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(71) Applicant *(for all designated States except US)*: **SHOWA DENKO K.K.** [JP/JP]; 13-9, Shiba Daimon 1-chome, Minato-ku, Tokyo 105-8518 (JP).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **KAWAMATA, Yasuji** [JP/JP]; c/o Oyama Regional Office, Showa Denko K.K., 480, Inuzuka 1-chome, Oyama-shi, Tochigi 323-8678 (JP). **KOBORI, Kazuhiro** [JP/JP]; c/o Oyama Regional Office, Showa Denko K.K., 480, Inuzuka 1-chome, Oyama-shi, Tochigi 323-8678 (JP). **YAMANOI, Tomoaki** [JP/JP]; c/o Showa Denko Sakai Aluminum K.K., 224, Kaizancho 6-cho, Sakai-shi, Osaka 590-0982 (JP).

(74) Agents: **SHIMIZU, Hisayoshi** et al.; Idemitsu Nagahori Building, 4-26, Minamisemba 3-chome, Chuo-ku, Osaka-shi, Osaka 542-0081 (JP).

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(54) Title: ALUMINUM HOT FORGED ARTICLE, AND METHOD FOR PRODUCING THE SAME

(57) Abstract: In some embodiments, a method for producing an aluminum heat forged article excellent in corrosion resistance and corrosion fatigue strength includes the steps of: subjecting a base material of an aluminum alloy consisting essentially of Si: 0.6 to 1.5 mass%, Mg: 0.8 to 1.5 mass %, and the balance being Al and inevitable impurities to hot forging; applying Zn to a surface of the base material at a rate of 2 to 50 g/m^2, subjecting the base material to solution treatment at 500 to 580 °C for 5 to 180 minutes; and subjecting the base material to quenching treatment for cooling the base material at a cooling rate of 10 ° C/second until it reaches 250 °C.

DESCRIPTION

ALUMINUM HOT FORGED ARTICLE, AND METHOD FOR PRODUCING THE SAME

This application claims priority to Japanese Patent Application No. 2004-339854 filed on November 25, 2004 and U.S. Provisional Application S.N. 60/631,868 filed on December 1, 2004, the entire disclosures of which are incorporated herein by reference in their entireties.

Cross Reference to Related Applications

This application is an application filed under 35 U.S.C. §111(a) claiming the benefit pursuant to 35 U.S.C. §119(e)(1) of the filing date of U.S. Provisional Application S.N. 60/631,868 filed on December 1, 2004, pursuant to 35 U.S.C. §111(b).

Technical Field

The present invention relates to an aluminum hot forged article and a method for producing the same, especially to an aluminum hot forged article excellent in corrosion resistance and corrosion fatigue strength and a method for producing the same.

Background Art

The following description sets forth the inventor's knowledge of related art and problems therein and should not be construed as an admission of knowledge in the prior art.

In automotive parts, recently, it is strongly required to attain weight reduction of vehicle body structural parts to increase mileage and prevent an increase of vehicle body weight. For this reason, using an aluminum as materials has rapidly become popular. Especially, in suspension parts, adoption of aluminum forged parts or aluminum extruded parts has been increased.

As an aluminum alloy for such suspension parts, Al-Mg-Si series alloy is popularly used due to its excellent strength. In order to attain the weight saving thereof, there are various proposals directed to compositions, hot forging conditions, heat treatments and surface treatments to improve the strength and the corrosion resistance.

Japanese Unexamined Laid-open Patent Publication No. S63-103046 (hereinafter, "Patent Document 1") discloses an aluminum alloy to which trace elements such as Ti are added to enhance the strength.

Japanese Laid-open Patent Publication No. 2002-348630

(hereinafter, "Patent Document 2") discloses an aluminum forged member in which alloy compositions, forging conditions, solution treatments and aging conditions are regulated to improve the mechanical characteristics.

Japanese Laid-open Patent Publication No. 2000-119785 (hereinafter, "Patent Document 3") discloses an Al-Mg-Si series alloy member in which compositions of a zincate film for improving processing of a zinc phosphate treatment to be executed to improve the resistance to filiform rust are regulated.

Japanese Laid-open Patent Publication No. 2000-313932 (hereinafter, "Patent Document 4") discloses an aluminum alloy plate in which an adhesion amount of zinc phosphate in a zinc phosphate treatment to be executed to improve the resistance to filiform rust is regulated.

Japanese Laid-open Patent Publication No. H5-78888 (hereinafter, "Patent Document 5") discloses an aluminum plate which was subjected to Zn series plating or Fe series plating, and then heated to diffuse the aluminum into the plating.

In general, it is said that 6000 series alloy (Al-Mg-Si series alloy) is excellent in corrosion resistance as compared with 7000 series alloy or 2000 series alloy. If 6000 series alloy is orientated to high strength, problems including, e.g., deterioration of

ductility due to intergranular cracking or intergranular corrosion in corrosive environment arise. Especially, in parts required to have mechanical strength, fatigue strength and corrosion resistance, deterioration of characteristics becomes a big problem. However, the composition restriction and/or the heat treatment as disclosed by Patent Documents 1 and 2 cannot sufficiently cope with the aforementioned deterioration of characteristics.

Furthermore, the surface treatments as disclosed by Patent Documents 3 to 5 cannot attain sufficient corrosive environment strength, weather resistance, corrosion resistance of a structural member such as a suspension member.

The description herein of advantages and disadvantages of various features, embodiments, methods, and apparatus disclosed in other publications is in no way intended to limit the present invention. Indeed, certain features of the invention may be capable of overcoming certain disadvantages, while still retaining some or all of the features, embodiments, methods, and apparatus disclosed therein.

Other objects and advantages of the present invention will be apparent from the following preferred embodiments.

Disclosure of Invention

The present invention has been developed in view of the above-mentioned and/or other problems in the related art. The present invention can significantly improve upon existing methods and/or apparatuses.

Among other potential advantages, some embodiments can provide an aluminum hot forged article excellent in corrosion resistance and corrosion fatigue strength.

Among other potential advantages, some embodiments can provide a method of producing such aluminum hot forged article.

A method for manufacturing an aluminum forged article according to the present invention has the structures as recited in the following Items [1] to [15].

[1] A method for producing an aluminum heat forged article, comprising the steps of:

subjecting a base material of an aluminum alloy consisting essentially of Si: 0.6 to 1.5 mass%, Mg: 0.8 to 1.5 mass%, and the balance being Al and inevitable impurities to hot forging;

applying Zn to a surface of the base material at a rate of 2 to 50 g/m^2;

subjecting the base material to solution treatment at 500 to 580 °C for 5 to 180 minutes; and

subjecting the base material to quenching treatment for cooling the base material at a cooling rate of 10 °C/second or more until it reaches 250 °C.

