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(54) Aluminum alloys for casting, aluminum alloy castings and process for producing aluminum alloy castings

Aluminiumlegierungen zum Gießen, Aluminiumlegierungsgussstücke und Verfahren zur Herstellung von Aluminiumlegierungsgussstücken

Alliages d'aluminium pour moulage, moulages d'alliage d'aluminium et processus de production de moulages d'alliage d'aluminium

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Description

Technical Field

[0001] The present invention relates to an aluminum alloy casting that is excellent not only in strength but also in practical fatigue resistances such as fatigue strength and thermal fatigue resistance, a process for producing an aluminum alloy casting, and an aluminum alloy suitable for production of an aluminum alloy casting.

Background Art

[0002] Aluminum alloys are now replacing iron and other metals in various mechanical parts, in order to meet the needs for weight reduction and the like. Even mechanical parts made of aluminum alloys are designed to have thinner thicknesses for further weight reduction. Accordingly, aluminum alloys are required to provide higher reliabilities in strength and fatigue resistance than before. Especially, when aluminum alloys are used for automotive engine parts that are exposed to high temperatures, the alloys are required to have high heat resistances such as high temperature strength and creep resistance as well as high thermal fatigue strength to cope with hot and cold cycles, not to speak of the strength at ordinary temperatures.

[0003] A cylinder head of a reciprocating engine is among such engine parts. A casting process is generally employed to produce such cylinder head because it is complicated in shape and large in size. AC2A, AC2B, AC4B, AC4C(JIS) and the like can be named as such aluminum alloys for casting. Besides these alloys, a large number of aluminum alloys have been developed, as exemplified in the following patent publications.

[Patent Publication 1]
Japanese Unexamined Patent Publication (KOKAI) No.9-263867
[Patent Publication 2]
Japanese Unexamined Patent Publication (KOKAI) No.10-317085
[Patent Publication 3]
Japanese Unexamined Patent Publication (KOKAI) No.2001-303163
[Patent Publication 4]
Japanese Unexamined Patent Publication (KOKAI) No.2004-217953
[Patent Publication 5]
Japanese Unexamined Patent Publication (KOKAI) No.2004-225134
[Patent Publication 6]
Japanese Unexamined Patent Publication (KOKAI) No.2005-139552

Disclosure of Invention

Assignments to be Solved by Invention

[0004] Aluminum alloys for casting, disclosed in the above-mentioned patent publications 1 and 2, are alloys that are precipitation strengthened by included Cu and Mg. However, as seen from the embodiments of the patent publications, either of the aluminum alloys has Cu content exceeding 3%. In the alloys with the disclosed compositions, Cu is converted into thermally unstable precipitates, which become coarse during use of the castings. As a result, stresses and strains tend to easily concentrate on these local precipitates. This lowers the thermal fatigue resistance of aluminum alloy castings as well as their ductility and tenacity.

[0005] The above-mentioned patent publications 3-5 disclose aluminum alloys for casting in which Cu content is suppressed below 1%, in order to prevent excessive hardening due to precipitation strengthening and improve the ductility as well as the strength and fatigue resistance of the castings. However, in the aluminum alloys disclosed in these patent publications, the thermal fatigue life was not significantly improved because local deformation in the castings was not suppressed when the castings were subjected to repetitive expansion and contraction due to prolonged heat and cold cycles.

[0006] Patent publication (6) discloses an aluminum alloy which substantially does not include Cu (less than 0.2% by mass) and includes optimum amounts of Ni, Fe and Ti. In addition, patent publication 6 discloses that when the castings made of the aluminum alloy is subjected to solution treatment and aging treatment, the casting can provide high static and fatigue strengths as well as high thermal strength. The solution treatment in patent publication 6 adopts a method to cool a casting with cold or warm water after heating.

[0007] However, according to the study of the present inventors, when such large and complicated casting made of aluminum alloy as a cylinder head was cooled with water in solution treatment, the rapid cooling rate caused non-uniform cooling and tended to generate residual strains within the casting. Since the residual strains cause lowering of the practical fatigue strength (explained later), even the cast product made of the aluminum alloy disclosed in patent publication 6 is to be further improved to provide sufficient performances in both fatigue strength and thermal fatigue strength under practical environments.

Especially, high thermal fatigue strength for a considerable long period as well as high static and fatigue strengths are required for cylinder heads, engine blocks and the like of diesel engines that are used under severe conditions of high pressures, high temperatures and strong vibrations. Accordingly, an aluminum alloy for casting has been long searched for to produce an aluminum alloy casting with higher static and fatigue strengths and higher thermal fatigue strength that can meet the performance requirements of such engine parts.

[0008] In the tests conducted by the present inventors, when the casting made of the aluminum alloy disclosed in patent publication 6 was subjected to solution treatment by air cooling after heating, Mg_2Si proceeded to precipitate within the casting, resulting in failure to obtain a casting with sufficient static and fatigue strengths. The Al-Si-Cu-Mg alloy of patent publications (5) and (6) provided fair static and fatigue strengths when the alloy was solution treated by air cooling but was found to provide insufficient thermal fatigue resistance when the alloy was subjected to hot and cold cycles because repetitive expansion and contraction of residual strains caused non-uniform deformation, leading to insufficient thermal fatigue strength.

In addition, even when this alloy is made to include Ni, Ti, Zr, and the like and was subjected to aging treatment, sufficient hardness was not obtained and the static and fatigue strengths tended to rather decrease.

[0009] JP 2004-076110 A discloses an aluminum cast alloy comprising, by weight, 0.3 to 2 % Mg, 0.15 to 0.4 % Ti, 0 to 0.3 % Zr, 0 to 0.3 % V, 10 to 17 % Si, 2.5 to 3.5 % Cu, 0.2 to 1.0 % Fe, 0.2 to 1.0 % Mn, 1.8 to 3 % Ni and 0.001 to 0.015 % P, the balance being Al with inevitable impurities.

[0010] US 2005/0224145 A1 discloses a cast part with high creep resistance, made of an aluminum alloy with a composition comprising, in % by weight, Si: 5-11, Fe: <0.6, Mg: 0.15-0.6, Cu: 0.3-1.5, Ti: 0.05-0.25, Zr: 0.05-0.25, Mn: <0.4, Zn: <0.3, Ni: <0.4, other elements <0.10 each and 0.30 total, the remainder being Al.

[0011] JP 2006-316725 A discloses an aluminum alloy including ≥ 8 mass% and ≤ 18 mass% Si, ≥ 0.2 mass% and ≤2.0 mass% Mg and at least one of ≥0.5 mass% and ≤7 mass% Cu, ≥0.2 mass% and ≤1.5 mass% Fe, ≥0.2 mass% and ≤1 mass% Mn and ≥1 mass% and ≤7 mass% Ni.

[0012] US 2004/0057865 A1 discloses an aluminum cast alloy containing ≤0.2 mass% Mg, 0.05 to 0.3 mass% Ti, 10 to 21 mass% Si, 2 to 3.5 mass% Cu, 0.1 to 0.7 mass% Fe, 1 to 3 mass% Ni, 0.001 to 0.02 mass% P, the remainder being Al and impurities.

[0013] JP 7-216487 A discloses an aluminum alloy consisting of, by weight, 10 to 14 % Si, 3 to 6 % Cu, 0.1 to 1 % Mg, 0.6 to 1.8 % Fe, 0.8 to 3 % Ni, 0.1 to 0.7 % Mn, 0.1 to 0.7 % Ti, 0.05 to 0.3 % Zr, 0.05 to 0.5 % V, the balance being Al and inevitable impurities.

[0014] JP 2000-204428 discloses an aluminum alloy containing 11 to 16 % Si, 0.5 to 2.0 % Mg, 3 to 7 % Cu, 3 to 7 % Ni, 0.2 to 1.5 % Fe, 0.2 to 1.0 % Mn, 0.003 to 0.015 % P and ≤ 0.002 % Ca, the remainder being Al and impurities.

[0015] US 2006/0266443 A1 discloses an aluminum alloy including 8 to 18 wt% of Si, 0.5 to 3 wt% of Cu and 1 to 5 wt% of Ni, further including Al and inavoidable impurities.

[0016] WO 00/71772 A1 discloses an aluminum alloy having the composition, by weight percent, of Si: 6.0 to 14.0, Cu: 3.0 to 8.0, Fe: 0.01 to 0.8, Mg: 0.5 to 1.5, Ni: 0.05 to 1.2, Mn: 0.01 to 1.0, Ti: 0.05 to 1.2, Zr: 0.05 to 1.2, V: 0.05 to 1.2, Sr: 0.001 to 0.10, the balance being Al and impurities. WO 2005/059195 A1 discloses an aluminum alloy containing Si: 10.5 to 13.5 mass%, Fe: 0.15 to 0.65 mass%, Cu: 2.5 to 5.5 mass% and Mg: 0.3 to 1.5 mass%, the balance being Al and impurities:

[0017] The present invention has been done in view of such circumstances. Namely, it is an object to provide an aluminum alloy for casting to produce a casting that is excellent not only in static and fatigue strengths but also in thermal fatigue strength. Especially, it is an object to provide an aluminum alloy which can produce a casting that can exhibit stable thermal fatigue strength through solution treatment and aging treatment, even when the casting is used as a complicated and large-size cylinder head of a diesel engine and the like.

In addition, it is another object to provide such aluminum alloy casting and a process to produce such casting.

Means to Solve Assignments

[0018] The present inventors have been studying earnestly and have repeated trials and errors in order to solve these assignments. As a result, the inventors reviewed the content of Cu, one of the essential elements, and made optimum selection of other elements and their contents. By doing this, the inventors have found a new aluminum alloy for casting which can produce an excellent casting with sufficient static and fatigue strengths as well as sufficient thermal fatigue strength and well balanced in every aspect, even without water cooling in solution treatment. Thus, the inventors have arrived at completing the present invention.

Aluminum Alloy for Casting

[0019] The aluminum alloy for casting, in accordance with claim 1 of the present invention, consists of the following essential and optional elements and inevitable impurities with the contents as shown below, when the entirety is taken as 100% by mass (simply expressed by %, hereinafter) and can produce an aluminum alloy casting that is excellent in practical fatigue strength.

