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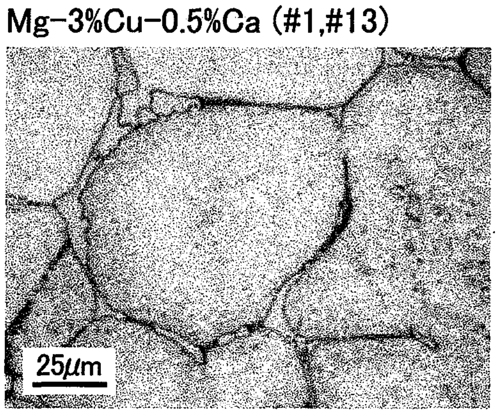
(54) CASTING MAGNESIUM ALLOY AND PROCESS FOR PRODUCTION OF CAST MAGNESIUM ALLOY

(57) Amagnesiumalloy for casting according to the present invention is **characterized in that**, when the entirety is taken as 100% by mass, it includes copper (Cu) in an amount of from 0.5% by mass or more to 10% by mass or less, calcium (Ca) in an amount of from 0.01% by mass or more to 3% by mass or less, and the balance comprising magnesium (Mg) and inevitable impurities.

Since the magnesium alloy for casting according to the present invention includes Cu whose heat conductivity is high in a predetermined amount, it is good in terms of heat-conducive ability. The heat-conductive ability is improved by carrying out heat treatment. Moreover, in the magnesium alloy for casting according to the present invention being in as-cast state, grain-boundary crystallized substances including Cu and Ca constitute three-dimensional networks in grain boundaries between Mg crystalline grains. In the network-shaped grain-boundary crystallized substances, grain-boundary sliding, which becomes active when they become high temperature, is suppressed, and thereby high-temperature strength and creep resistance improve.

Fig.4B


Mg-3%Cu-0.5%Ca (#1,#13)

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Description

TECHNICAL FIELD

[0001] The present invention is one which relates to a magnesium alloy for casing, magnesium alloy which is suitable for service under high temperature.

BACKGROUND ART

[0002] Magnesium alloy, which is much lightweight than aluminum alloy is, is about to come to be used widely for aircraft material, vehicle material, and the like, from the viewpoint of weight saving. However, in magnesium alloy, since the strength and heat resistance are not sufficient depending on applications, further improvement of the characteristics has been sought.

[0003] For example, in Japanese Unexamined Patent Publication (KOKAI) Gazette No. 2005-54,233, a magnesium alloy that possesses heat resistance is disclosed. Concretely speaking, it is a magnesium alloy that includes aluminum (Al) in an amount of 4-9% by mass, copper (Cu) in an amount of 1-5% by mass, zinc (Zn) in an amount of 4% by mass or less, and beryllium (Be) in an amount of 0.001-0.01% by mass, and that is provided with a metallic structure in which Mg-Al-Cu system compounds are scattered in the mother-phase Mg.

[0004] Moreover, as a general magnesium alloy, AZ91D (ASTM code) is present, for instance. Although AZ91D is good in terms of the mechanical characteristics and castability, the heat conductivity of AZ91D is 73 W/mK approximately and is extremely low compared with the heat conductivity of pure magnesium (167 W/mK). Accordingly, when AZ91D is used in member whose service environment is high temperature, or in member that generates heat in service, the radiation of heat cannot be carried out satisfactorily, and thereby thermal deformation might occur in the member. In particular, when a magnesium alloy whose heat conductivity is low is used as a magnesium alloy that is used in a cylinder head or cylinder block of internal-combustion engine, the cylinder head undergoes thermal deformation, or heat dwells within the cylinder block so that the thermal deformation of cylinder bores augments, and thereby adverse affects, such as increased friction and declined airtightness, occur. Consequently, a magnesium alloy has been sought, magnesium alloy in which the radiation of heat is carried out satisfactorily by possessing a high heat conductivity, and magnesium alloy which is thereby suitable for usage under high temperature.

DISCLOSURE OF THE INVENTION

[0005] In view of the aforementioned problematic issues, it is an object for the present invention to provide a magnesium alloy for casting, magnesium alloy which is suitable for usage under high temperature. Moreover, it is an object to provide a productionmethod of cast product, which comprises that magnesium alloy for casting.

[0006] As a result of wholehearted studies, the present inventors found out that it is possible to improve the heat-conductive ability of magnesium alloy by letting it contain copper whose heat conductivity is high in an adequate amount along with calcium, and then arrived at completing the present invention based on this.

[0007] Specifically, a magnesium alloy for casting according to the present invention is **characterized in that**, when the entirety is taken as 100% by mass, it includes: copper (Cu) in an amount of from 0.5% by mass or more to 10% by mass or less; calcium (Ca) in an amount of from 0.01% by mass or more to 3% by mass or less; and the balance comprising magnesium (Mg) and inevitable impurities. In this instance, it is preferable that the copper (Cu) can be from 1% by mass or more to 5% by mass or less.

[0008] In an as-cast state (hereinafter being abbreviated to as an "as-cast material"), the magnesium alloy for casting according to the present invention that includes Cu and Ca possesses a metallic structure that is constituted of Mg crystalline grains including Mg, and grain-boundary crystallized substances including Cu and Ca and being crystallized as three-dimensional network shapes (three-dimensionally mesh constructions) in grain boundaries between the Mg crystalline grains. By means of the grain-boundary crystallized substances that take on three-dimensionally mesh constructions, grain-boundary sliding, which becomes active especially when becoming high temperature, is suppressed, and thereby high-temperature strength and creep resistance at high temperature improve. And, it was understood newly that, in the magnesium alloy for casting according to the present invention, the heat conduction between the Mg crystalline grains is less likely to be hindered even when the grain-boundary crystallized substances are crystallized as network shapes by letting the present magnesium alloy contain copper whose heat conductivity is high in a predetermined amount as an alloying element.

[0009] Moreover, in a heat-treated state in which the aforementioned as-cast material is treated with heat (hereinafter being abbreviated to as a "heat-treated material"), the magnesium alloy for casting according to the present invention has a metallic structure that is constituted of Mg crystalline grains including Mg, and granular compounds including Cu and being dispersed as granular shapes in grain boundaries between the Mg crystalline grains. The grain-boundary crystallized substances that are crystallized as network shapes in the grain boundaries between the Mg crystalline grains in the as-cast material are dispersed granularly in the grain boundaries between the Mg crystalline grains by means of heat treatment. Consequently, the contact areas between the Mg crystalline grains in the grain boundaries augment, and thereby heat conductivity improves. Moreover, even being a heat-treated material, the high-temperature strength and creep resistance at high temperature are less likely to lower when it contains Cu and Ca in the aforementioned predetermined ranges.