[2] The method for producing an aluminum heat forged article as recited in the aforementioned Item 1, wherein the aluminum alloy further includes one or more elements selected from the group consisting of Cu: 0.1 to 0.5 mass%, Mn: 0.05 to 0.5 mass%, Cr: 0.05 to 0.5 mass%, and Fe: 0.5 mass% or less.

[3] The method for producing an aluminum heat forged article as recited in the aforementioned Item 1, wherein the application of Zn is executed by thermal spraying.

[4] The method for producing an aluminum heat forged article as recited in the aforementioned Item 2, wherein the application of Zn is executed by thermal spraying.

[5] The method for producing an aluminum heat forged article as recited in the aforementioned Item 3, wherein the thermal spraying of Zn is executed when the hot forged base material is in a hot-temperature state of 350 °C or above without cooling the base material.

[6] The method for producing an aluminum heat forged article as recited in the aforementioned Item 4, wherein the thermal spraying of Zn is executed when the hot forged base material is in a hot-temperature state of 350 °C or above without cooling the base material.

[7] The method for producing an aluminum heat forged article as recited in the aforementioned Item 1, wherein the application of Zn is executed by plating.

[8] The method for producing an aluminum heat forged article as recited in the aforementioned Item 2, wherein the application of Zn is executed by plating.

[9] The method for producing an aluminum heat forged article as recited in the aforementioned Item 7, wherein zincate treatment is executed as pretreatment of the plating.

[10] The method for producing an aluminum heat forged article as recited in the aforementioned Item 8, wherein zincate treatment is executed as pretreatment of the plating.

[11] The method for producing an aluminum heat forged article as recited in the aforementioned Item 1, wherein the application of Zn is executed after cooling the hot forged base material and cleaning a surface of the base material.

[12] The method for producing an aluminum heat forged article as recited in the aforementioned Item 2, wherein the application of Zn is executed after cooling the hot forged base material and cleaning a surface of the base material.

[13] The method for producing an aluminum heat forged article as recited in the aforementioned Item 7, wherein the application of Zn is executed after cooling the hot forged base material and cleaning a surface of the base material.

[14] The method for producing an aluminum heat forged article as recited in the aforementioned Item 8, wherein the application of Zn is executed after cooling the hot forged base material and cleaning a surface of the base material.

[15] The method for producing an aluminum heat forged article as recited in any one of the aforementioned Items 1 to 14, wherein the application amount of Zn is 4 to 20 g/m^2.

An aluminum forged article according to the present invention has the structures as recited in the following Items [16] to [22]

[16] An aluminum forged article having a Zn concentration layer containing Zn of 0.01 mass% or more in a surface layer portion of the article,

wherein a base material excluding the Zn concentration layer is formed of an aluminum alloy consisting essentially of Si: 0.6 to 1.5 mass%, Mg: 0.8 to 1.5 mass%, Zn: less than 0.01 mass%, and the balance being Al and inevitable impurities,

wherein a thickness of the Zn concentration layer is 100 to 500 μm,

wherein a surface Zn concentration at a depth of 5 μm from a surface of the Zn concentration layer is 1 to 10 mass%, and a mean Zn concentration of the Zn concentration layer is 0.1 mass% or more but less than 1 mass%.

[17] The aluminum forged article as recited in the aforementioned Item 16, wherein the aluminum alloy further includes one or more elements selected from the group consisting of Cu: 0.1 to 0.5 mass%, Mn: 0.05 to 0.5 mass%, Cr: 0.05 to 0.5 mass%, and Fe: 0.5 mass% or less.

[18] The aluminum forged article as recited in the aforementioned Item 16, wherein the aluminum hot forged article is a structural member for vehicles.

[19] The aluminum forged article as recited in the aforementioned Item 17, wherein the aluminum hot forged article is a structural member for vehicles.

[20] The aluminum forged article as recited in the

aforementioned Item 18, wherein the aluminum hot forged article is a wheel related member.

[21] The aluminum forged article as recited in the aforementioned Item 19, wherein the aluminum hot forged article is a wheel related member.

[22] The aluminum forged article as recited in the aforementioned Item 20 or 21, wherein the wheel related member is a suspension arm.

Effects of the Invention

According to the method for producing the aluminum hot forged article of the present invention [1], since a Zn concentration layer can be formed at the surface of the base material due to the heating at the time of the solution treatment, an aluminum hot forged article excellent in corrosion resistance and corrosion fatigue strength can be produced.

According to the invention as recited in the aforementioned Item [2], the strength of the aluminum hot forged article can be enhanced.

According to the invention as recited in the aforementioned Items [3] and [4], a Zn applied layer high in adhesiveness to the

base material can be formed, and the workability is good.

According to the invention as recited in the aforementioned Items [5] and [6], an aluminum hot forged article especially excellent in adhesiveness between the base material and the applied Zn layer can be produced.

According to the invention as recited in the aforementioned Items [7] and [8], a Zn applied layer high in adhesiveness to the base material can be formed, and the workability is good.

According to the invention as recited in each of the aforementioned Items [9] to [14], an aluminum hot forged article especially excellent in adhesiveness between the base material and the applied Zn layer can be produced.

According to the invention as recited in the aforementioned Item [15], a Zn concentration layer excellent especially in long term anticorrosion effect can be formed.

The aluminum hot forged article according to the invention as recited in the aforementioned Item [16] is excellent in corrosion resistance and corrosion fatigue strength due to the Zn concentration layer formed at the surface layer portion.

The aluminum hot formed article according to the invention

as recited in the aforementioned Item [17] is especially excellent in strength.

According to the invention as recited in the aforementioned Item [18] and [19], a structural member for vehicles excellent in corrosion resistance and corrosion fatigue strength can be provided.

According to the invention as recited in the aforementioned Item [20] and [21], a wheel related member excellent in corrosion resistance and corrosion fatigue strength can be provided.

According to the invention as recited in the aforementioned Item [22], a suspension arm excellent in corrosion resistance and corrosion fatigue strength can be provided.

Brief Description of Drawings

The preferred embodiments of the present invention are shown by way of example, and not limitation, in the accompanying figures, in which:

Fig. 1 is a graph schematically showing the relationship between the depth from the surface and the Zn concentration in the Zn concentration layer.

Best Mode for Carrying Out the Invention

In the following paragraphs, some preferred embodiments of the invention will be described by way of example and not limitation. It should be understood based on this disclosure that various other modifications can be made by those in the art based on these illustrated embodiments.

In a method for producing an aluminum hot forged article according to the present invention, aluminum alloy compositions of a base material are specified, and solution treatment and quenching treatment are executed after the application of Zn to the surface of the base material to thereby secure strength. Further, a Zn concentration layer as a sacrificial corrosion layer is formed at the surface layer portion.