Silicon (Si) :	6-9 %
Copper (Cu) :	1.0-2.5 %
Magnesium (Mg) :	0.2-0.6%
Nickel (Ni) :	0.2-3%
Iron (Fe) :	0.1-0.7%
Titanium (Ti) :	0.1-0.3%
Zirconium (Zr) :	0.03-0.5%
Manganese (Mn) :	0.1-0.7%
Vanadium (V) :	0.01-0.5%
and	
one or more of	
Strontium (Sr) :	0.003-0.05%
Antimony (Sb) :	0.02-0.2%
Sodium (Na) :	0.001-0.03%
Aluminum (Al) :	balance, wherein the total amount of Ti and Zr is less than 0.5%

Effects of Interaction

[0020] The aluminum alloy for casting, in accordance with the present invention, can produce an aluminum alloy casting which simultaneously provides excellent strength, fatigue resistance and thermal fatigue resistance at high levels that have been difficult to be achieved with conventional aluminum alloys.

The aluminum alloy casting with such excellent properties can be obtained only when the above-mentioned elements with the above-mentioned content ranges interact with each other synergetically. Thus, the present invention can be said to have an epoch-making value in that such optimum composition has been newly discovered.

[0021] Nevertheless, the detailed reason and mechanism why the casting made of the aluminum alloy for casting of the present invention can provide such excellent properties are not necessarily certain at present. Accordingly, explanation will be made hereinafter of the development processes to discover the optimum composition of the aluminum alloy of the present invention as well as the reason and mechanism for such excellent properties as far as is possible at present. And, hereinafter, "aluminum alloy" will be appropriately used to denote either an aluminum alloy as a raw material of a casting or an aluminum alloy casting, a cast product made of an aluminum alloy.

[0022] (1) A general method to increase the static and fatigue strengths of an aluminum alloy is to make solution treatment of an as-cast casting, followed by heat treatment for aging treatment. This results in precipitation of included Cu, Mg and other precipitation strengthening elements, leading to strengthening of the casting. Here, solution treatment is generally a process to heat a casting to a temperature higher than the solubility lines at which Cu, Mg, and other precipitation strengthening elements, are dissolved in a solid solution and then rapidly cool the casting with water and the like to prepare a supersaturated solution of the strengthening elements.

[0023] However, as described above, when a casting to be solution treated is cooled with water (so-called quenching process) after heating, as described above, the parts in direct contact with water are rapidly cooled, while the interior and other parts difficult to be reached by water are slowly cooled. Thus, the casting is not uniformly cooled; cooling conditions are different from place to place. As a result, some parts are cooled and contract more rapidly, while other parts are otherwise. This is likely to generate a large number of residual strains. As a matter of course, this tendency is more significant with larger and more complicated castings.

[0024] The inventors of the present invention thought that these residual strains is one of the causes to lower the practical fatigue strength of a casting. And, the inventors thought that the metallographic structure is preferable, which is obtainable when an aluminum alloy is precipitation strengthened by the action of precipitation strengthening elements, while residual strains are prevented to occur or residual strains and stresses are almost uniformly distributed within the entire range of castings. On the basis of this concept, the inventors have achieved to develop the aluminum alloy for casting disclosed in the present invention.

[0025] (2) Initially, the inventors tried to suppress the occurrence of residual strains or make them uniformly distributed, by lowering the cooling rate in solution treatment below the rate of the conventional water cooling. However, since the cooling process in solution treatment is a sort of quenching process, simple reduction of the cooling rate is thought to cause precipitation of coarse compounds of precipitation strengthening elements and result in failure to provide sufficient effect of precipitation strengthening.

[0026] The aluminum alloy of the present invention includes suitable amounts of Ti, Zr transition elements. These transition elements are dissolved in the base phase as a solid solution after casting and begin to precipitate in fine particles in the subsequent heating process for solution treatment. This is due to the fact that the precipitation temperature zone of Ti, Zr transition elements is higher than that of Cu, Mg and the like. In the cooling step in solution treatment, when the cooling rate is slow, precipitates mainly consisting of Ti, Zr, etc., formed in the previous heating step are considered to provide nuclei for initiating stable or metastable precipitation of Cu and Mg which are completely dissolved in a solid solution in the previous heating step.

[0027] Namely, since the aluminum alloy of the present invention includes suitable amounts of Ti and Zr in addition to suitable amounts of Cu and Mg, precipitation strengthening elements such as Cu and Mg are considered to precipitate on the nuclei which are previously formed precipitates of Ti and Zr, in the cooling step with a slower cooling rate than the conventional cooling step. And, aging treatment subsequent to solution heat treatment initiates proper precipitation of the remaining Cu and Mg, frozen in the previous solution treatment. This aging process assures sufficient amounts (volumes) of precipitates of Cu and Mg.

[0028] Here, it may be considered to increase the content of Cu to the conventional level, in order to simply increase the amounts of precipitates of Cu and Mg. However, this approach may increase the strength of an aluminum alloy but it may lower the toughness and ductility and may not increase the fatigue strength that is influenced by stress concentration and average stress level. In addition, decreased toughness and ductility may induce lowering of the thermal fatigue strength. The present invention prevents such unfavorable circumstances by suitable selection of the contents of Cu and Mg.

Even when air cooling is used in the cooling step in solution treatment, the present invention assures sufficient effect of precipitation strengthening by suitable amounts of Cu and Mg and prevents or minimizes the decrease of the thermal fatigue strength due to residual strains while assuring sufficient static and fatigue strengths. Thus, the present invention is considered to have succeeded in achieving sufficient thermal fatigue strength as well as static and fatigue strengths of an aluminum alloy at high levels.

[0029] In this connection, precipitates of Cu and Mg, already formed in the cooling step in solution treatment, are comprised of metastable phases as well as stable phases and the precipitate particles of these elements can grow in aging treatment. Therefore, when an aluminum alloy casting is subjected to solution treatment and the subsequent aging treatment, a large particle phase (first precipitation phase) and a small particle phase (second precipitation phase) can appear in the precipitation phase of Cu and Mg. Accordingly, the aluminum alloy casting of the present invention, after solution treatment and aging treatment, as described above, has a multi-phase precipitates which include at least first and second precipitation phases with different particle sizes. The particle sizes of the first and second precipitation phases are 30-300nm and 1-20nm, respectively.

[0030] (3) The above description explained the effects of precipitation strengthening elements such as Cu and Mg (especially Cu) and the functions of transition elements such as Ti and Zr. However, these effects are not the only reason why the aluminum alloy of the present invention is excellent in various properties as described above. Namely, the favorable effects are also significantly favored by the metallographic structure in which a skeleton phase precipitated so as to surround a substrate phase mainly comprising α-Al, in a network configuration, is finely and almost isotropically distributed in the base phase.

Then, this skeleton phase will be explained in more detail hereinafter.

[0031] The skeleton phase is formed by crystallization of the compounds of Si, Ni, or Fe and develops like a network to surround the base phase. In the aluminum alloy of the present invention, a suitable amount of the skeleton phase prevents local concentration of residual stresses and strains and makes it easy to distribute them entirely and uniformly. Insufficient skeleton phase causes insufficient stress distribution, while excessive skeleton phase unfavorably lowers the ductility and the fatigue strength. Accordingly, a suitable amount of skeleton phase is considered to exhibit high static and fatigue strengths as well as high thermal fatigue strength.

[0032] In addition, the aluminum alloy of the present invention includes Ti and Zr as well. Because of this, the base phase as well as the surrounding skeleton phase are comprised of very fine crystallites, which are isotropically distributed in the aluminum alloy. Therefore, the skeleton phase formed in a network configuration makes imposing internal stresses and strains distribute not only entirely but also more isotropically and more uniformly.

[0033] As described above, Ti and Zr provide nuclei for precipitation of Cu and Mg. In addition, Ti and Zr are dissolved in the base phase as a solid solution and contribute to strength improvement of the aluminum alloy.

[0034] (4) As explained heretofore, the simultaneous achievement of static and fatigue strengths as well as thermal fatigue strength at higher levels than the conventional level is considered to be possible only by synergetic interactions of suitable amounts of alloying elements such as Si, Cu, Mg, Ni, Fe, Ti, Zr, Mn, V and one or more of Sr, Sb and Na in the aluminum alloy of the present invention.

[0035] In a casting made of the aluminum alloy of the present invention, the metallographic structure of some parts may change to some extent in the initial stage of use. For example, in a cylinder head with individual parts exposed to different temperatures, the part close to the combustion chamber is heated to a higher temperature, at which the compounds of Cu and Mg precipitated from the base phase may grow to coarse particles in the initial stage of use.

[0036] However, in the present invention, the precipitate particles stop growing and subsequent heating recovers the toughness and ductility of the alloy.

And, even if the toughness and ductility decrease slightly, the thermal fatigue strength rarely decreases significantly since the base phase is strengthened by the skeleton phase with crystallized Ni compounds and the like.

[0037] As a matter of course, since the base phase is strengthened by multi-phase precipitate of Cu and Mg compounds, the aluminum alloy exibits sufficient strength and hardness as a base material.

Accordingly, the aluminum alloy of the present invention is most favorable for a high performance cylinder head of a gasoline engine and a cylinder head of a diesel engine which requires a high durability under severe environments of use. It is needless to say that the aluminum alloy of the present invention is suitable for other castings than cylinder heads, irrespective of environments (temperature, etc) of use.

(Aluminum Alloy Casting)

[0038] The present invention can be grasped not only as an aluminum alloy for casting but also as an aluminum alloy casting or a cast product made of aluminum alloy which is excellent in practical fatigue resistance.

Namely, the present invention can also be grasped as an aluminum alloy casting with excellent practical fatigue resistance, which has the composition of the above-mentioned aluminum alloy for casting and has the metallographic structure comprising a base phase mainly consisting of α-Al, a skeleton phase crystallized so as to surround the base phase like a network and a multi-phase precipitate with the first precipitation phase with the particle size of 30-300nm and the second precipitation phase with the particle size of 1-20nm, both of which are precipitated in the base phase, wherein said skeleton phase is comprised of crystallized substances of compounds including Si, Ni or Fe, wherein said first precipitation phase is comprised of Ti compound or Zr compounds and Cu compounds or Mg compounds, and said second precipitation phase is comprised of Cu compounds or Mg compounds, and wherein the size of secondary dendrites (DASII) is below 40 μm.

(Method to Produce an Aluminum Alloy Casting)

[0039] Further, the present invention can also be grasped as a favorable method to produce a casting made of the aluminum alloy.

