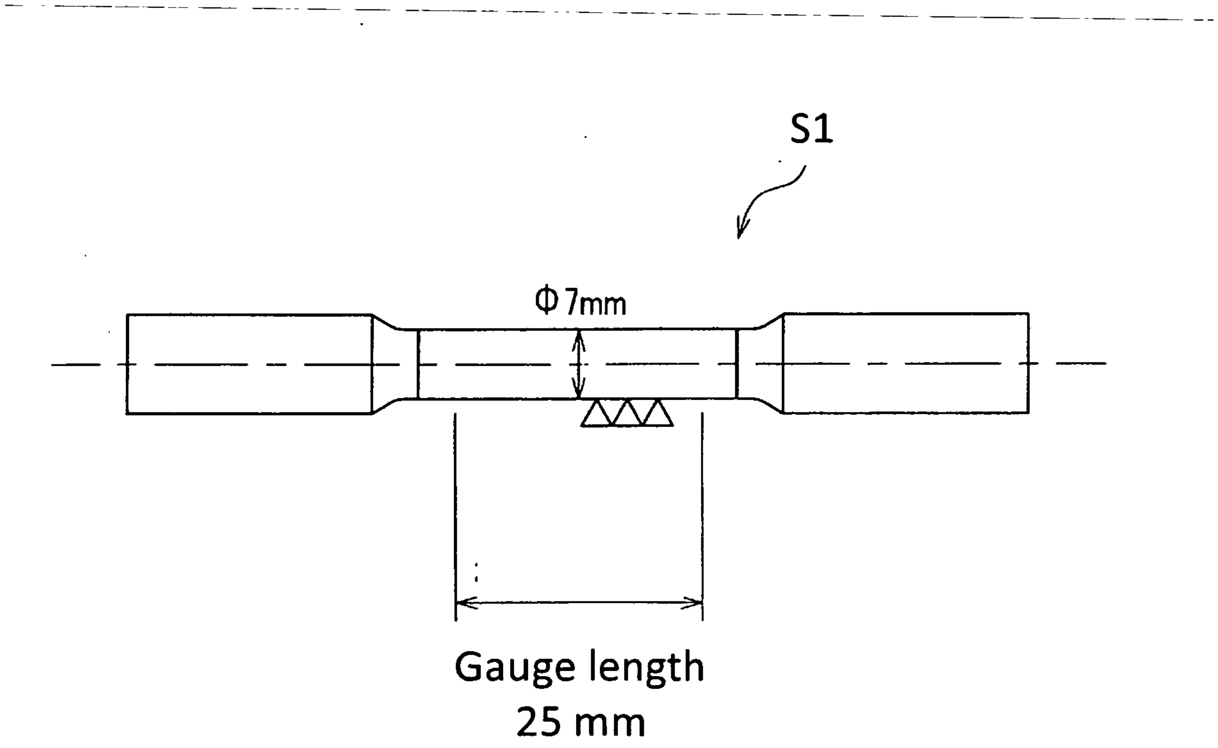


FIG. 2