In the aluminum alloy compositions of the base material, Si and Mg are an element to be added to increase the strength of the alloy, respectively. The Si content should fall within the range of from 0.6 to 1.5 mass%. If the Si content is less than 0.6 mass%, it is difficult to secure sufficient strength by the solution treatment and the quenching treatment, and even after the subsequent aging treatment. To the contrary, if it exceeds 1.5 mass%, it becomes difficult to suppress grain boundary precipitation even if the cooling rate is increased sufficiently, resulting in deterioration of corrosion fatigue strength. The preferable Si content is 0.8

to 1.2 mass%. On the other hand, the Mg content should fall within the range of from 0.8 to 1.5 mass%. If the Mg content is less than 0.8 mass%, it is difficult to secure sufficient strength by the solution treatment and the quenching treatment, and even after the subsequent aging treatment. To the contrary, if it exceeds 1.5 mass%, the quenching sensitivity deteriorates, which in turn make it difficult to secure strength increasing effect even if the cooling rate is increased sufficiently. The preferable Mg content is 0.8 to 1 mass%. The balance of the aluminum alloy includes Al and inevitable impurities.

In addition to the aforementioned Si and Mg, the aluminum alloy can contain a slight amount of one or more elements which can contribute to strength enhancement of the aluminum alloy. Examples of such element include Cu, Mn, Cr and Fe. Excessive amount of such elements may cause deterioration of the corrosion resistance and/or deterioration of the quenching sensitivity. Accordingly, it is preferable that the Cu content is 0.1 to 0.5 mass%, the Mn content is 0.05 to 0.5 mass%, the Cr content is 0.05 to 0.5 mass%, and the Fe content is 0.5 mass% or less. In detail, if the Cu content is less than 0.1 mass%, the strength enhancing effect becomes poor. To the contrary, if it exceeds 0.5 mass%, the corrosion resistance may deteriorate. If the Mn content and Cr content are less than 0.05 mass% respectively, the crystal grain miniaturization effect becomes poor. To the contrary, if each of them exceeds 0.5 mass%, quenching sensitivity is enhanced, which in turn may cause

deterioration of strength. Furthermore, if Fe content exceeds 0.5 mass%, the corrosion resistance may deteriorate. Strength enhancing effects can be secured when the Fe content exceeds 0.2 mass%. By adding one or any combination of the aforementioned elements, strength enhancing effects can be attained.

The amount of Zn for forming the Zn concentration layer as a sacrificial corrosion layer should fall within the range of from 1 to 50 g/m^2. If it is less than 1 g/m^2, a sacrificial corrosion layer cannot be formed. To the contrary, the exceeding of 50 g/m^2 causes early corrosion, resulting in insufficient long term anticorrosion effect, and also causes a cost rise. The preferable Zn application amount is 4 to 20 g/m^2.

Although the Zn application method is not specifically limited, a thermal spraying method or a plating method can be preferably used because these methods can attain excellent adhesiveness between the applied Zn and the base material and excellent in workability.

The aforementioned thermal spraying method is not specifically limited, and the thermal spraying can be performed with a well known means such as a thermal spraying gun. In order to prevent oxidization of the sprayed layer, the thermal spraying can be performed in a non-oxidization atmosphere such as N_2 gas atmosphere. The thickness of the sprayed layer is not specifically limited so long as the Zn application amount falls within the aforementioned range.

Concretely, the preferable thickness of the sprayed layer is 0.1 to 20 μm. If it is less than 0.1μm, it becomes difficult to control the thickness since it is too thin. To the contrary, it exceeds 20 μm, initial corrosion occurs, which makes it difficult to attain a long term anticorrosion effect. As the spraying material, pure Zn or Zn-Al alloy can be used. In order to enhance the adhesiveness between the base material and the thermally sprayed layer, it is preferable that the base material is produced by hot forging at 450 °C or above and then thermal spraying is performed when the base material is still in a high temperature status of 350 °C or above.

Although the aforementioned plating method is not specifically limited, a method using zinc sulfate plating bath can be exemplified. As to the conditions of the plating, it is preferable that the plating is performed at room temperature and a current density of 1 to 10 A/dm^2. In order to enhance the adhesiveness of the plated layer, it is also preferable to perform zincate treatment as pretreatment of the plating. The zincate treatment can be preferably performed by immersing the article in normal zincate bath containing sodium hydrate and zinc oxide as major ingredients for several ten seconds at room temperature.

The aforementioned plating and zincate treatment can be preferably performed after the cooling of the hot forged base material, removing of burrs if necessary, and the surface cleaning thereof.

Dirt and/or oxide films can be removed by the surface cleaning, resulting in enhanced adhesiveness of the plated film or zincate film. Such surface cleaning method can be any common method. Examples of such surface cleaning include cleaning using weak alkaline detergent containing surfactant, caustic wash, and a combination thereof. Such surface cleaning can preferably be applied to the case in which Zn is thermally sprayed after cooling the base material, which can enhance the adhesiveness of the Zn sprayed layer.

The purposes of the solution treatment are to enhance the strength improvement by heat treatment and form a Zn concentration layer by Zn diffusion. By applying Zn before executing the solution treatment, strength enhancement of the alloy and formation of the Zn concentration can be simultaneously attained by single heat treatment. The Zn applied to the surface diffuses in the base material in the depth direction thereof by heating to form a Zn concentration layer with a concentration gradient along the depth direction in which the Zn concentration gradually decreases from the surface portion toward the deep portion.

The solution treatment should be executed at 500 to 580 °C for 5 to 180 minutes. If the temperature is less than 500 °C or the time is less than 5 minutes, desired strength cannot be obtained since sufficient sold solubility of M_2Si cannot be attained. To the contrary, if it exceeds 580 °C, partial solution occurs, causing

deterioration of mechanical characteristics. This also causes deep diffusion of Zn, resulting in an excessively thick Zn concentration layer. Such excessively thick Zn concentration layer results in deterioration of long term anticorrosion effects due to the increased corrosion depth and deterioration of strength due to the increased corrosion loss. Furthermore, if the treatment time exceeds 180 minutes, the productivity deteriorates. The solution treatment can be preferably performed at 500 to 550 °C for 30 to 60 minutes.

In the quenching treatment to be executed after the solution treatment, in order to secure predetermined strength, it is necessary to quickly cool the base material at a cooling rate of 10 °C/second or more until it reaches 250 °C. In other words, if the cooling is performed at a cooling rate of 10 °C/second or more until it reaches 250 °C, predetermined strength can be obtained. If the cooling rate is less than 10 °C/second, sufficient strength cannot be obtained since M_2Si solution will separate out. The preferable cooling rate is 50 °C/second or above. Although the cooling method is not specifically limited, water cooling and two-phase cooling of water cooling + compressed air cooling can be exemplified. Furthermore, the cooling conditions after it is cooled to 250 °C are not specifically limited. For example, the cooling can be preferably executed at a cooling rate of 1 °C/second or above.