Namely, the present invention can be grasped as a method for producing a cast product made of the above-mentioned aluminum alloy, comprising a casting process to pour the molten aluminum alloy with the composition of the above-mentioned aluminum alloy for casting into a casting die and solidify the molten alloy and a heat treatment process to make solution treatment and aging treatment of the aluminum alloy casting, wherein said solution treatment is comprised of a heating step, wherein said casting is maintained at 450 to 550°C for 1 to 10 hours, and a subsequent rapid cooling step, and said rapid cooling step is made at a cooling rate of 20-200°C/min, and wherein in said aging treatment said casting is maintained at 140 to 300°C for 1 to 20 hours.

[0040] Hereupon, "strength" expressed in the present specification indicates the rupture strength of an aluminum alloy casting in its early stage of use. This strength can be almost maintained in a temperature range from room temperature to 150°C. This strength may be indexed by either the tensile strength or the entire hardness of the aluminum alloy. And, an alloy with a high fatigue strength, described later, is generally considered to have a high tensile strength.

[0041] "Fatigue strength" is the strength to high cycle fatigue in a general sense and "fatigue resistance" is the resistance to such fatigue. "Fatigue strength" is the rupture strength of an aluminum alloy casting which is subjected to repetitive stress cycles at a predetermined temperature. The fatigue strength is indexed by the average stress, stress amplitude and repetition number (life to rupture).

[0042] "Thermal fatigue" is a kind of low cycle fatigue and is observed when temperature and strain are changed periodically. "Thermal fatigue resistance" is the resistance to such fatigue. The "practical fatigue resistance" expressed in the present specification includes both this thermal fatigue resistance and the fatigue resistance described above. And, the "practical fatigue strength" expressed in the present specification includes both the fatigue strength and the thermal fatigue strength.

For reference, more specifically speaking, thermal fatigue is a kind of fatigue phenomenon, in which restriction of thermal expansion and contraction causes strains in compressive or tensile direction during heating and in tensile or compressive direction during cooling. This fatigue phenomenon is classified into two kinds, out-of-phase and in-phase fatigues, according to the phase difference between temperature and strain.

[0043] Thermal fatigue is indexed by a thermal fatigue life and its test method will be described later. Since an aluminum alloy has a large thermal expansion coefficient, the alloy is subject to out-of-phase thermal fatigue in which restriction of thermal expansion is likely to generate compressive strains during heating and tensile strains during cooling. The aluminum alloy is required to have the resistance to this kind of fatigue.

[0044] Here, "thermal fatigue strength" indicates the rupture strength of an aluminum alloy which is subjected to hot and cold cycles, namely periodically repeated heating and cooling under a predetermined restraint (stressing) condition. However, since the thermal fatigue strength is intrinsically indexed by the thermal fatigue life, it is not easy to measure its own value. Therefore, in the present specification, there are some cases in which the expression, "practical thermal fatigue strength" is qualitatively used to denote either rupture strength or thermal fatigue resistance in almost the same meaning. For example, it is to be noticed that, in some cases, the expression, "high thermal fatigue strength" does not mean "high rupture strength" but simply means "high thermal fatigue resistance".

Brief description of the drawings

[0045]

(Fig. 1A) A metallographic photograph of the aluminum alloy casting of the present invention.
(Fig. 1B) An enlarged metallographic photograph of the base phase in Fig.1A.

Best Mode for Carrying out the Invention

[0046] Next, the present invention will be described in more detail, while naming embodiment modes. The contents explained in the present specification including the embodiment modes can be appropriately applied to the aluminum alloy for casting, the aluminum alloy casting and the method to produce the casting, which are related with the present invention. And, it should be also noticed that the best mode of embodiment is different according to the kinds of castings, the performances required of castings and the like.

(1) Alloy Composition

[0047] The chemical composition of the aluminum alloy of the present invention is determined by the following reasons.

< Si >

[0048] The amount of Si in the aluminum alloy of the present invention is 6-9% (percent by mass, being the same hereinafter). Insufficient amount of Si is likely to cause deteriorated castability and generate casting defects. And, it increases the thermal expansion coefficient of the casting. On the other hand, excessive Si increases the degree of orientation of the metallographic structure when a molten alloy is solidified, leading to a non-uniform metallographic structure. And, it may cause a risk of generating a large number of casting defects in the part solidified at the final stage. In addition, increased amount of brittle Si particles may lower the ductility and toughness of a casting, leading to the decrease of the fatigue strength as well as the thermal fatigue strength.

[0049] A preferable lower limit of Si content is 6.5% and a more preferable lower limit is 7%. A preferable upper limit of Si content is 8.5% and a more preferable upper limit is 8%. And, these lower and upper limits can be optionally combined (this kind of combination can also be applied to other elements described below).

Further, Si contributes to the formation of the skeleton phase in the aluminum alloy of the present invention. The amount of Si within a range of 6-9% can produce a suitable amount of eutectic Si, leading to production of an aluminum alloy excellent in strength and ductility. Especially, the Si amount of 7-8% is optimum in producing an aluminum alloy with an excellent balance among castability, various kinds of strengths and ductility.

< Cu >

[0050] The range of Cu content is 1-2.5%. Insufficient Cu causes insufficient effect of precipitation strengthening owing to Cu and cannot provide required strength and hardness of an aluminum alloy casting.

Inversely, excessive Cu generates a base phase excessively hardened due to increased precipitation strengthening effect of Cu. Especially, when the amounts of crystallites of other elements are large as in the present invention, excessive Cu is likely to lower the fatigue strength because of increased stress concentration. In addition, excessive Cu increases the porosity of an aluminum alloy casting, leading to decreased fatigue strength.

[0051] A preferable lower limit of Cu content is 1.3% or 1.4% and a more preferable lower limit is 1.5%. For example, a preferable range of Cu content is 1.5-2.5%.

< Mg >

[0052] The range of Mg content is 0.2-0.6%. Mg is an element to provide the effect of precipitation strengthening. It is very important to include a suitable amount of Mg in order to assure sufficient static and fatigue strengths of an aluminum alloy as a base material.
Insufficient amount of Mg cannot provide sufficient strength because of the too soft base phase in the aluminum alloy. Excessive amount of Mg lowers the ductility and toughness of the aluminum alloy and thus cannot provide sufficient fatigue strength and thermal fatigue strength.
A preferable upper limit of Mg content is 0.5% or 0.4% and a more preferable upper limit is 0.3%. For example, a preferable range of Mg content is 0.2-0.5% and a more preferable range is 0.2-0.4%.

< Ni >

[0053] The range of Ni content is 0.2-3%. Ni is an element which has a role to crystallize Ni compounds and strengthen the skeleton phase in a network configuration.
Insufficient amount of Ni decreases the amount of crystallized Ni compounds and causes insufficient formation of a network skeleton phase comprising crystallized substances. Excessive amount of Ni is likely to generate coarse Ni compounds and thus significantly lower the ductility and toughness. Neither insufficient nor excessive amount of Ni is preferable because the fatigue strength as well as the thermal fatigue strength of the aluminum alloy is lowered.

[0054] A preferable lower limit of Ni content is 0.5% or 0.7% and a more preferable lower limit is 0.8%. A preferable upper limit of Ni content is 2% or 1.5% and a more preferable upper limit is 1.2%. Especially, when Ni content exceeds 2%, Ni compounds become larger and the metallographic structure becomes less uniform. When Ni content is in a range of 0.5-2%, the amount and size of crystallized Ni compounds are suitable and a favorably uniform solidified structure is obtained. Further, when Ni content is in a range of 0.7-1.5%, more preferable results are obtained to produce an aluminum alloy with a stable and high thermal fatigue resistant. Here, Ni compounds is a generic name for various compounds that contain Ni. For example, Al-Ni, Al-Ni-Cu, and Al-Fe-Ni compounds can be named as Ni compounds.

< Fe >

[0055] The range of Fe content is 0.1-0.7%.
Insufficient Fe amount reduces the amount of formed Fe compounds and prohibits sufficient development of the network of crystallized substances in the skeleton phase. Excessive Fe amount is likely to generate coarse Fe compounds and significantly lower the ductility and tenacity. Neither insufficient nor excessive Fe amount is preferable since the fatigue strength as well as the thermal fatigue strength are lowered.

[0056] A preferable lower limit of Fe content is 0.2% and a more preferable lower limit is 0.3%. A preferable upper limit of Fe content is 0.6% and a more preferable upper limit is 0.5%. For example, a preferable range of Fe content is 0.2-0.6% and a more preferable range is 0.3-0.5%. When the Fe content is within this range, crystallized Fe compounds are suitable in both amount and size and a still higher thermal fatigue strength is obtained.
Here, Fe compounds is a generic name for various compounds that contain Fe. For example, Al-Si-Fe-Mn, Al-Si-Fe, and Al-Fe-Ni compounds can be named as Fe compounds.

< Ti >

[0057] The range of Ti content is 0.1-0.3%. Ti is an element which makes crystal particles fine and strengthens the base phase by precipitation or formation of a solid solution. Further, since the crystal particles are made to be sufficiently fine by the action of Ti, the skeleton phase with a network of crystallites becomes more isotropical.
And, inclusion of Ti in the base phase by precipitation or formation of a solid solution suitably hardens the base phase and prevents strain concentration within the base phase. As a result, the strain distribution becomes more uniform and the fatigue strength as well as the thermal fatigue strength are improved.
In addition, Ti, along with Zr, provides nuclei for generation of the precipitation phase including Cu and Mg. Because of this, the precipitation phase including Cu and Mg is precipitated on the nuclei comprising the precipitate phase including compounds of such transition elements as Ti and Zr, as a thermally stable phase, in the high temperature zone of the cooling step and therefore the thermal fatigue strength of the aluminum alloy of the present invention is considered to be improved.

[0058] Insufficient amount of Ti causes formation of crystallized particles which are not sufficiently fine as well as development of the dendrite structure peculiar to the structure of a casting, thus making it difficult to obtain a skeleton phase with an isotropic network configuration.
On the other hand, excessive amount of Ti increases the amount of Ti which is dissolved in the base phase as a solid

solution and makes the base phase too hard, thus causing a risk that the casting is subjected to shear rupture. And, it causes formation of coarse Ti compounds in the base phase and is likely to significantly lower the ductility and toughness of a casting. Neither insufficient nor excessive amount of Ti is preferable because of reduced fatigue strength and thermal fatigue strength. A preferable range of Ti content is 0.15-0.25% and a more preferable range is 0.18-0.24%.

[0059] Ti can be added to an aluminum alloy as an alloy of Al-Ti at the final stage of melting of the raw materials. Addition of Ti in a form of a mother alloy (aluminum alloy) prevents coagulation of Ti compounds and improves formation of sufficiently fine crystal particles as well as isotropic and uniform metallographic structure.