[0010] Moreover, it is preferable that the magnesium alloy for casting according to the present invention can include aluminum (Al) in an amount of 10% by mass or less, or further 3% by mass or less. In the magnesium alloy for casting according to the present invention, the mechanical strengths of the magnesium alloy at room temperature and high temperature are improved by further including Al.

[0011] Moreover, it is even allowable that the magnesium alloy for casting according to the present invention can further include manganese (Mn) in an amount of 1% by mass or less. In the magnesium alloy for casting according to the present invention, the creep resistance, the corrosion resistance, the castability, and the like, are improved by including Mn, in addition to the mechanical strengths at room temperature and high temperature.

[0012] Moreover, a production method of magnesium-alloy cast product according to the present invention is a process for producing cast product comprising the magnesium alloy for casting according to the present invention. The production method of magnesium-alloy cast product according to the present invention is **characterized in that** it includes:

> a molten-metal pouring step of pouring an alloy molten metal into a casting mold, the alloy molten metal including: copper (Cu) in an amount of from 0.5% by mass or more to 10% by mass or less; calcium (Ca) in an amount of from 0.01% by mass or more to 3% by mass or less; and the balance comprising manganese (Mg) and inevitable impurities; when the entirety is taken as 100% by mass; and
> a solidifying step of solidifying the alloy molten metal after the molten-metal pouring step by cooling it.

[0013] It is even allowable that the production method of magnesium-alloy cast product according to the present invention can include, after said solidifying step, a heat-treating step of granulating crystallized substances including Cu in grain boundaries between Mg crystalline grains including Mg.

[0014] Hereinafter, "% by mass" might be abbreviated to "%" simply (however, [%], the units of "0.2% proof stress" and "elongation," does not mean "% by mass"). Note that any one of the respective alloying elements' contents is their proportions when the entire magnesium alloy for casting is taken as 100% by mass.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] Fig. 1 is a graph for illustrating the changes of heat conductivities with respect to Al contents in magnesium alloys that include Cu and Ca at least.

[0016] Fig. 2 is a graph for illustrating the changes of heat conductivities with respect to Al/Cu values (mass ratio) in magnesium alloys that include Cu and Ca at least.

[0017] Fig. 3 is a graph for illustrating the changes of tensile strengths and elongations with respect to Ca contents in magnesium alloys that include Cu and Ca at least.

[0018] Fig. 4A and Fig. 4B are photographs for substituting for drawings that show the metallic structure of Mg-3%Cu-0.5%Ca alloy, and are a photograph (A) with low magnification and a photograph (B) with high magnification, respectively.

[0019] Fig. 5A and Fig. 5B are photographs for substituting for drawings that show the metallic structure of Mg-3%Cu-0.2%Ca-3%Al alloy, and are a photograph (A) with lowmagnification and a photograph (B) with high magnification, respectively.

[0020] Fig. 6A and Fig. 6B are photographs for substituting for drawings that show the metallic structure of Mg-3%Cu-3%Ca-3%Al-0.5%Mn alloy, and are a photograph (A) with low magnification and a photograph (B) with high magnification, respectively.

[0021] Fig. 7 is a graph for illustrating the change of tensile strengths with respect to Ca contents in magnesium alloys that include Cu and Ca at least.

[0022] Fig. 8 is a graph for illustrating the change of elongations with respect to Ca contents in magnesium alloys that include Cu and Ca at least.

[0023] Fig. 9 is a graph for illustrating the change of heat conductivities with respect to Al contents in magnesium alloys that include Cu and Ca at least.

[0024] Fig. 10 is a graph for illustrating the changes of stress lowering magnitudes with respect to Al contents in magnesium alloys that include 3% Cu and 1% Ca.

[0025] Fig. 11A through Fig. 11D are photographs for substituting for drawings that show the metallic structure of magnesium alloys including 3% Cu and 1% Ca, and show the metallic structures of magnesium alloys that further include Al in an amount of 0.5% (A), 2% (B), 4% (C) and 8% (D), respectively.

[0026] Fig. 12 shows the analyzed results on Mg-3%Cu-1%Ca-1%Al alloy by means of electron-beam microanalysis (EPMA).

[0027] Fig. 13 is a graph for illustrating the changes of tensile strengths, 0.2% proof stresses and elongations with respect to Cu contents in magnesium alloys (as-cast materials) that include 1% Ca, 1% Al and 0.5% Mn.

[0028] Fig. 14 is a graph for illustrating the changes of tensile strengths, 0.2% proof stresses and elongations with respect to Cu contents in magnesium alloys (heat-treated materials) that include 1% Ca, 1% Al and 0.5% Mn.

[0029] Fig. 15 is a graph for illustrating the changes of stress lowering magnitudes with respect to Cu contents in magnesium alloys that include 1% Ca, 1% Al and 0.5% Mn.

[0030] Fig. 16 is a graph for illustrating the changes of tensile strengths with respect to Mn contents in magnesium alloys that include 3% Cu,1% Ca and 1% Al.

[0031] Fig. 17 is a graph for illustrating the changes of stress lowering magnitudes with respect to Mn contents in magnesium alloys that include 3% Cu,1% Ca and 1% Al.

[0032] Fig. 18A and Fig. 18B are photographs for substituting for drawings that show the metallic structure of Mg-3%Cu-1%Ca alloy, and are a photograph (A) with low magnification and a photograph (B) with high magnification.

[0033] Fig. 19 shows the analyzed results on Mg-3%Cu-1%Ca alloy by means of EPMA.

[0034] Fig. 20 is a photograph for substituting for a drawing that shows the metallic structure of heat-treated Mg-3%Cu-1%Ca alloy.

[0035] Fig. 21 shows the analyzed results on heat-treated Mg-3%Cu-1%Ca alloy by means of EPMA.

Best Mode for Carrying Out the Invention

[0036] Hereinafter, the best mode for carrying out the magnesium alloy for casting according to the present invention and the production method of magnesium-alloy cast product according to the present invention will be explained.

[0037] The magnesium alloy for casting according to the present invention is **characterized in that** it includes copper (Cu), calcium (Ca), and the balance comprising magnesium (Mg) and inevitable impurities.