After the quenching treatment, aging treatment can be arbitrarily performed to further enhance the strength. Such aging

treatment can be preferably performed at 150 to 200 °C for 2 to 48 hours. If it is less than 150 °C, it takes a significantly long time to reach the highest strength, which is not preferable in terms of the production efficiency. On the other hand, if it exceeds 200 °C, the time range for obtaining the highest strength becomes short, which makes it difficult to perform the production management. It is more preferable that the aging treatment is executed at 160 to 190 °C for 5 to 24 hours.

An aluminum hot forged article according to the present invention has a prescribed Zn concentration layer at a surface of a base material, and can be produced by, for example, the aforementioned method of the present invention.

Such Zn concentration layer of the aluminum hot forged article according to the present invention can be formed by diffusing Zn applied to the surface of the base material in the base material by heat treatment. In this case, as shown in Fig. 1, the surface portion of the Zn concentration layer has the highest Zn concentration, and the concentration gradually decreases toward the deep portion of the Zn concentration layer. In this invention, the Zn concentration layer is defined as a layer covering from the surface to a portion where the Zn concentration becomes higher than that of the base material by 0.01 mass%. This depth is defined as a thickness T of the Zn concentration layer. In other words, the Zn concentration at any depth in the Zn concentration layer is 0.01

mass% or above. Since the sacrificial corrosion effect becomes poor if the Zn concentration is 0.01 mass% or less, the Zn concentration layer is defined as a layer containing Zn: 0.01 mass% or more as mentioned above.

The base material includes Zn of 0.01 mass% or less due to diffusion of the applied Zn in addition to Si: 0.6 to 1.5 mass%, Mg: 0.8 to 1.5 mass% before the solution treatment. Since the Zn is caused by the diffusion of the Zn applied to the surface, the Zn concentration is not constant along the depth direction. The Zn concentration becomes maximum, i.e., almost near 0.01 mass%, at the vicinity of the Zn concentration layer. The concentration gradually decreases toward the deep portion.

The thickness T of the Zn concentration layer should falls within the range of from 100 to 500 μm to secure a long-term anticorrosion effect. If the thickness T is less than 100 μm, corrosion exceeding the sacrificial corrosion layer occurs. Thus, a sacrificial anticorrosion effect cannot be expected. On the other hand, if it exceeds 500 μm, the final corrosion depth becomes excessively deep, which may cause insufficient strength as a member. The preferable thickness T of the Zn concentration layer is 100 to 250 μm.

The Zn concentration in the Zn concentration layer is regulated by the surface Zn concentration Cs at the depth of 5 μm from the

surface and the mean Zn concentration Cm of the entire Zn concentration layer. Using these two concentrations, the Zn diffusion state is regulated to secure prescribed corrosion resistance.

The surface Zn concentration Cs should fall within the range of from 1 to 10 mass%. If the surface Zn concentration Cs is less than 1 mass%, corrosion exceeding the sacrificial corrosion layer occurs. Thus, a sacrificial anticorrosion effect cannot be expected. On the other hand, if it exceeds 10 mass%, the potential of the surface of the aluminum hot forged article becomes unnecessary low, which enhances excessive corrosion. Thus, a long-term anticorrosion effect cannot be obtained. The preferable surface Zn concentration Cs is 5 to 10 mass%.

The aforementioned mean Zn concentration Cm is a value obtained by dividing the entire Zn amount of any cross-section in the thickness direction of the article with the thickness T of the Zn concentration layer. If the mean Zn concentration Cm is less than 0.1 mass%, corrosion exceeding the sacrificial corrosion layer (Zn concentration layer) occurs. Thus, a sacrificial anticorrosion effect cannot be expected. On the other hand, if it exceeds 1 mass%, the potential of the surface of the Zn concentration layer becomes unnecessary low, which enhances excessive corrosion. Thus, a long-term anticorrosion effect cannot be obtained. The preferable mean Zn concentration Cm is 0.1 to 0.5 mass%.

Since the aluminum hot forged article according to the present invention is excellent in corrosion resistance and fatigue corrosion strength, it can be preferably used as various structural members/parts. Especially, since such member has light-weightiness of the aluminum alloy, it can be preferably used as structural members for vehicles. Among structural members for vehicles, it can be preferably used as a wheel related member, especially a suspension arm, which is exposed to corrosion environment and required to have both the corrosion resistance and the fatigue corrosion strength.

EXAMPLES

[Production of aluminum hot forged article]

An aluminum alloy having the composition as disclosed in each Example and Comparative Example in Tables 1 to 5 was continuously forged to produce a round bar with a diameter of 15 cm (6 inches). The round bar was formed into a flat plate with a thickness of 20 mm by hot forging at 470 °C. In each Table, the balance of the aluminum alloy is Al and inevitable impurities.

Next, Zn was applied to each surface of the flat plates except for Comparative Examples 12 and 32 by any one of the following methods.

(a) Thermal spraying

Subsequent to the hot thermal forging, pure Zn was thermally

sprayed to a plate which was in a hot temperature statue of 350 °C without being cooled through a thermal spraying gun disposed one side of the plate. The thermal spraying conditions were: thermal spraying voltage: 30 V, thermal spraying currency: 50 A, thermal spraying distance: 200 mm, and Zn application amount: shown in Tables 1-5.

(b) Plating

After the hot forging, the plate was cooled to room temperature. Subsequently, the plate was subjected to caustic washing, and then subjected to zinc plating. The plating was executed at the current density of 3 A/dm^2 in plating bath of room temperature containing zinc metal, boric acid, and ammonium sulfate. The Zn application amount is shown in Tables 1 and 2.

(c) Zincate treatment + Plating

After hot casting, the plate was cooled to room temperature. Subsequently, the plate was subjected to caustic washing. Thereafter, the plate was immersed in zincate treatment bath of room temperature for 60 seconds, and then subjected to zinc plating under the same conditions as the aforementioned (b). The total Zn application amount by the zincate treatment and plating is shown in Tables 1 and 2.

Next, each plate to which Zn was applied was subjected to solution treatment at temperature for a certain time as shown in

Tables 1 to 5. Immediately thereafter, quenching treatment was executed. The quenching was performed so that the plate was cooled to 250 °C by water cooling or two-phase cooling (water + compressed air) at the cooling rate as shown in Tables 1 to 5. After the quenching, the plate was further subjected to aging treatment of 180 °C x 8 hours. Thus, an aluminum hot forged article was obtained.

In the aluminum hot forged article, Zn applied to the surface of the plate by solution treatment was diffused in the base material, and a layer containing Zn in its base material at high density was formed at a surface layer portion of the plate. In the Zn diffusion layer, the surface portion had the highest Zn concentration, and the Zn concentration gradually decreased toward the deep portion.