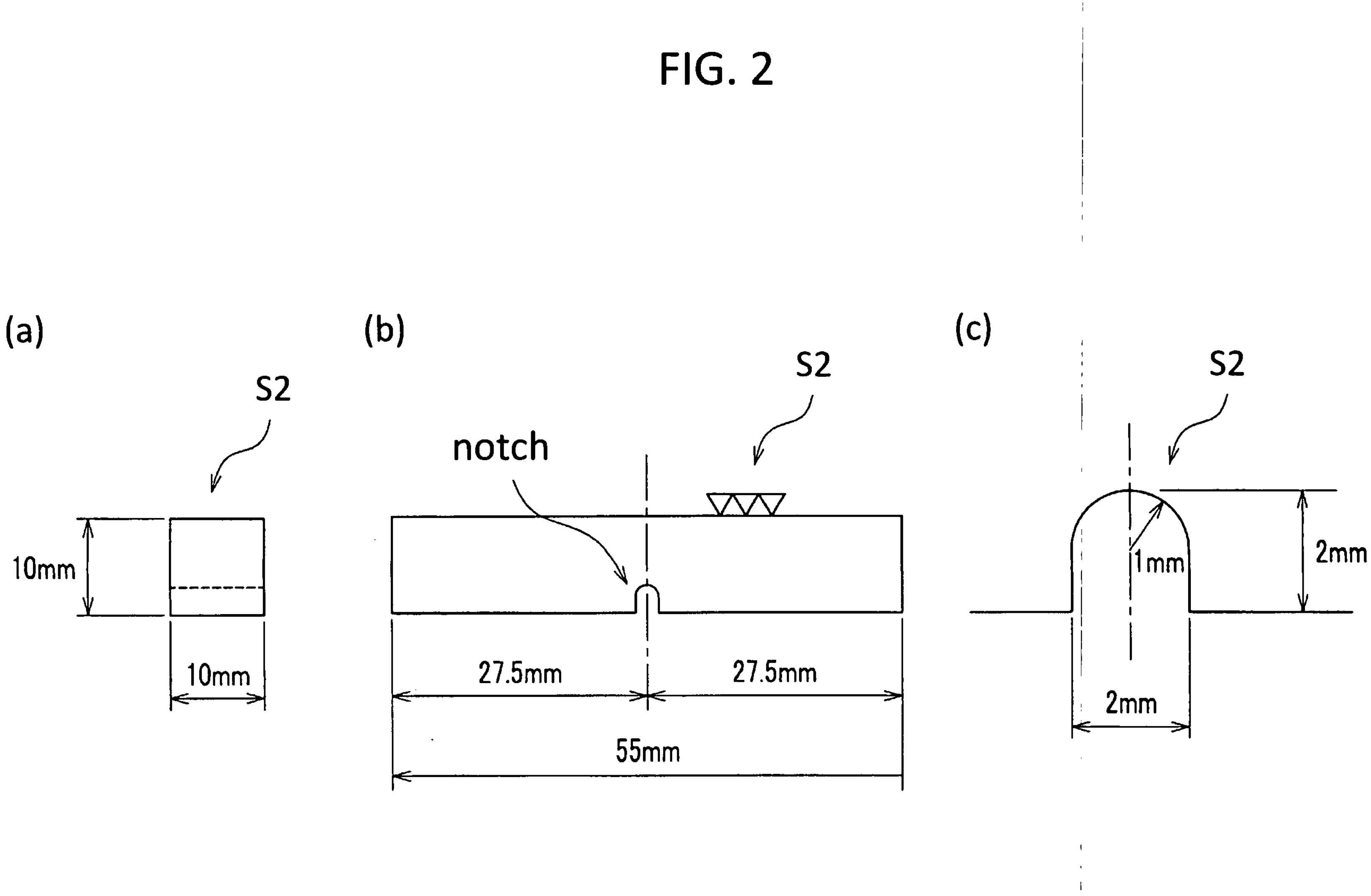
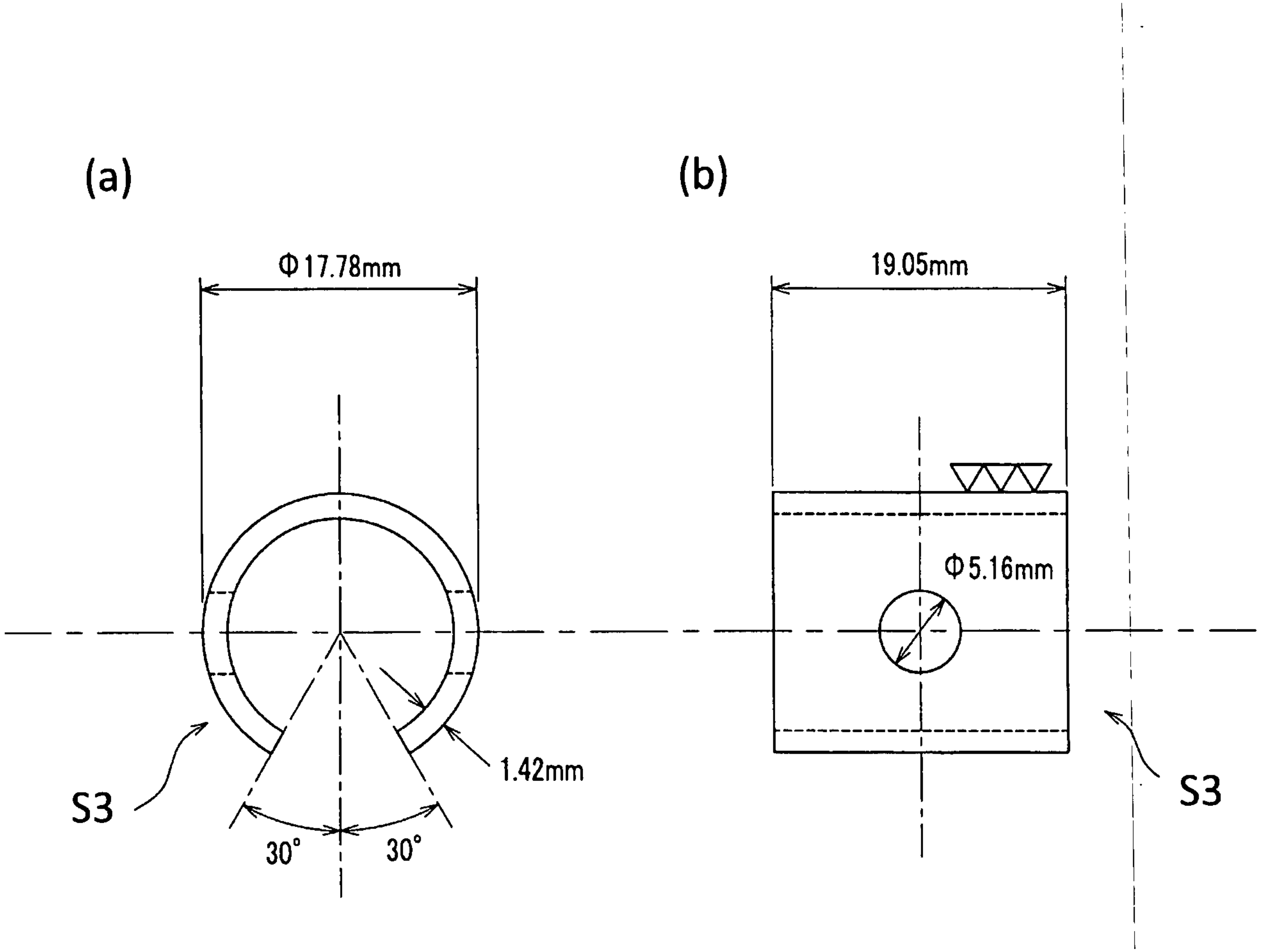