[0038] In an as-cast material of the magnesium alloy for casting according to the present invention that includes Cu and Ca, at least Cu and Ca crystallize in crystalline grain boundaries, and thereby a network-shaped metallic structure (three-dimensional mesh construction) is formed. Note that, as a general magnesium alloy, although there has been a magnesium alloy to which a rare-earth element, or the like, is added for the improvement of heat resistance, the three-dimensional mesh construction is less likely to be formed in suchamagnesiumalloy. Therefore, it is desirable that the magnesium alloy for casting according to the present invention cannot include any rare-earth element virtually.

[0039] It is preferable that, when the entire magnesium alloy for casting is taken as 100% by mass, the content of Cu can be 0.5% by mass or more, or further 1% by mass or more; and it is preferable that it can be 10% by mass or less, or further 5% by mass or less, or 4% by mass or less. When the content of Cu is less than 0.5% by mass, the improvement effect of heat conductivity that results from adding Cu cannot be obtained satisfactorily. Although heat is likely to flow when Cu is abundant, when it surpasses 10% by mass, no greater improvement of heat conductivity can be expected, and accordingly that is not economical. Moreover, that is not preferable because creep resistance at high temperature lowers.

[0040] Note that, in Cu and Cu compounds, their coefficients of thermal expansion are low. Consequently, the magnesium alloy for casting according to the present invention exhibits a low coefficient of thermal expansion.

[0041] The magnesium alloy for casting according to the present invention includes Ca along with Cu. Ca also crystallizes in crystalline grain boundaries along with Cu, and thereby it also contributes to the formation of three-dimensional mesh construction. For example, Mg-Ca system compounds crystallize along with Mg-Cu system compounds, and thereby a more complete three-dimensional mesh construction in which discontinuous sections are present less is formed. Moreover, Ca possesses an anti-inflammation effect. When Ca is added to magnesium alloy, since the ignition temperature of the magnesium alloy rises, the combustion that might occur when turning magnesium alloy into molten metal is prevented. It has been known that, in the magnesium alloy (AZ91) that includes Ca in an amount of 0.5% by mass, the ignition temperature is high by about 300 °C, compared with that of AZ91 that does not include Ca. Consequently, in the magnesium alloy for casting according to the present invention as well, it is preferable that, when the entire magnesium alloy for casting is taken as 100% by mass, the content of Ca can be from 0.01% by mass or more to 3% by mass or less, or further from 0.5% by mass or more to 2% by mass or less. Although it is allowable that Ca can be added to the magnesium alloy even in a small amount, the mechanical properties, such as the tensile strength and elongation, have lowered when it surpasses 3% by mass.

[0042] Moreover, it is believed that intermetallic compounds, such as the Mg-Cu compounds and the Mg-Ca compounds, which crystallize as network shapes in crystalline grain boundaries in the magnesium alloy for casting according to the present invention, suppress the grain-boundary sliding within the magnesium alloy. Consequently, it seems that the magnesium alloy for casting according to the present invention demonstrates such good creep resistance that creep deformations, and the like, are less even in high-temperature regions.

[0043] It is allowable that themagnesiumalloy for casting according to the present invention can further include aluminum (Al). In the magnesium alloy for casting according to the present invention to which Al is added, since Mg-Al-Cu system compounds andMg-Al-Ca system compounds crystallize in crystalline grain boundaries, the mechanical properties, such as the tensile strength and elongation, improve. Meanwhile, the addition of Al might bring about the decline of heat conductivity. Consequently, it is preferable that, when the entire magnesium alloy for casting is taken as 100% by mass, the content of Al canbe 10% by mass or less; and further it is preferable that it can be 4% by mass or less, or 3% by mass or less; depending on applications, it is desirable that it cannot rather include Al. In the case where mechanical strength is needed along with high heat conductivity, it is allowable to set the Al content when the entire magnesium alloy for casting according to the present invention is taken as 100% by mass at 0.5% by mass at least.

[0044] Moreover, it is preferable that the content of Al can exhibit a mass ratio to Cu (Al/Cu) of being 1 or less. When it is 1 or less, high heat conductivity and high mechanical strength are compatible with each other.

[0045] Moreover, it is allowable that, when the entire magnesium alloy for casting is taken as 100% by mass, the magnesium alloy for casting according to the present invention can further include manganese (Mn) in an amount of 1% by mass or less. Mn is an element that solves into the base material of magnesium alloy to solution harden the magnesium alloy. In addition, Mn also produces an effect of removing Fe, one of impurities that become a cause of corrosion, by sedimentation. That is, in the magnesium alloy according to the present invention to which Mn is added, the corrosion resistance improves along with the mechanical strength. However, such effects are subtle when Mn is too less; but, even when it surpasses 1% by mass, no improvement of the effects can be expected, and accordingly that is not economical. Therefore, a preferable Mn content can be 0.1% by mass or more, or 0.2% by mass or more, or further 0.3% by mass or more; and moreover it can be 1% by mass or less, or 0.8% by mass or less, or further 0.7% by mass or less.

[0046] Moreover, it is allowable that, when the entire magnesium alloy for casting is taken as 100% by mass, the magnesium alloy for casting according to the present invention can further include strontium (Sr) in an amount of 1% by mass or less. The magnesium alloy according to the present invention to which Sr is added produces an effect of improving corrosion resistance in magnesium alloy including Ca. Consequently, Sr is suitable as an alloying element for improving the corrosion resistance of the magnesium alloy for casting according to the present invention. In addition, Sr improves the castability (molten-metal flowability, and the like) of magnesium alloy. A preferable Sr content can be from 0.01% by mass or more to 1% by mass or less, or further from 0.1% by mass or more to 1% by mass or less.

[0047] Moreover, it is allowable that, when the entire magnesium alloy for casting is taken as 100% by mass, the magnesium alloy for casting according to the present invention can further include barium (Ba) in an amount of 1% by mass or less. In the magnesium alloy according to the present invention to which Ba is added, the castability improves. A preferable Ba content can be from 0.01% by mass or more to 1% by mass or less, or further from 0.1% by mass or more to 1% by mass or less.

[0048] Note that the alloying elements, such as Mn, Sr and Ba, do not impair the network-shaped metallic structure of the magnesium alloy for casting according to the present invention even when they are added to it.