On the other hand, as to the plates of Comparative Examples 12 and 32, without applying Zn, each plate was subjected only to solution treatment, quenching treatment and aging treatment to obtain an aluminum hot forged article.

[Zn concentration layer in aluminum hot forged article]

As to each of the aluminum hot forged articles of Examples and Comparative Examples 1 to 11, 21 to 31 to which Zn was applied before solution treatment, assuming that the portion in which the Zn concentration was larger than the Zn concentration of the base material by 0.01 mass% was defined as a Zn concentration layer,

the thickness T of this Zn concentration layer was measured. Furthermore, the surface Zn concentration Cs at the depth of 5 μm from the surface of the Zn concentration layer and the mean Zn concentration Cm of the Zn concentration layer were measured. The mean Zn concentration Cm denotes a value obtained by dividing the entire Zn amount at any cross-section in the thickness direction by the thickness T of the Zn concentration layer. The aforementioned each Zn concentration and the depth of the Zn concentration layer were measured by EPMA.

The thickness T of the Zn concentration, surface Zn concentration Cs and mean Zn concentration Cm are also shown in Tables 1 to 5.

[Mechanical characteristics of aluminum hot forged article]

The tensile strength and elongation of each plate were measured by a well known method. These results are also in Tables 1 to 5.

[Corrosion resistance of aluminum hot forged article]

In SWAAT (Synthetic sea Water Acetic Acid salt spray Test), using corrosion test liquid of ASTM D1141, a cycle of spraying the corrosion test liquid for 0.5 hour and then holding for 1.5 hours was repeated for 320 hours.

After the SWAAT, corrosion depth was measured, and it was evaluated as one of the following four levels depending on the corrosion state. These results are also shown in Tables 1 to 5.

◎: Corrosion depth was shallow, and general corrosion occurred

○: general corrosion occurred, but the corrosion depth was shallower than the thickness of the Zn concentration layer

△: Intergranular corrosion or pitting corrosion occurred, and the corrosion depth was less than 250 μm

X: Intergranular corrosion or pitting corrosion occurred, and the corrosion depth was 250 μm or more

[Fatigue corrosion strength of aluminum hot forged article]

After the corrosion test in accordance with SWAAT, a flat plate test piece with a Zn concentratin layer (corroded surface in Comparative Example 14) only remained on one side was cut out, and subjected to a plate bending fatigue test. The test conditions were minimal maximal stress ratio R=-1, stress value: 200 MPa, number of cycles: 10^5 times. The decreasing rate of the fatigue strength with respect to 6061-T6 material (no corrosion) as a comparison material was obtained. Based on the decreasing rate, it was evaluated as the following three levels. The evaluation results are also shown in Tables 1 to 5.

○: Decreasing rate was less than 20%

△: Decreasing rate was more than 20% but less than 40%

X: Decreasing rate was more than 40%

Table 1

Example	Base material composition (mass%)		Solution treatment		Cooling rate	Zn application		Zn concentration layer			Mechanical characteristics		Corrosion resistance		Fatigue corrosion strength
	Si	Mg	Temp °C	Time min	°C/sec	Method	Amount g/m^2	Depth μm	Surface Zn concentration Cs mass%	Mean Zn concentration Cm mass%	Tensile strength MPa	Elongation %	Depth μm	Form	
1	0.60	1.00	502	60	800	Thermal spraying	12	103	8.8	0.8	301	17	78	◎	○
2	0.60	1.00	530	60	800		12	258	4.3	0.8	323	15	112	◎	○
3	0.60	1.00	552	60	800		12	119	7.8	0.8	320	13	98	◎	○
4	0.60	1.00	577	60	800		12	404	1.8	0.9	318	9	239	○	○
5	0.60	1.00	549	60	12		12	432	1.7	0.9	301	15	217	◎	○
6	0.60	1.00	549	60	52		12	250	4.1	0.8	325	13	189	◎	○
7	0.60	1.00	549	5	800		12	308	3.2	0.8	331	12	161	◎	○
8	0.60	1.00	549	30	800		12	330	2.5	0.8	329	12	177	◎	○
9	0.60	1.00	549	180	800		12	453	1.5	0.9	323	13	248	○	○
10	0.60	1.00	549	60	800		3	115	8.7	0.1	320	13	109	◎	○
11	0.60	1.00	549	60	800		21	378	4.1	0.7	319	12	201	◎	○
12	0.60	1.00	549	60	800		48	485	1.0	0.9	323	12	249	◎	○
13	0.98	1.06	549	60	800		12	350	3.8	0.8	341	12	155	◎	○
14	1.50	1.06	549	60	800		12	361	3.6	0.8	352	11	221	○	○
15	0.79	0.80	549	60	800		12	337	3.2	0.8	290	16	148	◎	○
16	0.80	1.50	549	60	800		12	354	3.6	0.8	305	15	174	◎	○
17	0.60	1.00	549	60	800	Plating	12	125	8.9	0.8	326	12	115	◎	○
18	0.60	1.00	549	60	12		12	380	1.9	0.8	310	12	198	◎	○
19	1.50	1.06	549	60	800		12	344	2.8	0.8	337	14	183	◎	○
20	0.60	1.00	549	60	800	Zincate + Plating	12	115	8.9	0.8	325	12	105	◎	○
21	0.60	1.00	549	60	12		12	391	1.7	0.7	309	13	210	◎	○
22	1.50	1.06	549	60	800		12	340	2.9	0.7	348	12	198	◎	○