< Zr >

[0060] The range of Zr content is 0.03-0.5%. Zr is an element which makes crystal particles fine, prevents the growth of dendrites and develops a more isotropic skeleton phase comprising a network of crystallized substances.

And, Zr dissolved as a solid solution or precipitated in the base phase suitably improves the high temperature strength of the base phase and develops more uniform strain distribution by suppressing excessive strain concentration in the base phase.

Further, Zr as well as Ti provides nuclei for formation of the precipitation phase including Cu and Mg. Because of this, the precipitation phase including Cu and Mg is precipitated on the nuclei comprising the precipitate phase including compounds of such transition elements as Ti and Zr, as a thermally stable phase, at the high temperature stage of a cooling step and therefore the thermal fatigue strength of the aluminum alloy of the present invention is improved.

[0061] Insufficient amount of Zr does not provide sufficient effects as described above. Excessive amount of Zr generates coarse primary crystalline compounds and thus significantly lowers the ductility and toughness as well as the fatigue strength and thermal fatigue strength of the aluminum alloy. Excessive amount of Zr is not preferable because uniform dissolution of Zr is difficult unless the temperature of the molten metal is raised to a higher temperature.

A preferable lower limit of Zr content is 0.05% or 0.07% and a more preferable lower limit is 0.08%. A preferable upper limit of Zr content is 0.4%, 0.3% or 0.2% and a more preferable upper limit is 0.15%. For example, a preferable range of Zr content is 0.03-0.3% and a more preferable range is 0.05-0.15%.

[0062] For reference, when the total content of Ti and Zr exceeds 0.5%, coarse Ti compounds are formed. This not only lowers the ductility and toughness of an aluminum alloy casting but also reduces the amount of Ti that is effective for making the above-mentioned crystal particles fine and is likely to make the particles more coarse. As a result, the metallographic structure of an aluminum alloy casting becomes less isotropic and less uniform and therefore the strength, fatigue strength and thermal fatigue strength are likely to be lowered. Therefore, the total amount of Ti and Zr is less than 0.5% and a more preferable range of Zr content is 0.03-0.15%.

< Mn >

[0063] The range of Mn content is 0.1-0.7%. Mn is crystallized as Mn compounds and strengthens the skeleton phase more effectively. And, Mn prevents the formation of coarse and needle-like Fe compounds and

thus inhibits the reduction of the ductility and toughness of an aluminum alloy casting. In addition, Mn as well as Zr and Ti provides nuclei for formation of the precipitation phase including Cu and Mg. Because of this, the precipitation phase including Cu and Mg is formed on the nuclei comprising the precipitate phase including compounds of such transition elements as Ti and Zr, as a thermally stable phase, at a high temperature stage of a cooling step, and therefore the thermal fatigue strength of the aluminum alloy of the present invention is improved.

[0064] Insufficient amount of Mn provides no satisfactory effects. Excessive amount of Mn generates coarse Mn compounds, significantly lowers the ductility and toughness of an aluminum alloy casting and is likely to reduce the fatigue strength as well as the thermal fatigue strength of the casting.

A preferable lower limit of Mn content is 0.2% and a more preferable lower limit is 0.25%. A preferable upper limit of Mn content is 0.6% and a more preferable upper limit is 0.4%. For example, a range of Mn content of 0.2-0.5% is preferable and a range of 0.25-0.4% is more preferable to generate the above-mentioned effects most favorably.

< V >

[0065] The range of V content is 0.01-0.5%. V is an element which solution strengthens the base phase and improves the high temperature strength of the base phase of an aluminum alloy casting. Insufficient amount of V does not sufficiently provide this effect.

Excessive amount of V generates coarse primary crystal compounds and thus is likely to significantly lower the ductility and toughness and reduce the fatigue strength as well as the thermal fatigue strength of an aluminum alloy casting.

[0066] A preferable lower limit of V is 0.015% or 0.02% and a more preferable lower limit is 0.05%. A preferable upper limit of V is 0.3% and a more preferable upper limit is 0. 15%. For example, a preferable range of V content is 0.15-0.3%

and a more preferable range is 0.02-0.15%.

< Sr, Sb, Na >

[0067] Strontium(Sr), antimony(Sb), sodium(Na) and the like are elements which refine eutectic Si crystals. Inclusion of one or more of such elements further improves the thermal fatigue life, namely thermal fatigue strength. As a matter of course, insufficient amount of either of these elements does not provide sufficient effect of making fine eutectic Si crystal particles.

[0068] The range of Sr content is 0.003-0.05%. When the amount of Sr is excessive, the effect of making fine eutectic Si crystal particles becomes saturated and gas absorption becomes violent. Therefore, a more preferable range of Sr content is 0.003-0.01%. The range of Sb content is 0.02-0.2%. Excessive amount of Sb makes Sb compounds crystallize and thus lowers the ductility, fatigue strength and thermal fatigue strength of the aluminum alloy. Therefore, a more preferable range of Sb content is 0.05-0.12%. The range of Na content is 0.001-0.03%. Excessive amount of Na is likely to lower the toughness of the aluminum alloy and deteriorate the fatigue strength and thermal fatigue strength. Therefore, a more preferable range of Na content is 0.001-0.01%.

(2) Metallographic Structure

[0069] The aluminum alloy for casting of the present invention or a cast product made of the aluminum alloy for casting of the present invention (for convenience, "aluminum alloy casting(s)" or simply "casting(s)" is used here to denote either or both of these) is comprised of a base phase and a skeleton phase. The base phase mainly consists of α-Al and the skeleton phase is comprised of crystallized substances to surround the base phase in a network configuration (see Fig. 1). This kind of metallographic structure is obtained, for example, when a skeleton phase is crystallized around a base phase by eutectic reaction after the base phase is solidified as primary crystals. This metallographic structure is a kind of hypoeutectic structure mainly obtained when a molten aluminum alloy solidifies in a gruel state within a casting die.

[0070] The base phase includes not only α-Al but also alloying elements (Ti, Zr, Cu, Mn etc) dissolved in the phase in a state of solid solution and precipitated particles of compounds (for example, precipitated particles of Cu compounds and Mg compounds). And the skeleton phase includes not only eutectic A1-Si crystals but also compounds simultaneously crystallized with the eutectic crystals and alloying elements (Ni, Fe etc) dissolved in the crystals in a state of solid solution. Hereafter, the particles which are crystallized or precipitated in the skeleton phase and strengthen the phase will be referred to as "skeleton phase strengthening particles" (see Fig. 1).

[0071] These strengthening particles include particles of Al-Ni, Al-Si-Ni, Al-Fe, Al-Si-Fe, and Al-Si-Fe-Mn compounds as well as eutectic Si crystals. Especially, crystallized particles comprising Ni compounds or Fe compounds exhibit significant strengthening effect. In addition, SiC, Al_2O_3 and TiB_2 particles and the like can be strengthening particles, according to added elements and raw materials.

[0072] Here, the skeleton phase is comprised of crystallized substances with high elasticity and high yield stress as well as hard strengthening particles. These substances and particles are linked with each other and surround the base phase in a network configuration. Since the structure of the skeleton phase is finely and uniformly distributed in a casting, the stresses acting on the casting are uniformly dispersed in the skeleton phase and the stresses loaded on the base phase to trigger fatigue cracking tend to be reduced. As a result, the fatigue strength as well as the thermal fatigue strength of the aluminum alloy casting of the present invention is considered to be improved.

[0073] It is preferable that the aluminum alloy casting of the present invention has a hypoeutectic structure without primary Si crystals. In casting a cylinder head which is large and has a complicated shape with an internal cavity, it is difficult to completely control the direction of solidification and expel porosities out to the riser. In this case, if a casting with a hypoeutectic structure is obtained by gruel solidification of a molten alloy, it is possible to prevent local concentration of porosities. And, it is possible to prevent lowering of the fatigue resistance of a casting due to stress concentration on the porosities. And, such hypereutectic structure makes it possible to disperse crystallized substances and thus effectively generates a skeleton phase even with a small amount of crystallized substances.

[0074] The primary Si crystals in a casting may provide starting points to initiate fatigue fracture. Especially, in a large casting like a cylinder head, since the entire solidification rate is slow, primary Si crystals formed during solidification are likely to float up into the upper molten zone and segregate. The primary Si crystals, thus formed, are likely to become starting points for fatigue fracture. Therefore, no substantial existence of primary Si crystals is preferable.
In the present invention, since the amount of Si is lower than the eutectic point of the binary Al-Si system, it is relatively difficult for primary Si crystals to crystallize. However, according to the kinds and amounts of alloying elements other than Si, the eutectic point may shift to lower Si side and thus primary Si crystals are likely to be generated. In such case, it is preferable to adjust the amount of Si within a range where the castability and other properties are not impaired.

[0075] Since the aluminum alloy casting of the present invention includes suitable amounts of Cu and Mg, not only the skeleton phase but also the base phase are precipitation strengthened and not only the thermal fatigue resistance but also the hardness as a base material, strength and fatigue resistance are sufficiently assured. The hardness of the base phase in the initial stage of use generally exceeds 80 HV(Vickers hardness) and more preferably exceeds 85HV. The upper limit of the hardness may vary according to the contents of Cu and Mg, heat treatment conditions and the like but it is generally about 120 HV.

[0076] For reference, "initial hardness in use" signifies the hardness of an aluminum alloy casting before it is subjected to thermal hysteresis (hardness in a virgin state). For example, in a cylinder head of an engine, a typical casting made of an aluminum alloy, the "initial hardness in use" is the hardness of the casting before the first operation of the engine (namely, before firing).

[0077] When an aluminum alloy casting is used at a relatively low temperature (for example, below 150°C) or a specific part of the casting is exposed to a low temperature, the hardness of the base phase in the part is maintained at the initial hardness level as described above. This tendency is observed in the hardness of the entire casting. A preferable hardness exceeds 95 HV and a more preferable hardness exceeds 100 HV.

(3) Method of Production

[0078] The method of making the aluminum alloy casting of the present invention is comprised of a casting process in which a molten aluminum alloy with the same composition as the above-mentioned aluminum alloy for casting is poured into a casting die and then solidified to make an aluminum alloy casting and a heat treatment process in which the aluminum alloy casting is subjected to solution treatment and aging treatment, including the features indicated above.