[0049] When the magnesium alloy for casting according to the present invention makes an as-cast material, although it has a metallic structure that is constituted of Mg crystalline grains including Mg, and grain-boundary crystallized substances including Cu and Ca and being crystallized as three-dimensional network shapes in grain boundaries between the Mg crystalline grains, granular compounds including Cu, for example, Mg-Cu system compounds, are dispersed in the grain boundaries between the Mg crystalline grains including Mg by carrying out heat treatment. That is, it is allowable that the magnesium alloy for casting according to the present invention can have a metallic structure that is constituted of Mg crystalline grains including Mg, and granular compounds including Cu and being dispersed as granular shapes in grain boundaries between the Mg crystalline grains. It has been known that performing an appropriate heat treatment to magnesium alloy improves the mechanical characteristics. In the magnesium alloy for casting according to the present invention that possesses the aforementioned composition, the heat conductivity is improved by granulating Cu compounds by means of heat treatment. Moreover, when the contents of the additive elements, such as Cu and Ca, fall in the aforementioned ranges, the decline of creep resistance after heat treatment is suppressed.

[0050] Beginning with the fields of space, military and aviation, the magnesium alloy for casting according to the present invention being explained as above can be used in various fields, such as automobiles and electric instruments. Moreover, as a member comprising the magnesium alloy for casting according to the present invention, the following can be given, taking advantage of its characteristics at high temperature: products being utilized in high-temperature environments, for example, component parts constituting compressor, pumps and various cases that become high temperatures in service; moreover, engine component parts being used under high temperature and high load, especially, cylinder heads, cylinder blocks and oil pans of internal-combustion engine, impellers for turbocharger of internal-combustion engine, transmission cases being used for automobile and the like, and so forth.

[0051] Moreover, the production method of magnesium-alloy cast product according to the present invention is a production method of cast product comprising the magnesium alloy for casting according to the present invention that has been described in detail as above. The production method of magnesium-alloy cast product according to the present invention includes a molten-metal pouring step, and a solidifying step. The molten-metal pouring step is a step of pouring an alloy molten metal into a casting mold, the alloy molten metal including: copper (Cu) in an amount of from 0.5% by mass or more to 10% by mass or less; calcium (Ca) in an amount of from 0.01% by mass or more to 3% by mass or less; and the balance comprising manganese (Mg) and inevitable impurities; when the entirety is taken as 100% by mass. The solidifying step is a step of solidifying the alloy molten metal after the molten-metal pouring step by cooling it.

[0052] The magnesium-alloy cast product is not limited to those made by ordinary gravity casting and pressure casting, but can even be those made by die-cast casting. Moreover, even the casting mold being utilized for the casting does not matter if it is sand molds, metallic molds, and the like. Since even the solidification rate (cooling rate) in the solidifying step is not limited in particular, it is allowable to properly select such an extent of solidification rate, which permits to form the three-dimensional mesh construction, depending on the size of ingots. Note that, when it is solidified at a usual solidification rate, the metallic structure possessing the three-dimensional mesh construction is obtainable.

[0053] Moreover, it is even allowable that the production method of magnesium-alloy cast product according to the present invention can include, after the solidifying step, a heat-treating step of dispersing granular compounds including Cu in grain boundaries between Mg crystalline grains including Mg. In the heat-treating step, it is allowable to carry out a tempering treatment after quenching (or high-temperature working), tempering treatment which is specified by the thermal-refining code "T5" or "T6" that is used in the JIS standard. For example, it is allowable to subject an as-cast member being made of the magnesium alloy for casting according to the present invention to an age-hardening treatment at a temperature of 100-300 °C after subjecting it to a solution treatment at a temperature of from 400 °C or more to a eutectic temperature or less. More desirably, it is allowable to carry out the solution treatment at a temperature of 400-550 °C, or further at a temperature of 410-510 °C; and then to carry out the age-hardening treatment at a temperature of 150-250 °C. Moreover, it is allowable that the solution treatment can be carried out while holding it at the high temperature for 5-24 hours, or further for 5-10 hours. In addition, in the solution treatment, although it is cooled to a low temperature after it has been held at the high temperature, it is allowable that the cooling can be either air cooling or water cooling; or it is desirable to quench it by means of water cooling. Note that it is allowable to select an optimum temperature, time and cooling rate for the heat treatment by means of usual methods that have been carried out heretofore.

[0054] So far, the embodiment modes of the magnesium alloy for casting and production method of magnesium-alloy cast product according to the present invention have been explained, however, the present invention is not one which is limited to the aforementioned embodiment modes. It can be conducted in various modes to which modifications, improvements, and the like, which one of ordinary skill in the art can carry out, are performed, within a range not departing from the scope of the present invention.

[0055] Hereinafter, while giving examples of the magnesium alloy for casting and production method of magnesium-alloy cast product according to the present invention, the present invention will be explained in detail.

[0056] Test specimens whose contents of alloying elements in magnesium alloys were varied were made in a quantity of plural pieces, and then the evaluation of the characteristics and the observation of the metallic structures, and so forth, were carried out.

[0057] [Making of Test Specimens #1-#10]

[0058] A chloride-system flux was coated onto the inner surface of a crucible being made of iron that had been preheated within an electric furnace, and then a weighed pure magnesium base metal, pure Cu, and pure Al, if needed, were charged into it and were then melted. Further, weighed Ca was added into this molten metal that was held at 750 °C (a molten-metal preparing step).

[0059] After fully stirring this molten metal to melt the raw materials completely, it was held calmly at the same temperature for a while. The thus obtained alloy molten metal was poured into a metallic mold with a predetermined configuration (a molten-metal pouring step), and was then solidified in air atmosphere (a solidifying step), thereby casting test specimens (magnesium-alloy cast products) being labeled #1-#10. Note that the obtained test specimens had a size of 30 mm × 30 mm × 200 mm. The alloy compositions of the respective test specimens were specified in Table 1. Note that "Alloy Composition I" is the proportions of the respective components, which were weighed at the molten-metal preparing step, when the raw materials were taken as 100% as a whole; and that "Alloy Composition II" is the alloy compositions of the respective test specimens that were analyzed by means of fluorescent X-ray analysis; and that the balance is Mg.

[0060] [Measurements of Heat Conductivity and Mechanical Strength]

[0061] Regarding the test specimens being labeled #1-#10, the heat conductivities were found by means of laser flash method. Moreover, the tensile test by means of JIS Z 2241 (testing temperature: 25 °C) was carried out, thereby finding the tensile strengths and elongations. The test results are specified in Table 1 all together. In addition, a graph that exhibits the changes of the heat conductivities with respect to the Al contents is illustrated in Fig. 1; a graph that exhibits the changes of the heat conductivities with respect to the Al/Cu values (mass ratio) is illustrated in Fig. 2; and a graph that exhibits the changes of the tensile strengths and elongations with respect to the Ca contents is illustrated in Fig. 3, respectively.