Table 2

Example	Base material composition (mass%)							Solution treatment		Cooling rate	Zn application		Zn concentration layer			Mechanical characteristics		Corrosion resistance		Fatigue corrosion strength
	Si	Mg	Fe	Cu	Mn	Cr		Temp °C	Time min	°C/sec	Method	Amount g/m²	Depth μm	Surface Zn concentration Cs mass%	Mean Zn concentration Cm mass%	Tensile strength MPa	Elongation %	Depth μm	Form	
31	0.60	1.00	0.20	0.25	0.15	0.15		502	60	800	Thermal spraying	12	95	8.9	0.8	320	15	80	◎	○
32	0.60	1.00	0.20	0.25	0.15	0.15		530	60	800		12	253	4.5	0.8	335	12	120	◎	○
33	0.60	1.00	0.20	0.25	0.15	0.15		552	60	800		12	125	7.8	0.8	340	12	103	◎	○
34	0.60	1.00	0.20	0.25	0.15	0.15		577	60	800		12	387	1.9	0.9	327	9	241	○	○
35	0.60	1.00	0.20	0.25	0.15	0.15		549	60	12		12	412	1.0	0.9	298	9	230	○	○
36	0.60	1.00	0.20	0.25	0.15	0.15		549	60	52		12	246	4.1	0.8	311	12	193	◎	○
37	0.60	1.00	0.20	0.25	0.15	0.15		549	5	800		12	287	3.5	0.8	330	12	165	◎	○
38	0.60	1.00	0.20	0.25	0.15	0.15		549	30	800		12	335	2.4	0.8	335	12	189	◎	○
39	0.60	1.00	0.20	0.25	0.15	0.15		549	180	800		12	429	1.0	1.0	333	11	243	○	○
40	0.60	1.00	0.20	0.25	0.15	0.15		549	60	800		3	98	9.1	0.1	335	12	85	◎	○
41	0.60	1.00	0.20	0.25	0.15	0.15		549	60	800		21	327	3.5	0.8	331	12	211	◎	○
42	0.60	1.00	0.20	0.25	0.15	0.15		549	60	800		48	493	1.0	1.0	336	12	249	○	○
43	0.98	1.06	0.20	0.26	0.15	0.14		549	60	800		12	333	2.6	0.8	345	11	165	◎	○
44	1.50	1.06	0.20	0.25	0.16	0.15		549	60	800		12	372	3.5	0.8	365	10	236	○	○
45	0.79	0.80	0.20	0.24	0.14	0.15		549	60	800		12	320	3.3	0.8	309	13	151	◎	○
46	0.80	1.50	0.21	0.25	0.15	0.14		549	60	800		12	361	3.6	0.8	315	14	185	◎	○
47	0.60	1.00	0.20	0.25	0.15	0.15		549	60	800	Plating	12	113	8.9	0.8	331	12	101	◎	○
48	0.60	1.00	0.20	0.25	0.15	0.15		549	60	12		12	375	1.9	0.8	300	14	209	◎	○
49	1.50	1.06	0.20	0.25	0.15	0.15		549	60	800		12	332	3.2	0.8	347	11	195	◎	○
50	0.60	1.00	0.20	0.25	0.15	0.15		549	60	800		12	123	7.8	0.8	331	12	106	◎	○
51	0.60	1.00	0.20	0.25	0.15	0.15		549	60	12	Zincate + Plating	12	392	1.7	0.7	302	14	215	◎	○
52	1.50	1.06	0.20	0.25	0.15	0.15		549	60	800		12	342	2.8	0.8	345	11	185	◎	○

Table 3

Example	Base material composition (mass%)							Solution treatment		Cooling rate	Zn application		Zn concentration layer			Mechanical characteristics		Corrosion resistance		Fatigue corrosion strength
	Si	Mg	Fe	Cu	Mn	Cr		Temp ° C	Time min	° C/sec	Method	Amount g/m²	Depth μm	Surface Zn concentration Cs mass%	Mean Zn concentration Cm mass%	Tensile strength MPa	Elongation %	Depth μm	Form	
53	0.60	1.00	0.20	-	-	-		530	60	800	Thermal spraying	12	345	2.2	0.8	325	14	165	◎	○
54	0.60	1.00	0.20	-	-	-		549	30	800		12	370	3.4	0.8	327	14	196	◎	○
55	0.60	1.00	-	0.25	-	-		530	60	800		12	308	3.1	0.8	322	14	188	◎	○
56	0.60	1.00	-	0.25	-	-		549	30	800		12	347	2.2	0.9	336	12	205	◎	○
57	0.60	1.00	-		0.15	-		530	60	800		12	339	2.6	0.9	325	14	171	◎	○
58	0.60	1.00	-		0.15	-		549	30	800		12	363	3.5	0.8	329	13	205	◎	○
59	0.60	1.00	-		-	0.15		530	60	800		12	279	3.6	0.8	321	14	133	◎	○
60	0.60	1.00	-		-	0.15		549	30	800		12	340	2.5	0.8	330	13	190	◎	○
61	0.60	1.00	0.20	0.25	-	-		530	60	800		12	267	4.4	0.8	335	12	118	◎	○
62	0.60	1.00	-		0.15	0.15		549	30	800		12	295	3.3	0.8	337	12	175	◎	○
63	0.60	1.00	0.20	0.25	0.15			530	60	800		12	318	2.6	0.8	336	12	172	◎	○
64	0.60	1.00	0.20	0.25	-	0.15		549	30	800		12	330	2.4	0.8	339	12	186	◎	○

Table 4

		Base material composition (mass%)		Solution treatment		Cooling rate	Zn application		Zn concentration layer			Mechanical characteristics		Corrosion resistance		Fatigue corrosion strength
		Si	Mg	Temp ° C	Time min	° C/sec	Method	Amount g/m²	Depth μm	Surface Zn concentration Cs mass%	Mean Zn concentration Cm mass%	Tensile strength MPa	Elongation %	Depth μm	Form	
Comparative Example	1	0.62	1.02	485	60	800	Thermal spraying	12	85	8.9	0.8	281	21	78	◎	△
	2	0.62	1.02	585	60	800		12	509	0.09	0.9	319	8	415	X	X
	3	0.62	1.02	549	60	8		12	395	2.8	0.9	278	23	258	△	X
	4	0.62	1.02	549	1	800		12	121	10.3	0.8	298	16	101	◎	△
	5	0.62	1.02	549	200	800		12	519	0.08	0.7	310	8	326	X	X
	6	0.62	1.02	549	60	800		1	140	8.7	0.08	320	12	135	△	X
	7	0.62	1.02	549	60	800		52	560	0.07	1.2	323	12	520	X	X
	8	0.55	1.01	549	60	800		52	351	3.2	0.8	292	15	159	○	△
	9	1.55	1.02	549	60	800		52	375	3.1	0.9	355	10	251	X	X
	10	0.82	0.77	549	60	800		52	325	3.3	0.8	305	13	311	X	X
	11	0.82	1.52	549	60	800		52	361	3.4	0.8	310	12	298	X	X
	12	0.62	1.02	549	60	800	No Zn application					311	12	198	△	X