[0079] Here, solution treatment is a process in which a casting is maintained at a high temperature and then rapidly cooled to generate a supersaturated solid solution. Aging treatment is a process in which a solution treated casting is maintained at a relatively low temperature to precipitate the elements dissolved in the supersaturated solid solution and thus provide a suitable hardness to the casting. These heat treatments make finely precipitated particles disperse uniformly, provide a high level balance among strength, ductility and tenacity and produce a casting excellent in strength, fatigue strength and thermal fatigue strength.

[0080] In addition, these treatments make the edges of crystallized substances round and are expected to improve the practical fatigue resistance because of reduced stress concentration. In the heat treatments of the present invention, Cu and Mg are precipitated as Cu compounds (mainly, Al-Cu and Al-Cu-Si-Mg compounds) and Mg compounds (mainly, Al-Mg-Si compound), respectively and thus the hardness of the base phase is suitably increased.

[0081] Heat treatment conditions are appropriately selected according to the compositions and required properties of castings. Generally, there are T6, T4, T5, T7 and other heat treatments, according to the temperature and time of treatment. In the solution treatment according to the present invention, a casting is maintained at 450-550°C for 1-10 hours and then rapidly cooled. In solution treatment, a temperature range of 490-530°C and a duration range of 1-3 hours are more preferable from the viewpoints of cost and required properties of a casting. And, in the aging treatment according to the present invention, a casting is maintained at 140-300°C for 1-20 hours. In aging treatment, a temperature range of 160-200°C and a duration range of 1-5 hours are more preferable from the viewpoints of cost and required properties of a casting.

[0082] In the aluminum alloy casting of the present invention, the conventional water cooling step for rapid cooling in solution treatment can be substituted by a step in which a heated aluminum alloy casting is cooled in a gas. Air is generally used as such gas although an inert gas may be a candidate. Therefore, air cooling can be used for the rapid cooling. Here, it should be noticed that the solution treatment of the aluminum alloy casting of the present invention by use of water is not excluded from the scope of the present invention.

[0083] Since solution treatment is intrinsically a process to generate a solid solution, rapid cooling itself is required instead of furnace cooling used for annealing. Rapid cooling is required to temporarily freeze a solid solution of precipitation strengthening elements such as Cu and Mg which are sufficiently and uniformly dissolved in the base phase during heating and generate a finely and uniformly distributed precipitation phase of Cu and Mg in the subsequent aging treatment. If a long cooling step like furnace cooling is adopted in solution treatment, the so-called quenching effect is not obtained, Cu and Mg appear as coarse compounds and an aluminum alloy with required properties is unobtainable.

[0084] In the aluminum alloy of the present invention, the precipitation phase including Cu, Mg, etc which is stable at high temperatures can be generated in the base phase even at a cooling rate slower than the conventional water cooling rate in the rapid cooling step in solution treatment, because the alloy has the alloy composition as described above. This is due to the fact the Ti, Zr and other transition elements such as Mn already dissolved in the base phase as a solid solution in the casting process begin to precipitate antecedently as fine particles in the heating step of solution treatment. Namely, when the cooling rate in the rapid cooling step of solution treatment is relatively slow, the antecedent precipitation phase including the transition elements provides nuclei onto which Cu, Mg, etc precipitate at the higher temperature stage in the cooling step as a stable phase, which becomes an antecedent phase (mainly, first precipitation phase) and is dispersed in the base phase.

[0085] However, the entire amounts of Cu, Mg, etc included in the base phase in the rapid cooling step do not necessarily precipitate and the rest remains still frozen. The frozen precipitation strengthening elements begin to make intrinsic precipitation in the aging treatment after solution treatment. Since this aging treatment is made at a lower temperature and for a longer time than in the precedent rapid cooling step, fine precipitates including Cu, Mg, etc are dispersed in the entire base phase. As a result, the base phase is considered to include a multi-phase precipitation phase comprising the first precipitation phases which is stable and large in size and the second precipitation phase which is minute in size.

[0086] Thus, the aluminum alloy casting of the present invention exhibits excellent thermal fatigue strength since stresses are sufficiently dispersed in the base phase against varying strain amplitudes due to repetitive hot and cold cycles. In addition, residual strains are difficult to occur or only a limited number of residual strains occur within the aluminum alloy casting during solution treatment (especially, in the rapid cooling step), since the cooling rate in the rapid cooling step is set to be relatively slow. Because of this, the aluminum alloy casting is considered to exert a sufficient fatigue strength even when it is subjected to repetitive stresses. However, it should be noticed that, as described before, the reasons and mechanisms for the excellent practical fatigue resistance of the aluminum alloy of the present invention are not necessarily completely clear at present.

[0087] Irrespective of cooling means, the cooling rate in the rapid cooling step in solution treatment is 20-200°C/min, in order to obtain the metallographic structure as described above. Insufficient cooling rate cannot provide finely precipitated phases of Cu, Mg, etc. Excessive cooling rate generates lots of residual strains within the aluminum alloy casting and is likely to lower the practical fatigue resistance. A preferable lower limit of cooling rate is 25°C/min and a more preferable lower limit is 30°C/min. A preferable upper limit of cooling rate is 150°C/min and a more preferable upper limit is 100°C/min. These upper and lower limits can be optionally combined.

[0088] The rapid cooling with such cooling rate can be achieved, for example, by placing an aluminum alloy casting after heated in solution treatment in a space with forced circulation of air or an inert gas. Namely, in production of the aluminum alloy casting pf the present invention, it is preferable to adopt a rapid cooling step in which an aluminum alloy casting after heated in solution treatment is cooled in a gas.

[0089] The cooling rate can be suitably determined by adjustment of temperature, flow speed, density(thermal capacity) and the like of a gas as a working fluid. From the viewpoints of equipment, cost and the like, it is preferable to adopt the rapid air cooling process in which an aluminum alloy casting after heated is placed in a low temperature air or forcibly blown with air.

In addition, when air cooling is used in solution treatment, the degree of freedom of the solution treatment conditions is increased and this is significantly favorable in cost reduction in mass production of aluminum alloy castings.

(4) Aluminum Alloy Castings

[0090] As described above, in the aluminum alloy casting of the present invention, the precipitation strengthening elements such as Cu and Mg precipitate in solution treatment (more specifically, in the rapid cooling step) and the subsequent aging treatment. The precipitates generated in either of the treatments are fine in size and uniformly distributed and yet the precipitates antecedently generated in solution treatment may grow into larger particles to some extent. Therefore, the aluminum alloy of the present invention has a multiple phase metallographic structure, in which the first precipitation phase with particle size of 30-300nm and the second precipitation phase with particle size of 1-20nm are precipitated in the base phase. Namely, the aluminum alloy casting of the present invention has the same composition as the above-mentioned aluminum alloy for casting and has a metallographic structure comprising a base phase mainly consisting of α-Al, a skeleton phase crystallized to surround the base phase in a network configuration and a multi-phase precipitate comprising the first precipitation phase with particle size of 30-300nm and the second precipitation phase with particle size of 1-20nm, both of which are precipitated in the base phase.

[0091] Here, the particle sizes of the first and second precipitation phases can be varied by the conditions in solution treatment and aging treatment. In order to obtain more excellent strength and practical fatigue resistance, preferable particle sizes are 30-250nm in the first precipitation phase and 1-15nm in the second precipitation phase. More preferable particle sizes are 30-200nm and 1-10nm in the first and second precipitation phases, respectively.

[0092] However, the mechanical properties of the aluminum alloy casting are not exclusively influenced by the particle sizes in the precipitation phases but also significantly influenced by the amounts of precipitates in the first and second precipitation phases.

Insufficient amount of the first precipitation phase unfavorably causes non-uniform distribution of stresses due to thermal strains. Excessive amount of the first precipitation phase unfavorably reduces the ductility of the base phase and is likely lower the strength and fatigue strength.

[0093] Insufficient amount of the second precipitation phase unfavorably lowers the strength and fatigue strength. Excessive amount of the second precipitation phase unfavorably reduces the ductility of the base phase and is likely to lower the strength and fatigue strength.

[0094] As a matter of course, the theoretical upper limits of the amounts of respective precipitation phases are determined by the metallic composition. However, the practical amounts of precipitates are significantly influenced by the conditions in solution treatment and aging treatment after casting. In order to assure suitable amounts of the precipitates as described above, it is preferred to appropriately determine the conditions in solution treatment and aging treatment.

[0095] Here, in the aluminum alloy of the present invention, the precipitates of Cu, Mg, etc. which are precipitated on the nuclei of the precipitates of Ti, Zr, etc. in the rapid cooling step in solution treatment, are considered to be stable. The stable precipitation phase(first precipitation phase) is considered to make less contribution to the strength of the aluminum alloy casting, in comparison with the metastable fine precipitates generated in the conventional water cooling step in solution treatment.

[0096] In order to assure sufficient strength of the aluminum alloy casting of the present invention, it is necessary to sufficiently raise the volume ratio of the fine precipitates (second precipitation phase) by aging treatment subsequent to solution treatment. Yet, from the viewpoint of thermal fatigue resistance, dispersion of the precipitation phase with the same particle size as the stable first precipitation phase is considered to reduce the stresses acting on the aluminum alloy and thus improve the thermal fatigue resistance.

[0097] In casting of the aluminum alloy of the present invention, there is a possibility to cause such casting defects as micro shrinkages due to solidification shrinkages and gas porosities and pinholes due to dissolved gases in the casting. When such casting defects as porosities exist at stress concentrated places, they are likely to provide starting points for cracking or fracture. Inversely, an aluminum alloy casting with a lower porosity rate is more excellent in the fatigue strength as well as the thermal fatigue strength. Therefore, less casting defects such as porosities are more preferable.

[0098] However, it is difficult to completely avoid the generation of porosities and it is not necessarily required. A porosity ratio less than 0.3% by volume may suffice for the aluminum alloy casting. A preferable porosity ratio is less than 0.1% by volume and a still more preferable porosity ratio is less than 0.05% by volume. In addition, no significant problems may occur in many practical cases, even if a casting has casting porosities in areas with low acting stresses (other than stress concentrated areas). For example, it is mostly satisfactory when the above-mentioned preferable porosity ratio is achieved in the areas that specially require high thermal fatigue resistance, such as areas between valves in a combustion chamber of a cylinder head.

[0099] In addition, with reference to the above-mentioned casting process, in order for the aluminum alloy casting of the present invention to have a metallographic structure in which a base phase and a skeleton phase surrounding the base phase are isotropically and uniformly distributed, the size of secondary dendrites (DAS II) is below 40μm, a more preferable size is below 35μm and a still more preferable size is below 30μm. Excessive size of secondary dendrite arms increases the skeleton size of the strengthening phase comprising crystallized substances and thus generates a metallographic structure which is not suitable for uniform dispersion of acting stresses.