[0062]

[TABLE 1]

Test Specimen	Alloy Composition I [%]*			Alloy Composition II (Analyzed Value) [%]*			Al/Cu	Heat Conductivity [W/mK]	Tensile Strength [MPa]	Elongation [%]
	Cu	Ca	Al	Cu	Ca	Al				
#1	3	0.5		2.9	0.34	0.0	0.0	154	113.71	3.84
#2	3	1	1	2.9	0.85	0.8	0.3	138	125.36	2.47
#3	3	1	2	2.9	0.82	1.8	0.6	123	121.19	2.53
#4	3	1	3	2.9	0.74	3.0	1.0	105	120.00	3.32
#5	3	1	4	2.7	0.75	4.1	1.5	90	135.28	3.26
#6	3	1	5	2.7	0.72	5.4	2.0	80	-	-
#7	3	1	7	2.7	0.61	8.3	3.1	62	132.11	1.61
#8	3	2	3	2.7	1.50	2.7	1.0	110	94.30	1.23
#9	5	1		4.2	0.78	0.0	0.0	151	103.40	1.81
#10	3	0.2	3	2.9	0.13	2.7	0.9	104	161.64	7.18
*: The balance is Mg.										

[0063] From Fig. 1, it was understood that the heat conductivity lowers when the Al content increases. In particular, the magnesium alloys whose Al content was 3% by mass or less exhibited a high heat conductivity (100 W/mK or more). Moreover, from Fig. 2, it was understood that the smaller the Al/Cu value is the larger the heat conductivity becomes. In particular, in the case where the Cu content was equal to the Al content, or in the case where it surpassed the Al content, the magnesium alloys exhibited a high conductivity (100 W/mK or more).

[0064] Ca contributes to the formation of the three-dimensional mesh structure in magnesium alloy; however, from Fig. 3, it was understood that the greater the Ca content becomes the more the mechanical characteristics tend to lower.

[0065] [Observation of Metallic Structure]

[0066] Three types of test specimens for observing metallic structure were made in the same manner as the aforementioned procedures. Each "Alloy Composition I" was set at Mg-3%Cu-0.5%Ca (equivalent to #1), Mg-3%Cu-0.2%Ca-3%Al (equivalent to #10), and Mg-3%Cu-3%Ca-3%Al-0.5%Mn (the units, "%," were all "% by mass").

[0067] The observation of the metallic structures was carried out by observing cross sections, which were cut out of the respective test specimens, with a metallographic microscope. The metallic structures are shown in Fig. 4A-Fig. 6B. In any one of the test specimens, the three-dimensional mesh construction was confirmed, three-dimensional mesh construction which comprised intermetallic compounds that crystallized in crystalline grain boundaries. Therefore, it was understood that a magnesium alloy including Cu and Ca at least possesses the three-dimensional mesh construction. Note that it is believed that the compounds that crystallized in crystalline grain boundaries were Mg-Cu system compounds and Mg-Ca system compounds in Figs. 4A and B; that they were Mg-Al-Cu system compounds and Mg-Ca system compounds in Figs. 5A and B; and that they were Mg-Al-Cu system compounds and Mg-Ca system compounds in Figs. 6A and B.

[0068] [Making of Test Specimens #11-#35]

[0069] A chloride-system flux was coated onto the inner surface of a crucible being made of iron that had been preheated within an electric furnace, and then a weighed pure magnesium base metal, pure Cu, and pure Al and an Al-Mn alloy, if needed, were charged into it and were then melted. Further, weighed Ca was added into this molten metal that was held at 750 °C (a molten-metal preparing step).

[0070] After fully stirring this molten metal to melt the raw materials completely, it was held calmly at the same temperature for a while. The thus obtained alloy molten metal was poured into a metallic mold with a predetermined configuration (a molten-metal pouring step), and was then solidified in air atmosphere (a solidifying step), thereby casting test specimens (magnesium-alloy cast products) being labeled #11-#35. Note that the obtained test specimens had a size of 30 mm × 30 mm × 200 mm. The alloy compositions of the respective test specimens were specified in Table 2. Note that "Alloy Composition I" is the proportions of the respective components, which were weighed at the molten-metal preparing step, when the raw materials were taken as 100% as a whole; and that "Alloy Composition II" is the alloy compositions of the respective test specimens that were analyzed by means of fluorescent X-ray analysis; and that the balance is Mg.

[0071] Note that #13, #16-#21 and #32 are the same test specimens as those of #1, #2-7 and #9, respectively (see the remarks column in Table 2).

[0072] [Measurements of Heat Conductivity and Mechanical Strength]

[0073] Regarding the test specimens being labeled #11-#35, the heat conductivities were found by means of laser flash method. Moreover, the tensile test by means of JIS Z 2241 (testing temperature: 25 °C) was carried out, thereby finding the tensile strengths, elongations and 0.2% proof stresses. The test results are specified in Table 2 all together (with regard to the 0.2% proof stresses, see Table 3). In addition, a graph that exhibits the change of the tensile strengths with respect to the Ca contents is illustrated in Fig. 7; a graph that exhibits the change of the elongations with respect to the Ca contents is illustrated in Fig. 8; and a graph that exhibits the change of the heat conductivities with respect to the Al contents is illustrated in Fig. 9, respectively.

[0074]

[TABLE 2]