Table 5

		Base material composition (mass%)						Solution treatment		Cooling rate	Zn application		Zn concentration layer			Mechanical characteristics		Corrosion resistance		Fatigue corrosion strength
		Si	Mg	Fe	Cu	Mn	Cr	Temp °C	Time min	°C/sec	Method	Amount g/m²	Depth μm	Surface Zn concentration Cs mass%	Mean Zn concentration Cm mass%	Tensile strength MPa	Elongation %	Depth μm	Form	
Comparative Example	21	0.62	1.02	0.20	0.25	0.14	0.15	485	60	800	Thermal spraying	12	72	9.2	0.8	283	21	67	◎	△
	22	0.62	1.02	0.20	0.25	0.14	0.15	585	60	800		12	501	0.09	0.9	330	12	409	X	X
	23	0.62	1.02	0.20	0.25	0.14	0.15	549	60	8		12	372	3.1	0.8	271	24	265	△	X
	24	0.62	1.02	0.20	0.25	0.14	0.15	549	1	800		12	114	10.2	0.9	301	15	98	◎	△
	25	0.62	1.02	0.20	0.25	0.14	0.15	549	200	800		12	525	0.09	0.8	329	12	345	X	X
	26	0.62	1.02	0.20	0.25	0.14	0.15	549	60	800		1	129	7.7	0.09	335	12	110	△	X
	27	0.62	1.02	0.20	0.25	0.14	0.15	549	60	800		52	543	0.08	1.2	337	11	493	X	X
	28	0.55	1.01	0.20	0.24	0.15	0.15	549	60	800		52	345	3.3	0.8	307	14	165	○	△
	29	1.55	1.02	0.21	0.25	0.16	0.15	549	60	800		52	393	2.9	0.9	359	10	260	X	X
	30	0.82	0.77	0.20	0.25	0.15	0.15	549	60	800		52	312	3.3	0.8	310	12	289	X	X
	31	0.82	1.52	0.19	0.26	0.15	0.14	549	60	800		52	355	3.4	0.8	315	12	285	X	X
	32	0.62	1.02	0.20	0.25	0.14	0.15	549	60	800	No Zn application					335	12	205	△	X

As will be understood from the results shown in Tables 1 to 5, it was confirmed that the aluminum hot forged articles produced by the method of Examples were excellent in corrosion resistance and fatigue corrosion strength.

Industrial Applicability

According to the present invention, an aluminum hot forged article excellent in corrosion resistance and fatigue corrosion strength can be produced and utilized to manufacture structural members for vehicles such as suspension arms.

While the present invention may be embodied in many different forms, a number of illustrative embodiments are described herein with the understanding that the present disclosure is to be considered as providing examples of the principles of the invention and such examples are not intended to limit the invention to preferred embodiments described herein and/or illustrated herein.

While illustrative embodiments of the invention have been described herein, the present invention is not limited to the various preferred embodiments described herein, but includes any and all embodiments having equivalent elements, modifications, omissions, combinations (e.g., of aspects across various embodiments), adaptations and/or alterations as would be appreciated by those in the art based on the present disclosure. The limitations in the

claims are to be interpreted broadly based on the language employed in the claims and not limited to examples described in the present specification or during the prosecution of the application, which examples are to be construed as non-exclusive. For example, in the present disclosure, the term "preferably" is non-exclusive and means "preferably, but not limited to." In this disclosure and during the prosecution of this application, means-plus-function or step-plus-function limitations will only be employed where for a specific claim limitation all of the following conditions are present in that limitation: a) "means for" or "step for" is expressly recited; b) a corresponding function is expressly recited; and c) structure, material or acts that support that structure are not recited. In this disclosure and during the prosecution of this application, the terminology "present invention" or "invention" may be used as a reference to one or more aspect within the present disclosure. The language present invention or invention should not be improperly interpreted as an identification of criticality, should not be improperly interpreted as applying across all aspects or embodiments (i.e., it should be understood that the present invention has a number of aspects and embodiments), and should not be improperly interpreted as limiting the scope of the application or claims. In this disclosure and during the prosecution of this application, the terminology "embodiment" can be used to describe any aspect, feature, process or step, any combination thereof, and/or any portion thereof, etc. In some examples, various embodiments may include overlapping features. In this disclosure and during the prosecution

of this case, the following abbreviated terminology may be employed: "e.g." which means "for example;" and "NB" which means "note well."

CLAIMS

1. A method for producing an aluminum heat forged article, comprising the steps of:

subjecting a base material of an aluminum alloy consisting essentially of Si: 0.6 to 1.5 mass%, Mg: 0.8 to 1.5 mass%, and the balance being Al and inevitable impurities to hot forging;

applying Zn to a surface of the base material at a rate of 2 to 50 g/m^2;

subjecting the base material to solution treatment at 500 to 580 °C for 5 to 180 minutes; and

subjecting the base material to quenching treatment for cooling the base material at a cooling rate of 10 °C/second or more until it reaches 250 °C.

2. The method for producing an aluminum heat forged article as recited in claim 1, wherein the aluminum alloy further includes one or more elements selected from the group consisting of Cu: 0.1 to 0.5 mass%, Mn: 0.05 to 0.5 mass%, Cr: 0.05 to 0.5 mass%, and Fe: 0.5 mass% or less.

3. The method for producing an aluminum heat forged article as recited in claim 1, wherein the application of Zn is executed by thermal spraying.

4. The method for producing an aluminum heat forged article

as recited in claim 2, wherein the application of Zn is executed by thermal spraying.

5. The method for producing an aluminum heat forged article as recited in claim 3, wherein the thermal spraying of Zn is executed when the hot forged base material is in a hot-temperature state of 350 °C or above without cooling the base material.

6. The method for producing an aluminum heat forged article as recited in claim 4, wherein the thermal spraying of Zn is executed when the hot forged base material is in a hot-temperature state of 350 °C or above without cooling the base material.

7. The method for producing an aluminum heat forged article as recited in claim 1, wherein the application of Zn is executed by plating.

8. The method for producing an aluminum heat forged article as recited in claim 2, wherein the application of Zn is executed by plating.

9. The method for producing an aluminum heat forged article as recited in claim 7, wherein zincate treatment is executed as pretreatment of the plating.

10. The method for producing an aluminum heat forged article

as recited in claim 8, wherein zincate treatment is executed as pretreatment of the plating.

11. The method for producing an aluminum heat forged article as recited in claim 1, wherein the application of Zn is executed after cooling the hot forged base material and cleaning a surface of the base material.

12. The method for producing an aluminum heat forged article as recited in claim 2, wherein the application of Zn is executed after cooling the hot forged base material and cleaning a surface of the base material.

13. The method for producing an aluminum heat forged article as recited in claim 7, wherein the application of Zn is executed after cooling the hot forged base material and cleaning a surface of the base material.

14. The method for producing an aluminum heat forged article as recited in claim 8, wherein the application of Zn is executed after cooling the hot forged base material and cleaning a surface of the base material.

15. The method for producing an aluminum heat forged article as recited in any one of claims 1 to 14, wherein the application amount of Zn is 4 to 20 g/m^2.

16. An aluminum forged article having a Zn concentration layer containing Zn of 0.01 mass% or more in a surface layer portion of the article,

wherein a base material excluding the Zn concentration layer is formed of an aluminum alloy consisting essentially of Si: 0.6 to 1.5 mass%, Mg: 0.8 to 1.5 mass%, Zn: less than 0.01 mass%, and the balance being Al and inevitable impurities,

wherein a thickness of the Zn concentration layer is 100 to 500 μm,

wherein a surface Zn concentration at a depth of 5 μm from a surface of the Zn concentration layer is 1 to 10 mass%, and a mean Zn concentration of the Zn concentration layer is 0.1 mass% or more but less than 1 mass%.