FIG. 3



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2013/050314

A. CLASSIFICATION OF SUBJECT MATTER
C22C21/02(2006.01)i, *B22D21/04*(2006.01)i, *C22C21/06*(2006.01)i, *C22F1/05*(2006.01)i, *C22F1/00*(2006.01)n

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)
C22C21/02, B22D21/04, C22C21/06, C22F1/05, C22F1/00

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2013
Kokai Jitsuyo Shinan Koho	1971-2013	Toroku Jitsuyo Shinan Koho	1994-2013

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 2007/114078 A1 (Kobe Steel, Ltd.), 11 October 2007 (11.10.2007), claims 1 to 7; paragraphs [0005] to [0008], [0030] to [0041], [0077] to [0089], [0111], [0121] to [0125] & US 2009/0000705 A1 & EP 2003219 A2 & CA 2637273 A & KR 10-2008-0102414 A & CN 101365818 A & JP 2008-163445 A	1-4
X	JP 2004-043907 A (Kobe Steel, Ltd.), 12 February 2004 (12.02.2004), claims 1 to 3; paragraphs [0051], [0056] to [0065], [0070] to [0073]; tables 1, 2 (Family: none)	1-4

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier application or patent but published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 05 March, 2013 (05.03.13)	Date of mailing of the international search report 12 March, 2013 (12.03.13)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2013/050314

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2004-084058 A (Kobe Steel, Ltd.), 18 March 2004 (18.03.2004), claims 1 to 6; paragraphs [0038], [0042] to [0048], [0055] to [0073]; tables 1 to 3, no.12 to 14 (Family: none)	1-4
X	JP 2004-292937 A (Kobe Steel, Ltd.), 21 October 2004 (21.10.2004), claims 1 to 5; paragraphs [0038], [0042], [0045] to [0055], [0064]; tables 1 to 3, no. 1 to 6 (Family: none)	1-4
X	JP 2006-274415 A (Kobe Steel, Ltd.), 12 October 2006 (12.10.2006), claims 1 to 4; paragraphs [0038], [0048], [0052] to [0057], [0066], [0067]; tables 1, 2, no.1, 2, 4, 5, 7, 8 (Family: none)	1-4
X	JP 2003-277868 A (Kobe Steel, Ltd.), 02 October 2003 (02.10.2003), claims 1 to 12; paragraphs [0075], [0078] to [0084], [0093]; tables 1, 2, no.4 (Family: none)	1-4
X	JP 2004-315938 A (Kobe Steel, Ltd.), 11 November 2004 (11.11.2004), claims 1 to 5; paragraphs [0030], [0050], [0052], [0059], [0075], [0093]; tables 1 to 3, no.12, 16 (Family: none)	1-4
X	JP 08-232051 A (Sumitomo Light Metal Industries, Ltd.), 10 September 1996 (10.09.1996), claims 1 to 4; paragraphs [0026], [0027] (Family: none)	1-4

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 3766357 B **[0005] [0006] [0079]**
- JP 2002146447 A **[0068]**