Test Specimen	Alloy Composition I [%]*				Alloy Composition II {%}*				Al/Cu	Heat Conductivity [W/mK]	Tensile Strength [MPa]	Elongation [%]	Remarks
	Cu	Ca	Al	Mn	Cu	Ca	Al	Mn					
#11	1	1			0.88	0.69	0.00	0.00	0.0	158	90	2.3	
#12	2	1	0.5		1.90	0.70	0.54	0.00	0.3	146	120	2.6	
#13	3	0.5			2.90	0.34	0.00	0.00	0.0	154	114	3.8	#1
#14	3	1			2.80	0.51	0.00	0.00	0.0	155	129	3.9	
#15	3	1	0.5		2.80	0.62	0.54	0.00	0.2	145	112	2.0	
#16	3	1	1		2.90	0.85	0.78	0.00	0.3	138	125	2.5	#2
#17	3	1	2		2.90	0.82	1.80	0.00	0.6	123	121	2.5	#3
#18	3	1	3		2.90	0.74	3.00	0.00	1.0	105	120	3.3	#4
#19	3	1	4		2.70	0.75	4.10	0.00	1.5	90	135	3. 3	#5
#20	3	1	5		2.70	0.72	5.40	0.00	2.0	80	114	1. 5	#6
#21	3	1	7		2.70	0.61	8.30	0.00	3.1	62	132	1.6	#7
#22	3	1	0.335	1	2.90	0.85	0.20	0.52	0.1	136	98	1.5	
#23	3	1	0.5	1.5	2.90	0.69	0.52	1.10	0.2	130	121	2.1	
#24	3	1	1	0.2	3.30	0.78	0.89	0.19	0.3	136	137	3.3	
#25	3	1	1	0.5	3.23	0.82	0.93	0.51	0.3	135	131	2.2	
#26	3	1	1	0.8	3.27	0.86	0.93	0.67	0.3	132	142	2.9	
#27	3	1	1	3	2.90	0.82	0.97	1.20	0.3	130	114	1.8	
#28	3	2			2.80	1.80	0.00	0.00	0.0	154	93	0.9	
#29	3	2	1		2.99	2.14	0.98	0.00	0.3	134	96	0.8	
#30	3	2	1	0.2	3.14	1.87	0.99	0.19	0.3	134	99	0.7	
#31	3	2	1	0.5	3.21	2.14	0.98	0.45	0.3	131	113	0.9	
#32	5	1			4.20	0.78	0.00	0.00	0.0	151	103	1.8	#9
#33	1	1	1	0.5	1.21	0.74	1.20	0.38	1.0	128	128	3.7	
#34	5	1	1	0.5	5.16	0.84	0.85	0.40	0.2	132	128	2.0	

(continued)

Test Specimen	Alloy Composition I [%]*				Alloy Composition II {%}*				Al/Cu	Heat Conductivity [W/mK]	Tensile Strength [MPa]	Elongation [%]	Remarks
	Cu	Ca	Al	Mn	Cu	Ca	Al	Mn					
#35	10	1	1	0.5	9.42	0.53	0.81	0.30	0.1	133	143	1.8	

[0075] Test Specimens #11, #14 and #32 were magnesium alloys that included Ca in an amount of 1%, but whose Cu contents differed one another. Test Specimens #25 and #33-35 were magnesium alloys that included Ca in an amount of 1%, Al in an amount of 1% and Mn in an amount of 0.5%, but whose Cu contents differed one another. The heat conductivities of these magnesium alloys exhibited lowering magnitudes of 9-39 W/mK, which were small relatively compared with that of the heat conductivity of pure magnesium (167 W/mK) that was measured by the aforementioned method. It was understood that it is especially preferable that the Cu content can be 0.8-4.5%.

[0076] Moreover, Fig. 7 and Fig. 8 are graphs that summarize the change of the tensile strengths in Test Specimens #11-#35 and the change of the elongations in them for the Ca contents. As the Ca amounts increased, both the tensile strengths and elongations tended to decline. In particular, it was understood that magnesium alloys that possess high mechanical characteristic and high heat conductivity simultaneously can be obtained by keeping the Ca amount down to 2.5% or less, or further down to 1.5% or less. Further, according to Test Specimens #13, #14 and #28 which included Cu in an amount of 3% and whose Ca contents differed one another, it was understood that even varying the Ca contents has no great affect on the heat conductivities when the Ca amount falls in a range of 0.3-2.0%.

[0077] Moreover, Fig. 9 is a graph that summarizes the change of the heat conductivities in Test Specimens #11-#35 for the Al contents. As the Al amounts increased, the heat conductivities tended to decline. That is, in order to obtain magnesium alloy that possesses high heat conductivity, it is understood that it is preferable to keep down the Al content as much as possible.

[0078] [Stress Relief Test]

[0079] Regarding Test Specimens #11-#35 given in Table 2, a stress relief test was carried out, thereby examining the magnesium alloys' creep resistance under high temperature. In the stress relief test, a process was measured, process in which stress that arose when load was applied to test specimen until it deformed to predetermined deformation magnitude decreased with time during the time of testing. Concretely speaking, in 200 °C air atmosphere, a compression stress of 100 MPa was loaded to the respective test specimens, and then that compression stress was lowered as the time elapsed so that the test specimens' displacement on that occasion could be kept constant. The stress lowering magnitudes after 1 hour from the beginning of the test, those after 10 hours therefrom and those after 40 hours therefrom; and stress lowering rates from after 20 hours and up to 40 hours are given in Table 3, respectively.

[0080]

[TABLE 3]

Test Specimen	Alloy CompositionII(Analyzed Value) [%]*				0.2% Proof Stress [MPa]	Stress Lowering Magnitude			Stress Lowering Rate	Remarks
	Cu	Ca	Al	Mn		0-1 h [MPa]	0-10 h [MPa]	0-40 h [MPa]	20-40 [MPa/h]	
#11	0.88	0.69	0.00	0.00	49	26	48	59	0.26	
#12	1.90	0.70	0.54	0.00	62	-	-	-	-	
#13	2.90	0.34	0.00	0.00	51	26	53	65	0.31	#1
#14	2.80	0.51	0.00	0.00	58	22	51	65	0.29	
#15	2.80	0.62	0.54	0.00	60	26	44	52	0.21	
#16	2.90	0.85	0.78	0.00	64	22	34	42	0.19	#2
#17	2.90	0.82	1.80	0.00	61	24	35	42	0.14	#3
#18	2.90	0.74	3.00	0.00	52	29	41	48	0.19	#4
#19	2.70	0.75	4.10	0.00	60	29	42	51	0.20	#5
#20	2.70	0.72	5.40	0.00	67	29	43	55	0.30	#6
#21	2.70	0.61	8.30	0.00	72	26	43	54	0.26	#7
#22	2.90	0.85	0.20	0.52	62	21	36	42	0.12	
#23	2.90	0.69	0.52	1.10	69	17	27	33	0.15	
#24	3.30	0.78	0.89	0.19	62	17	26	28	0.13	
#25	3.23	0.82	0.93	0.51	70	12	19	20	0.09	

(continued)