[0100] A preferable ratio, d/DAS II, of the crystal particle diameter, d, to the secondary dendrite arm space, DAS II, in an aluminum alloy casting is, for example, 5-20. Excessive ratio impairs the uniformity of the metallographic structure and unfavorably causes non-uniform deformation due to local stress concentration.
For reference, the diameter of crystal particles, d, is determined by measurement in accordance with, for example, JIS-H-0501, "standard test for measuring the grain sizes of crystallites in rolled copper".

[0101] A preferable level of residual strains within the aluminum alloy casting of the present invention is below 1000 με, a more preferable level is below 800με and a still more preferable level is below 500με. Excessive residual strains are likely to lower the practical fatigue resistance since the stresses corresponding to residual strains are imposed on the casting in addition to the stress amplitudes generated during use and thus a higher average stress acts on the casting. For reference, the residual strains as mentioned in the present invention are those after heat treatment. And, a residual strain is measured by a method in which a strain gage is applied to the surface of a casting and the gage signal due to strain release during cutting of the casting is taken out and read.

(5) Uses

[0102] As a matter of course, the aluminum alloy for casting of the present invention is used as the raw material for producing an aluminum alloy casting. Although the aluminum alloy for casting may be used in any form, it is usually used in a form of ingot.

[0103] The aluminum alloy casting of the present invention can be used in any size and form and in any environment of use but it is suitable for the parts which simultaneously require high strength, fatigue resistance, thermal fatigue resistance, etc. Such parts include engine parts, motor parts, and heat radiation parts. A cylinder head and a turbo-rotor can be named as engine parts.

[0104] Since the aluminum alloy casting of the present invention has an excellent corrosion resistance, it is suitable for parts in exhaust systems (exhaust pipes, exhaust control valves, etc). In addition, since the aluminum alloy casting of the present invention is excellent in fatigue strength as well as corrosion resistance, it is suitable for the parts which require the both performances, such as underbody and chassis parts of automobiles. Such application contributes to weight reduction and performance improvement of those parts. More specifically, underbody parts include a disk wheel, an upper arm, a lower arm, a suspension arm, an axle carrier, an axle beam, etc. Chassis parts include a side member, a cross member, etc. And, the casting may be used for a transmission case and brackets used for mounting engine parts and their peripheral parts. Furthermore, when the aluminum alloy casting of the present invention is used to make parts that require corrosion resistance and thermal fatigue strength in various fields other than automotive field, they contribute to weight reduction and performance improvement of those parts.

[0105] The aluminum alloy for casting of the present invention is suitable for parts of high performance reciprocating engines which require high thermal resistance as well as high hardness and strength as the base material. Especially, since the aluminum alloy casting of the present invention has a more excellent thermal fatigue strength than conventional aluminum alloy castings, it is also suitable for parts of diesel engines which require a prolonged durability under severe conditions.

[0106] In particular, the aluminum alloy casting of the present invention is suitable for cylinder heads and engine blocks which are exposed to severe hot and cold environments and are subjected to repetitive thermal strains. It is particularly suitable for cylinder heads since an extremely high thermal fatigue resistance is required for the valve bridge parts between valves of a combustion chamber. However, other parts in the base material require high strength and fatigue resistance rather than high thermal fatigue resistance. And, high corrosion resistance is required for water jacket parts in order to assure a prolonged prevention of the decrease of cooling efficiency due to decreased heat transfer through formation of corrosion product films. The aluminum alloy casting of the present invention can satisfy all the aforementioned performance requirements for cylinder heads at high levels.

[0107] The aluminum alloy for casting of the present invention has a good castability and is most suitable as the raw alloy for cylinder heads which are large in size and complicated in shape. In addition, a cylinder head casting is subjected to mechanical processes such as cutting and polishing to be equipped with surfaces for mounting and bearing surfaces for cam shafts and the aluminum alloy casting of the present invention does not inhibit these processes.

[0108] The aluminum alloy casting of the present invention can be produced by any casting method. It may be sand casting, die casting, gravitational casting, low pressure casting or high pressure casting. From the viewpoint of mass productivity, die casting and low pressure casting are preferable.

Examples

[0109] Subsequently, while giving examples, the present invention will be described in more detail.

(1) Example No.1

(1) Preparation of test specimens

[0110] Aluminum alloys for casting with different compositions as shown in Table 1 were used. After each alloy was melted, the molten alloy was poured into a temperature-adjusted metal die, used for preparation of a test specimen of JIS No.4 type, followed by natural cooling and solidification. (Casting Process)

[0111] The obtained casting was heated at 500°C for 3 hours and then subjected to solution treatment in which the casting was quenched by air at a cooling rate of 30°C/min. Subsequently, it was subjected to aging treatment at 170°C for 3 hours. (Heat Treatment Process)

[0112] Test specimens with a parallel part of 4mm in diameter and 6mm in length, for fatigue and thermal fatigue tests, were taken out of each casting after heat treatment and No.1-1 ~ No. 1-4 test specimens, as shown in Table 1, were obtained. The sizes of secondary dendrites (DAS II) in a thermal fatigue test specimen and a fatigue test specimen of No. 1-4 sample were 25μm and 35μm, respectively.

For reference, the secondary dendrite arm spacing (DAS II) was measured in accordance with the procedure for measuring dendrite arm spacings, which is described in the "report of the casting and solidification committee of Japanese light metal society, No, 38(1988), 1.54".

(2) Test of thermal fatigue strength(thermal fatigue resistance)

[0113] The thermal fatigue strength of each test specimen was tested as described below.

Respective test specimens were mounted on a clamp holder made of a low expansion alloy and were subjected to a repetitive heating and cooling test. The test temperature range was 50-250°C and the cycle time of temperature change was 5min/cycle, comprising 2min for heating and 3min for cooling. The details of the thermal fatigue test are described in, for example, Japanese Unexamined Patent Publication(KOKAI) No.7-20031, "Zairyou (Materials) Vol.45(1996), pp. 125-130, and "Keikinzoku (Light Metals) Vol.45(1995), pp.671-676.

[0114] For reference, when high temperature strain gages were applied to a specimen made of JIS-AC2B aluminum alloy, the total strain range was about 0.6% in the initial stage of test. The total strain range indicates the range of amplitudes of strains in heating and cooling cycles and denotes the sum of elastic and plastic strains (elastic strain + plastic strain).

(3) Fatigue strength (Fatigue resistance) test

[0115] A fatigue test for determining a fatigue strength was made for a test specimen maintained at 150°C in a hydraulically operated, axial stress imposing type fatigue test equipment, under conditions of room temperature, a repetition rate of 100Hz and a minimum strain of 0.1%.
In the test specimens used in this test, a parallel part of 4mm in diameter and 6mm in length was axially and uniformly polished with a #1000 emery paper to which water was frequently applied.

(4) Strength (Hardness) test

[0116] Hardness measurement was made at room temperature by use of a Vickers hardness tester manufactured by Akashi Co. of Japan. A hardness was determined by measurement of the size of a dent on the surface of a test specimen loaded with a load of 5kg for 30 seconds.

(5) Assessment

[0117] Table 1 shows the results of the above-mentioned tests for respective test specimens.
The following findings are obtained from comparison of the results in Table 1.
First, No.1-4 test specimen with a composition outside the range of the present invention has a sufficiently long thermal fatigue life of 2600 cycles, a fatigue strength (10^7 cycle strength) exceeding 50MPa and a hardness of 90HV, namely, a sufficient strength. Therefore, No.1-4 test specimen is found to be an aluminum alloy casting with respective properties well balanced at high levels.

[0118] On the other hand, No.1-1 ~ No. 1-3 test specimens with compositions outside of the range of the present invention cannot satisfy all the practically required levels of the above-mentioned three properties. Namely, No.1-1 and No.1-2 test specimens which do not contain Ni and Zr, have sufficient hardnesses and fatigue strengths but have low thermal fatigue lives less than 2000 cycles, namely, low thermal fatigue strengths. And, No.1-3 test specimen which does not contain a substantial amount of Cu, has a high thermal fatigue life but has a low hardness, namely, an insufficient strength. No. 1-3 test specimen was not subjected to a fatigue test because it was found to have a low hardness.

(2) Example No.2

(1) Preparation of test specimens and their tests

[0119] No.2-1 ~ No.2-5 test specimens were prepared in the same manner as in Example No. 1, by use of aluminum alloys for casting with different compositions, as shown in Table 2. These test specimens were tested for respective properties in the same manner as in Example No.1 and their results are shown in Table 2. For reference, the test specimens in Table 2 have compositions mainly different in Cu content.

(2) Assessment

[0120] The following findings are obtained from comparison of the results of respective test specimens as shown in Table 2.
First, No.2-3 and No.2-4 test specimens with compositions outside the range of the present invention have sufficient thermal fatigue lives higher than 2400 cycles, fatigue strengths (10^7 cycle strength) higher than 50 MPa and hardnesses higher than 90HV, therefore sufficient strengths. Accordingly, No.2-3 and No.2-4 test specimens are found to be made of aluminum alloy castings with properties well balanced at high levels.

[0121] The effects of Cu content on hardness and fatigue strength are as follows. First, the hardness increases with increased amount of Cu. No.2-1 and No. 2-2 test specimens with Cu contents less than 1% have hardnesses less than 75HV, therefore insufficient strengths. No.2-5 test specimen with Cu content higher than 3% has a sufficient hardness higher than 100HV but has a fatigue strength less than 45MPa which is lower than those of test specimens with higher Cu contents.

[0122] As seen from No.2-1 ~ No.2-3 test specimens, the thermal fatigue life is thought to tend to increase with increased amount of Cu. However, as seen from No.2-3 ~ No.2-5 test specimens, the thermal fatigue life is almost constant at about 2500 cycles for Cu contents higher than 1.5% and thus the effect of Cu content on the thermal fatigue

life is considered to be little.
As seen from the porosity data in Table 4, the porosity in the castings tends to be larger for Cu contents higher than 3%.
[0123] For reference, porosities were determined from the density difference between a tested casting and a rapidly cooled defect-free copper casting. The densities were measured by the Archimedes method.
From the above-mentioned results, it can be said that the aluminum alloy castings with compositions within the range of the present invention are excellent in either of strength, fatigue strength and thermal fatigue strength and these properties are well balanced at high levels. Especially, the aluminum alloy castings with Cu contents of 1.5-2.5% are excellent in all these properties and therefore they are found to be most suitable as the material for high strength parts used in engines.