17. The aluminum forged article as recited in claim 16, wherein the aluminum alloy further includes one or more elements selected from the group consisting of Cu: 0.1 to 0.5 mass%, Mn: 0.05 to 0.5 mass%, Cr: 0.05 to 0.5 mass%, and Fe: 0.5 mass% or less.

18. The aluminum forged article as recited in claim 16, wherein the aluminum hot forged article is a structural member for vehicles.

19. The aluminum forged article as recited in claim 17, wherein the aluminum hot forged article is a structural member for vehicles.

20. The aluminum forged article as recited in claim 18, wherein the aluminum hot forged article is a wheel related member.

21. The aluminum forged article as recited in claim 19, wherein the aluminum hot forged article is a wheel related member.

22. The aluminum forged article as recited in claim 20 or 21, wherein the wheel related member is a suspension arm.

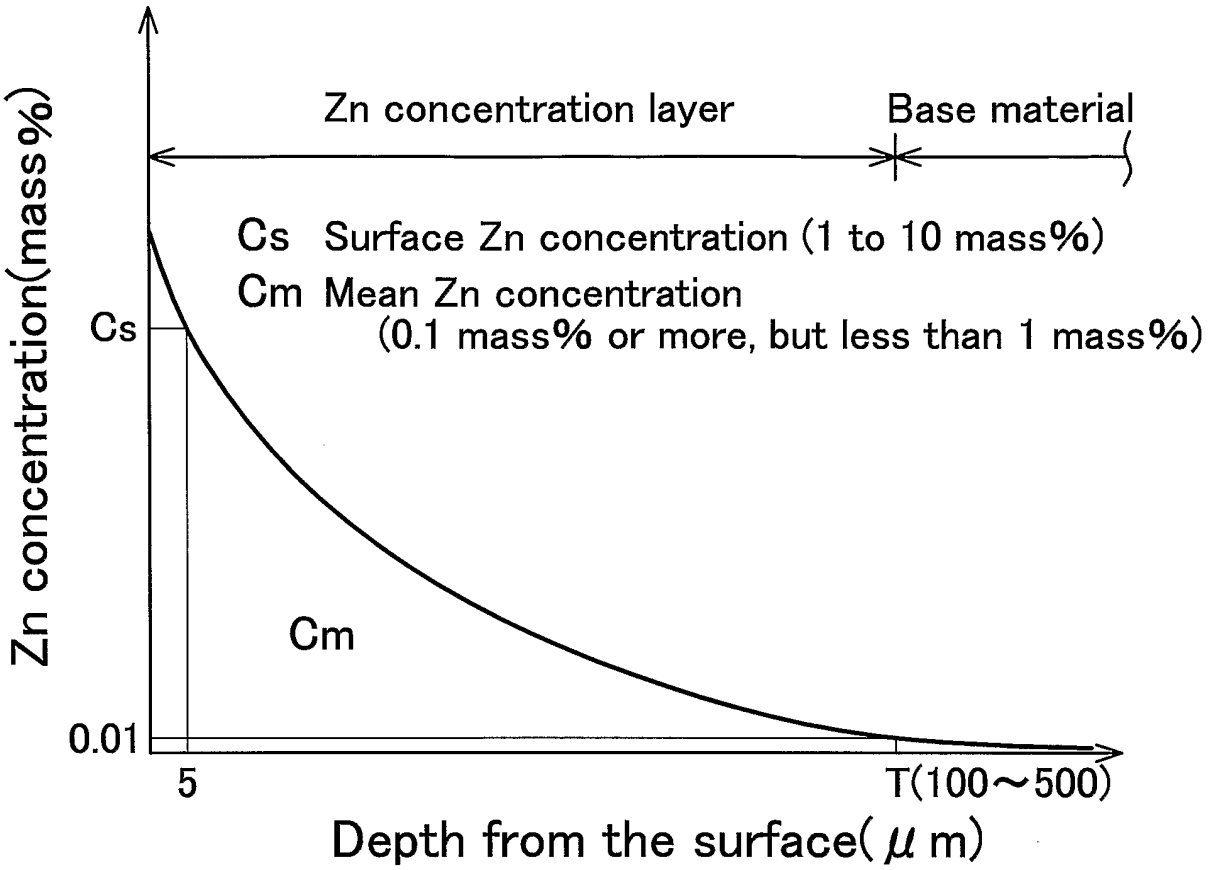
Zn concentration layer
Base material
Cs Surface Zn concentration (1 to 10 mass%)
Cm Mean Zn concentration
(0.1 mass% or more, but less than 1 mass%)
Zn concentration(mass%)
Cs
Cm
0.01
5
T(100～500)
Depth from the surface(μm)

FIG.1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2005/022142

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. *C22F1/05* (2006.01), *C25D5/50* (2006.01), *C23C4/18* (2006.01), *C22C21/06* (2006.01)

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)

Int.Cl. B21J 5/00, C22C 21/02, C22C 21/06, C22F 1/05, C23C 4/18, C23C 10/28, C25D 5/50

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2006
Registered utility model specifications of Japan 1996-2006
Published registered utility model applications of Japan 1994-2006

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.
Y	JP 2002-060881 A (NIPPON LIGHT METAL CO.) 2002.02.28, CLAIMS, 【0001】, TABLE 1 ALLOY NO.1 (FAMILY: NONE)	1-22
Y	JP 7-157861 A (KOBE STEEL CO.) 1995.06.20, CLAIMS, 【0015】 (FAMILY: NONE)	1-6,15
Y	JP 5-331627 A (NIPPON STEEL CO.) 1993.12.14, CLAIMS, 【0002】, 【0012】, 【0013】, TABLL1 EXAMPLE4 (FAMILY: NONE)	7-14
Y	JP 64-47896 A (SHOWA ALUMINIUM CO.) 1989.02.22, CLAIMS (FAMILY: NONE)	9,10

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

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
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"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
"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
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
01.02.2006	14.02.2006

Name and mailing address of the ISA/JP	Authorized officer	
Japan Patent Office	Takeshi Ogawa	4K 9270
3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No. +81-3-3581-1101 Ext. 3435	

Form PCT/ISA/210 (second sheet) (April 2005)

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 63-186857 A (SHOWA ALUMINIUM CO.) 1988.08.02, CLAIMS, PAGE 2 LOWER RIGHT COLUMN LINE 6 TO 13 (FAMILY: NONE)	18-22
Y	JP 2002-275567 A (ASAHI TEC CO.) 2002.09.25, CLAIMS, 【0004】, 【0005】 (FAMILY: NONE)	1,3,5,7,9,11,13,16,18,20