Test Specimen	Alloy Composition II (Analyzed Value) [%]*				0.2% Proof Stress [MPa]	Stress Lowering Magnitude			Stress Lowering Rate	Remarks
	Cu	Ca	Al	Mn		0-1 h [MPa]	0-10 h [MPa]	0-40 h [MPa]	20-40 [MPa/h]	
#26	3.27	0.86	0.93	0.67	69	13	18	21	0.15	
#27	2.90	0.82	0.97	1.20	70	14	20	23	0.10	
#28	2.80	1.80	0.00	0.00	69	25	50	61	0.31	
#29	2.99	2.14	0.98	0.00	68	13	27	37	0.15	
#30	3.14	1.87	0.99	0.19	75	12	20	24	0.08	
#31	3.21	2.14	0.98	0.45	75	11	18	23	0.20	
#32	4.20	0.78	0.00	0.00	68	26	52	64	0.17	#9
#33	1.21	0.74	1.20	0.38	58	14	18	24	0.17	
#34	5.16	0.84	0.85	0.40	75	17	24	27	0.08	
#35	9.42	0.53	0.81	0.30	85	16	29	34	0.17	

[0081] Fig. 10 is a graph that summarizes the changes of the stress lowering magnitudes after 40 hours from the beginning of the test in Test Specimens #14-#21, which included Cu in an amount of 3% and Ca in an amount of 1% but whose Al contents differed one another, for the Al contents. Magnesium alloy whose stress loweringmagnitude is small is good in terms of creep resistance at high temperature. According to Fig. 10, it was understood that good creep resistance was exhibited even at high temperature by setting the Al content to 0.5% or more, or further to 0.75% or more.

[0082] [Observation of Metallic Structure]

[0083] Four types of test specimens for observingmetallic structure were made in the same manner as the aforementioned procedures. Each "Alloy Composition I" was set at Mg-3%Cu-1%Ca-0.5Al (equivalent to #15), Mg-3%Cu-1%Ca-2%Al (equivalent to #17), Mg-3%Cu-1%Ca-4%Al (equivalent to #19), and Mg-3%Cu-1%Ca-8%Al (the units, "%," were all "% by mass").

[0084] The observation of the metallic structures was carried out by observing cross sections, which were cut out of the respectivetest specimens, with a metallographic microscope. The metallicstructures are shown in Fig. 11A-Fig. 11D. In Fig. 11A-11C, the three-dimensional mesh construction was confirmed, three-dimensional mesh construction which comprised intermetallic compounds that crystallized in crystalline grain boundaries. However, the three-dimensional mesh construction had come not to be seen as the Al contents increased. It is believed that the decrease of the three-dimensional mesh construction that was accompanied by the increase of Al had influence on the deterioration of the creep resistance. When taking the graph of Fig. 10 also into consideration, it is especially preferable that the Al content can be 4.5% or less.

[0085] [EPMA Analysis]

[0086] Regarding an Mg-3%Cu-1%Ca-1%Al (equivalent to #16), an analysis by means of electron-beam microanalysis (EPMA) was carried out. The results are shown in Fig. 12. Note that, in Fig. 12, the upper left photograph is the secondary electron-beam image (BEI) and the others are areal-analysis results that analyzed the elemental distributions in the regions of the secondary electron-beam image. It was understood that the magnesium alloy being labeled #16 possessed a metallic structure that comprised: Mg crystalline grains comprising mainly Mg; and grain-boundary crystallized substances being crystallized as three-dimensional network shapes in grain boundaries between the Mg crystalline grains, and including Cu, Ca and Al.

[0087] [Making of Heat-treated Test Specimen]

[0088] A forementioned Test Specimens #14-#16, #23-#27, #29-#31 and #33-#35 (as-cast materials) were heat treated, thereby making Test Specimens #14a-#16a, #23a-#27a, #29a-#31a and #33a-#35a (heat-treated materials). The heat treatment was carried out as follows: the as-cast materials were heated to 410-510 °C for 5-24 hours and then water cooled (a solution treatment); and thereafter they were reheated to 150-250 °C for 1-10 hours (an age-hardening treatment).

[0089] Regarding the heat-treated materials as well, the heat conductivities, tensile strengths, elongations, 0.2% proof stresses and stress lowering magnitudes were measured in the same manner as aforementioned. The results are given in Table 4.

[0090]

[TABLE 4]

Test Specimen	Alloy Composition II (Analyzed Value) [%]*				Heat Conductivity [W/mK]	Tensile Strength [MPa]	Elongation [%]	0.2% Proof Stress [MPa]	Stress Lowering Magnitude			Stress Lowering Rate
	Cu	Ca	Al	Mn					0-1 h [MPa]	0-10 h [MPa]	0-40 h [MPa]	20-40 h [MPa/H]
#14a	2.80	0.51	0.00	0.00	163	130	4.2	61	22	51	66	0.18
#15a	2.80	0.62	0.54	0.00	157	136	3.2	76	22	46	58	0.24
#16a	2.90	0.85	0.78	0.00	146	161	2.6	98	20	31	42	0.28
#23a	2.90	0.69	0.52	1.10	154	143	4.4	62	31	51	61	0.22
#24a	3.30	0.78	0.89	0.19	142	179	3.4	112	10	20	29	0.33
#25a	3.23	0.82	0.93	0.51	144	176	2.7	111	8	19	28	0.30
#26a	3.27	0.86	0.93	0.67	146	175	2.4	113	9	18	27	0.25
#27a	2.90	0.82	0.97	1.20	150	157	2.1	98	11	25	36	0.24
#29a	2.99	2.14	0.98	0.00	134	148	1.5	93	8	17	25	0.25
#30a	3.14	1.87	0.99	0.19	140	145	1.2	102	8	17	27	0.43
#31a	3.21	2.14	0.98	0.45	142	151	1.4	115	7	18	29	0.33
#33a	1.21	0.74	1.20	0.38	138	191	5.1	83	17	26	32	0.18
#34a	5.16	0.84	0.85	0.40	148	144	2.1	87	17	41	52	0.24
#35a	9.42	0.53	0.81	0.30	145	182	4.2	106	13	39	54	0.35

[0091] When comparing the heat conductivities before the heat treatment with those after it, there were no test specimens whose heat conductivities were lowered by means of the heat treatment, and improvements of the heat conductivities by means of the heat treatment were appreciated in most of the test specimens. Moreover, from the measurement results on the heat conductivities of Test Specimens #16, #24-#27 and #16a, #24a-#27a, or from those of Test Specimens #29-#31 and #29a-#31a, the more Mn contents the test specimens had, the greater the heat conductivities were improved by means of the heat treatment.