(Example No.3)

(1) Preparation of test specimens and their tests

[0124] As shown in Table 3, No. 3-1 ~ No. 3-3 test specimens with compositions different from those of the above-mentioned test specimens were prepared in the same manner as in Example No.1. No.3-1 test specimen has an addition of Na in comparison with the above-mentioned No. 2-3 specimen. This addition of Na for performance improvement was made in a conventional method using a commercial flux. No.3-2 test specimen has an addition of Sr in comparison with the above-mentioned No.2-3 specimen. This addition of Sr for performance improvement was made by addition of a mother alloy of Al-10%Sr. No.3-3 test specimen has an addition of Sb in comparison with the above-mentioned No. 2-3 specimen. This addition of Sb for performance improvement was made by addition of a mother alloy of Al-10%Sb. The properties of these test specimens were assessed in the same manner as in Example No.1 and their results are shown in Table 3. Table 3 includes the data of No.2-3 test specimen for comparison.

(2) Assessment

[0125] As seen from Table 3, addition of at least one element of Na, Sr and Sb for performance improvement significantly improves the thermal fatigue life of an aluminum alloy casting while maintaining the hardness and fatigue strength at high levels. Accordingly, the aluminum alloy castings with their performances improved by Na, Sr or Sb are found to be most suitable as the base materials for high strength parts of diesel engines which require a specially high thermal fatigue strength.

(Example No.4)

(1) Preparation of test specimens and their tests

[0126] As shown in Table 4, No.4-1, No.4-2 and No.4-3 test specimens with compositions different from those of the above-mentioned test specimens were prepared in the same manner as in Example No.1. The DAS II of the raw material was 35μm. The hardnesses of these test specimens were measured and the results are shown in Table 4. For reference, the test specimens in Table 4 have different contents mainly in Mg.

(2) Assessment

[0127] As seen from Table 4, No.4-1 and No.4-2 test specimens with Mg contents within the range of the present invention have sufficient hardnesses and the hardness is found to increase with increased Mg content. No.4-3 test specimen with Mg content higher than 0.6% has a sufficient hardness, which is, however, almost the same as that of No.4-2 test specimen. Therefore, it is found that addition of Mg in a larger amount than 0.6% makes little contribution to hardness increase.

(Metallographic structure)

[0128] Fig. 1A and Fig. 1B show the metallographic structures of No.2-4 test specimen. They are the metallographic structures after solution treatment and aging treatment subsequent to casting made in the manner as in Example No.1. Fig.1A is a metallographic structure observed with an optical microscope at a magnification of 400. Fig.1B is a TEM structure observed with an electron microscope.
[0129] From Fig. 1A, the aluminum alloy casting of the present invention is found to be comprised of an entirely uniform metallographic structure, in which a base phase mainly consisting of α-Al is surrounded by a skeleton phase comprising crystallized substances in an isotropic network configuration.

From Fig. 1B, the base phase is found to include precipitation phases with different particle sizes, namely, the first and second phases.

Table 1

Test Specimen No.	Chemical Composition (% by mass)													50°C⇔250°C Thermal Fatigue Rupture Cycles (cycle)	Hardness (HV5Kg)	Fatigue Strength at 150°C (10^7 cycle strength) (MPa)
	Si	Cu	Mg	Fe	Mn	Ni	Ti	Zr	V	Sr	Sb	Na	Al			
1-1*	7.02	0.78	0.34	0.13	-	-	-	-	-	-	-	-	bal.	1419	98	49
1-2*	5.16	1.00	0.56	0.13	-	-	0.14	-	-	-	0.099	-	bal.	1754	105	53
1-3*	7.50	0.01>	0.30	0.40	0.30	1.00	0.20	0.10	0.05	-	-	-	bal.	4353	60	-
1-4*	7.39	1.56	0.25	0.40	0.30	1.01	0.23	0.10	0.02	-	-	-	bal.	2645	90	51

* comparative example

Table 2

Test Specimen No	Chemical Composition (% by mass)													50°C⇔250°C Thermal Fatigue Rupture Cycles (cycle)	Hardness (HV5Kg)	Fatigue Strength at 150°C (10^7 cycle strength) (MPa)	Porosity (%)
	Si	Cu	Mg	Fe	Mn	Ni	Ti	Zr	V	Sr	Sb	Na	Al				
2-1*	7.50	0.01>	0.30	0.40	0.30	1.00	0.20	0.10	0.05	-	-	-	bal.	4353	60	-	0.2>
2-2*	7.65	0.78	0.26	0.38	0.30	1.00	0.20	0.09	0.06	-	-	-	bal.	3590	74	44	0.2>
2-3*	7.39	1.56	0.25	0.40	0.30	1.01	0.23	0.10	0.02	-	-	-	bal.	2645	90	51	0.2>
2-4*	7.44	2.47	0.25	0.40	0.30	1.00	0.20	0.10	0.02	-	-	-	bal.	2400	102	52	0.2>
2-5*	7.51	3.40	0.23	0.40	0.30	1.00	0.21	0.10	0.02	-	-	-	bal.	2544	108	44	0.34

* comparative example

Table 3

Test Specimen No.	Chemical Composition (% by mass)													50°C⇔250°C Thermal Fatigue Rupture Cycles (cycle)	Hardness (HV5Kg)	Fatigue Strength at 150°C (10^7 cycle strength) (MPa)
	Si	Cu	Mg	Fe	Mn	Ni	Ti	Zr	V	Sr	Sb	Na	Al			
3-1	7.30	1.54	0.24	0.38	0.30	0.97	0.21	0.09	0.07	-	-	0.002	bal.	4300	87	51
3-2	7.56	1.59	0.33	0.40	0.30	1.02	0.19	0.10	0.06	0.048	-	-	bal.	3413	95	52
3-3	7.45	1.56	0.24	0.40	0.30	0.99	0.20	0.10	0.02	-	0.093	-	bal.	3751	89	51
2-3 (reference)	7.39	1.56	0.25	0.40	0.30	1.01	0.23	0.10	0.02	-	-	-	bal.	2645	90	51

Table 4

Test Specimen No.	Chemical Composition (% by mass)													Hardness (HV5Kg)
	Si	Cu	Mg	Fe	Mn	Ni	Ti	Zr	V	Sr	Sb	Na	Al	
4-1*	7.45	3.00	0.24	0.40	0.30	0.99	0.20	0.10	0.02	-	-	-	bal.	103
4-2*	7.45	3.00	0.60	0.40	0.30	1.00	0.20	0.10	0.02	-	-	-	bal.	111
4-3*	7.39	3.10	0.71	0.40	0.30	1.01	0.23	0.10	0.02	-	-	-	bal.	110
* comparative examples														

Claims

1. An aluminum alloy for casting, consisting of silicon(Si): 6-9%, copper(Cu): 1.0-2.5%, magnesium(Mg): 0.2-0.6%, nickel(Ni): 0.2-3%, iron(Fe): 0.1-0.7%, titanium(Ti): 0.1-0.3%, zirconium(Zr): 0.03-0.5%, manganese(Mn): 0.1-0.7%, vanadium(V): 0.01-0.5%, and one or more of strontium(Sr): 0.003-0.05%, antimony(Sb): 0.02-0.2%, and sodium (Na): 0.001-0.03%, wherein the total amount of Ti and Zr is less than 0.5%, the balance being aluminum(Al) and inevitable impurities, when the entirety is taken as 100% by mass.

2. An aluminum alloy casting,
   having the composition according to claim 1, and
   possessing a metallographic structure comprising
   a base phase mainly consisting of α-Al,
   a skeleton phase crystallized to surround said base phase in a network configuration, and
   a multi-phase precipitate having the first precipitation phase with particle sizes of 30-300nm and the second precipitation phase with particle sizes of 1-20nm, which are both crystallized in said base phase,
   wherein said skeleton phase is comprised of crystallized substances of compounds including Si, Ni or Fe,
   wherein said first precipitation phase is comprised of Ti compounds or Zr compounds and Cu compounds or Mg compounds, and
   said second precipitation phase is comprised of Cu compounds or Mg compounds, and
   wherein the size of secondary dendrites (DASII) is below 40 μm.

3. The aluminum alloy casting set forth in claim 2, wherein the porosity is below 0.3%.

4. The aluminum alloy casting set forth in claim 2 or 3, wherein the initial hardness in use of said base phase is higher than 80HV in Vickers hardness (HV) scale.

5. The aluminum alloy casting set forth in any one of claims 2 to 4, wherein said aluminum alloy casting is used for engine parts.

6. The aluminum alloy casting set forth in claim 5, wherein said engine part is a cylinder head of a reciprocating engine.

7. A method for producing the aluminum alloy casting set forth in any one of claims 2 to 6, comprising
   a casting process of pouring a molten aluminum alloy having the composition according to claim 1 into a casting die and solidifying said molten aluminum alloy, and
   a heat treatment process of making solution treatment and aging treatment of said aluminum alloy casting,
   wherein said solution treatment is comprised of a heating step, wherein in said heating step said casting is maintained at 450-550°C for 1 to 10 hours, and a subsequent rapid cooling step, and said rapid cooling step is made at a cooling rate of 20-200°C/min, and wherein in said aging treatment said casting is maintained at 140 to 300°C for 1 to 20 hours.

8. The method set forth in claim 7, wherein said rapid cooling step is a step made in a gas atmosphere for cooling said aluminum alloy casting after said heating step.

Patentansprüche

1. Aluminiumgusslegierung, bestehend aus Silizium (Si): 6 bis 9 %, Kupfer (Cu): 1,0 bis 2,5 %, Magnesium (Mg): 0,2 bis 0,6 %, Nickel (Ni): 0,2 bis 3 %, Eisen (Fe): 0,1 bis 0,7 %, Titan (Ti): 0,1 bis 0,3 %, Zirkonium (Zr): 0,03 bis 0,5 %, Mangan (Mn): 0,1 bis 0,7 %, Vanadium (V): 0,01 bis 0,5 % und einem oder mehreren von Strontium (Sr): 0,003 bis 0,05 %, Antimon (Sb): 0,02 bis 0,2 %, und Natrium (Na): 0,001 bis 0,03 %, wobei die Gesamtmenge von Ti und Zr weniger als 0,5 % beträgt, wobei der Rest Aluminium (Al) und unvermeidbare Verunreinigungen ist, wenn die Gesamtmenge als 100 Massenprozent angesetzt wird.

2. Aluminiumlegierungsgussteil,
   das die Zusammensetzung gemäß Anspruch 1 aufweist und eine metallographische Struktur aufweist, umfassend
   eine Basisphase, die vorwiegend aus α-Al besteht,
   eine Gerüstphase, die so kristallisiert ist, dass sie die Basisphase in einer Netzwerkkonfiguration umgibt, und
   eine Mehrphasen-Ausscheidung mit einer ersten Ausscheidungsphase mit Teilchengrößen von 30 bis 300 nm und einer zweiten Ausscheidungsphase mit Teilchengrößen von 1 bis 20 nm, die beide in der Basisphase kristallisiert sind,

wobei die Gerüstphase kristallisierte Substanzen von Verbindungen umfasst, die Si, Ni oder Fe enthalten,
wobei die erste Ausscheidungsphase Ti-Verbindungen oder Zr-Verbindungen und Cu-Verbindungen oder Mg-Verbindungen umfasst, und
wobei die zweite Ausscheidungsphase Cu-Verbindungen oder Mg-Verbindungen umfasst, und
wobei die Größe von Sekundärdendriten (DASII) unter 40 μm liegt.

3. Aluminiumlegierungsgussteil nach Anspruch 2, bei dem die Porosität unter 0,3 % liegt.

4. Aluminiumlegierungsgussteil nach Anspruch 2 oder 3, bei dem die anfängliche Härte der Basisphase im Gebrauch höher als 80 HV auf der Vickers-Härte (HV)-Skala ist.

5. Aluminiumlegierungsgussteil nach einem der Ansprüche 2 bis 4, wobei das Aluminiumlegierungsgussteil für Motorenbauteile verwendet wird.

6. Aluminiumlegierungsgussteil nach Anspruch 5, wobei das Motorenbauteil ein Zylinderkopf eines Kolbenmotors ist.

7. Verfahren zur Herstellung eines Aluminiumlegierungsgussteils nach einem der Ansprüche 2 bis 6, umfassend
einen Gießprozess des Gießens einer geschmolzenen Aluminiumlegierung mit der Zusammensetzung gemäß Anspruch 1 in eine Gussform und Verfestigen der geschmolzenen Aluminiumlegierung, und
einen Wärmebehandlungsprozess des Durchführens einer Lösungsbehandlung und einer Alterungsbehandlung des Aluminiumlegierungsgussteils,
wobei die Lösungsbehandlung einen Erwärmungsschritt, wobei das Gussteil in dem Erwärmungsschritt 1 bis 10 Stunden bei 450 bis 550 °C gehalten wird, und einen anschließenden Schritt eines schnellen Abkühlens umfasst, und der Schritt des schnellen Abkühlens bei einer Abkühlungsgeschwindigkeit von 20 bis 200 °C/min durchgeführt wird und wobei das Gussteil bei der Alterungsbehandlung 1 bis 20 Stunden bei 140 bis 300 °C gehalten wird.

8. Verfahren nach Anspruch 7, bei dem der Schritt des schnellen Abkühlens ein Schritt ist, der in einer Gasatmosphäre zum Kühlen des Aluminiumlegierungsgussteils nach dem Erwärmungsschritt durchgeführt wird.

Revendications

1. Alliage d'aluminium pour le moulage, comprenant les éléments suivants : silicium (Si) : 6 à 9%, cuivre (Cu) : 1,0 à 2,5 %, magnésium (Mg): 0,2 à 0,6 %, nickel (Ni) : 0,2 à 3 %, fer (Fe) : 0,1 à 0,7 %, titane (Ti) : 0,1 à 0,3 %, zirconium (Zr) : 0,03 à 0,5 %, manganèse (Mn) : 0,1 à 0,7 %, vanadium (V) : 0,01 à 0,5 %, et un ou plusieurs des éléments suivants : strontium (Sr) : 0,003 à 0,05 %, antimoine (Sb) : 0,02 à 0,2 % et sodium (Na) : 0,001 à 0,03 %, dans lequel la quantité totale des éléments Ti et Zr est inférieure à 0,5 %, le restant étant représenté par l'aluminium (Al) et les inévitables impuretés, en considérant que la totalité représente 100 % en masse.

2. Moulage d'un alliage d'aluminium,
ayant la composition selon la revendication 1, et présentant une structure métallographique comprenant
une phase de base principalement constituée de α-Al,
une phase de squelette cristallisée de manière à entourer ladite phase de base selon une configuration en réseau, et
un précipité multiphase dont la première phase de précipitation présente des tailles particulaires de 30 à 300 nm et dont la seconde phase de précipitation présente des tailles particulaires de 1 à 20 nm, toutes deux étant cristallisées au sein de ladite phase de base,
dans lequel ladite phase de squelette est constituée de substances cristallisées à base de composés comprenant les éléments Si, Ni ou Fe,
dans lequel ladite première phase de précipitation est constituée de composés de Ti ou de composés de Zr et de composés de Cu ou de composés de Mg, et
ladite seconde phase de précipitation est constituée de composés de Cu ou de composés de Mg, et
dans lequel la taille des dendrites secondaires (DASII) est inférieure à 40 μm.

3. Moulage d'un alliage d'aluminium selon la revendication 2, dans lequel la porosité est inférieure à 0,3 %.

4. Moulage d'un alliage d'aluminium selon la revendication 2 ou 3, dans lequel la dureté initiale à l'utilisation de ladite phase de base est supérieure à 80 HV selon l'échelle de dureté de Vickers (HV).

5. Moulage d'un alliage d'aluminium selon l'une quelconque des revendications 2 à 4, dans lequel ledit moulage d'alliage d'aluminium est utilisé pour des pièces de moteur.

6. Moulage d'un alliage d'aluminium selon la revendication 5, dans lequel ladite pièce de moteur est une tête de cylindre d'un moteur à mouvement alternatif.

7. Procédé pour produire le moulage d'alliage d'aluminium selon l'une quelconque des revendications 2 à 6, comprenant un procédé de moulage consistant à verser un alliage d'aluminium fondu ayant la composition selon la revendication 1 dans une filière de moulage et à solidifier ledit alliage d'aluminium fondu, et
un procédé de traitement à chaud consistant en un traitement de mise en solution et en un traitement de vieillissement dudit moulage d'alliage d'aluminium,
dans lequel ledit traitement de mise en solution est constitué d'une étape de chauffage où, dans ladite étape de chauffage, ledit moulage est maintenu à une température de 450 à 550°C pendant 1 à 10 heures, et d'une étape suivante de refroidissement rapide, et ladite étape de refroidissement rapide est conduite à une vitesse de refroidissement de 20 à 200°C/min et dans lequel, dans ledit traitement de vieillissement, ledit moulage est maintenu à une température de 140 à 300°C pendant 1 à 20 heures.

8. Procédé selon la revendication 7, dans lequel ladite étape de refroidissement rapide est une étape effectuée dans une atmosphère gazeuse pour refroidir ledit moulage d'alliage d'aluminium après ladite étape de chauffage.

Fig. 1A

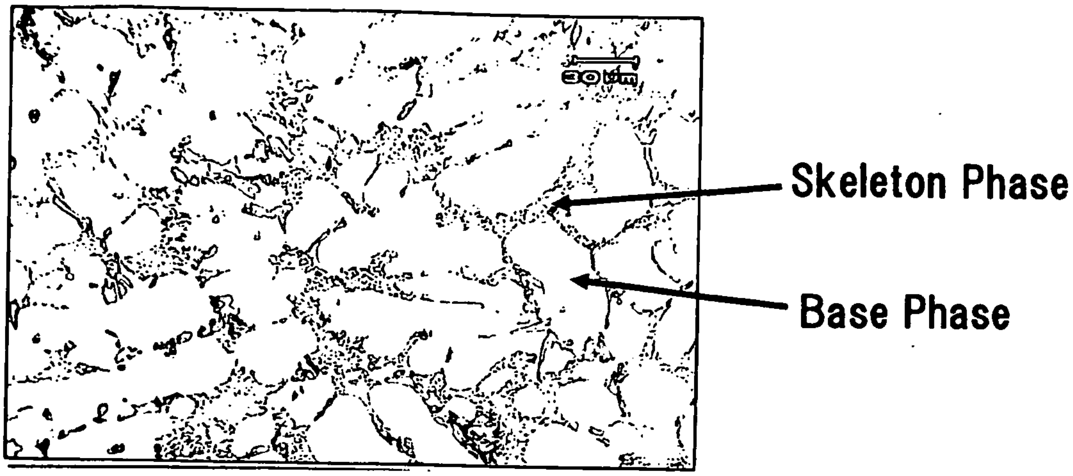
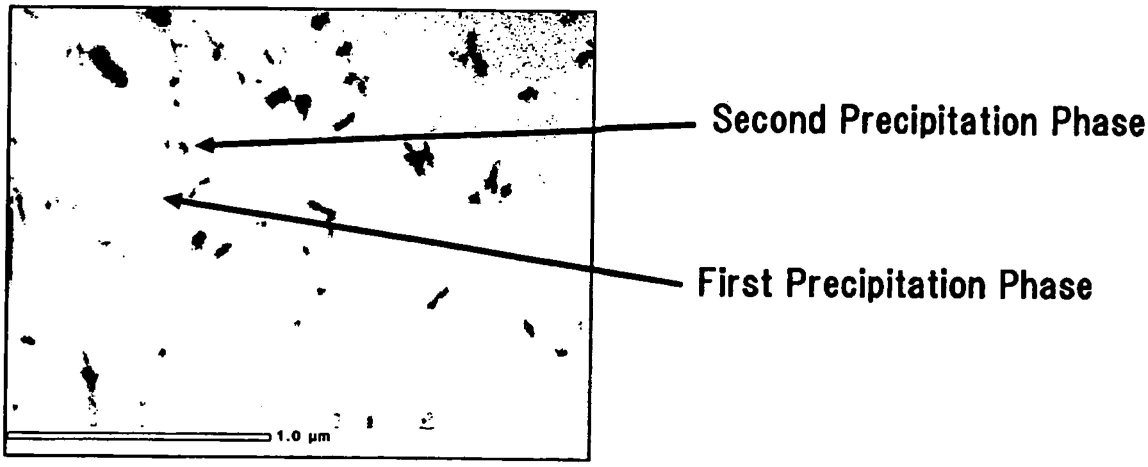

30µm
Skeleton Phase
Base Phase

Fig. 1B


Second Precipitation Phase
First Precipitation Phase
1.0 µm

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