[0092] Fig. 13 and Fig. 14 are graphs that summarize the change of the mechanical characteristics in the magnesium alloys, which included Ca in an amount of 1%, Al in an amount of 1% and Mn in an amount of 0.5% but whose Cu contents differed, for the Ca contents. Note that Fig. 13 illustrates those in the as-cast materials; and Fig. 14 illustrates those in the heat-treated materials. In any one of the test specimens, the mechanical characteristics were improved by means of the heat treatment.

[0093] Fig. 15 is a graph that summarizes the changes of the stress lowering magnitudes after 40 hours from the beginning of the test in the magnesium alloys, which included Ca in an amount of 1%, Al in an amount of 1% and Mn in an amount of 0.5% but whose Cu contents differed, for the Cu contents. In both the as-cast materials and heat-treated materials, the more the Cu contents were the more the creep resistances at high temperature tended to decline. Moreover, although the creep resistances at high temperature were declined by means of the heat treatment, it was understood that, not limited to those in the as-cast materials, the decline of creep resistance by means of heat treatment can be kept down by setting the Cu content to 3.5% by mass or less.

[0094] Fig. 16 is a graph that summarizes the changes of the tensile strengths in the magnesium alloys, which included Cu in an amount of 3%, Ca in an amount of 1% and Al in an amount of 1% but whose Mn contents differed, for the Mn contents. Despite the Mn contents, the tensile strengths after the heat treatment improved. Moreover, Fig. 17 is a graph that summarizes the changes of the stress lowering magnitudes after 40 hours from the beginning of the test in the magnesium alloys, which included Cu in an amount of 3%, Ca in an amount of 1% and Al in an amount of 1% but whose Mn contents differed, for the Mn contents. In the as-cast materials, the more the Mn contents were the more the creep resistances tended to improve. However, when containing it in excess of 1%, no improvement of creep resistances is appreciated, but the decline of creep resistances is predicted adversely. In addition, when the Mn content exceeded 1%, the creep resistances of the heat-treated materials declined greatly. Therefore, it is possible to say that an especially preferable Mn content can be 0.1-0.8%, or further 0.3-0.7%.

[0095] In Fig. 18A, Fig. 18B and Fig. 19-Fig. 21, the observation results on the metallic structures of Test Specimen #14 before and after the heat treatment, and the EPMA analysis results thereon. Fig. 18A and Fig. 18B show the metallic structure of the as-cast material. In Fig. 18A, the three-dimensional mesh construction was observed. In Fig. 18B with high magnification, the following were observed in the crystalline grain boundaries: portions whose contrasts were uniform (a part of them is specified with "P1"); and portions whose contrasts were striped shapes (a part of them is specified with "P2"). According to the EMPA analysis results shown in Fig. 19, it was understood that "P1" comprises Mg-Cu system compounds and "P2" comprises Mg-Ca system compounds. Moreover, it was understood that Cu and Ca, most of them, exist in the crystalline grain boundaries.

[0096] Meanwhile, Fig. 20 shows the metallic structure of one of the heat-treated materials (#14a). In the heat-treated material, granular compounds (a part of them is specified with "P3"), which had granular shapes and existed dispersedly, were appreciated. Moreover, like portions being specified with "P4," locations at which neighboring Mg crystalline grains contacted with each other, were appreciated abundantly. It is believed that heat-treated material comes to exhibit high heat conductivity by means of possessing such a metallic structure. According to the EMPA analysis results shown in Fig. 21, it was understood that "P3" comprises Cu system compounds including mainly Cu. In addition, it was understood that, although Cu, most of it, exists in the crystalline grain boundaries, the major part of Ca exists diffusedly in the Mg crystalline grains. This is definite from the facts that, when the areal-analysis results on Ca shown in Fig. 19 (as-cast material) is compared with the areal-analysis results on Ca shown in Fig. 21 (heat-treated material), the contrast is brighter as a whole in Fig. 21 than in the other (in the color photograph, Ca that is indicated in blue is dotted within the area that comprises Mg mostly and is indicated in black.)

Claims

1. A magnesium alloy for casting, the magnesium alloy being **characterized in that**, when the entirety is taken as 100% by mass, it includes:

   copper (Cu) in an amount of from 0.5% by mass or more to 10% by mass or less;
   calcium (Ca) in an amount of from 0.01% by mass or more to 3% by mass or less; and
   the balance comprising magnesium (Mg) and inevitable impurities.

2. The magnesium alloy for casting as set forth in claim 1 further including aluminum (Al) in an amount of 10% by mass or less when the entirety is taken as 100% by mass.

3. The magnesium alloy for casting as set forth in claim 1 further including aluminum (Al) in an amount of 3% by mass or less when the entirety is taken as 100% by mass.

4. The magnesium alloy for casting as set forth in claim 1, wherein said copper (Cu) is from 1% by mass or more to 5% by mass or less.

5. The magnesium alloy for casting as set forth in claim 1 further including manganese (Mn) in an amount of 1% by mass or less when the entirety is taken as 100% by mass.

6. The magnesium alloy for casting as set forth in claim 1 having a metallic structure that is constituted of Mg crystalline grains including Mg, and grain-boundary crystallized substances including Cu and Ca and being crystallized as three-dimensional network shapes in grain boundaries between the Mg crystalline grains.

7. The magnesium alloy for casing as set forth in claim 1 having a metallic structure that is constituted of Mg crystalline grains including Mg, and granular compounds including Cu and being dispersed as granular shapes in grain boundaries between the Mg crystalline grains.

8. A cylinder head of internal-combustion engine, the cylinder head comprising the magnesium alloy for casting as set forth in claim 1.

9. A cylinder block of internal-combustion engine, the cylinder block comprising the magnesium alloy for casting as set forth in claim 1.

10. An oil pan of internal-combustion engine, the oil pan comprising the magnesium alloy for casting as set forth in claim 1.

11. An impeller for turbocharger of internal-combustion engine, the impeller comprising the magnesium alloy for casting as set forth in claim 1.

12. A transmission case comprising the magnesium alloy for casting as set forth in claim 1.

13. A production method of magnesium-alloy cast product, the production method being **characterized in that** it includes:

a molten-metal pouring step of pouring an alloy molten metal into a casting mold, the alloy molten metal including: copper (Cu) in an amount of from 0.5% by mass or more to 10% by mass or less; calcium (Ca) in an amount of from 0.01% by mass or more to 3% by mass or less; and the balance comprising manganese (Mg) and inevitable impurities; when the entirety is taken as 100% by mass; and
a solidifying step of solidifying the alloy molten metal after the molten-metal pouring step by cooling it.

14. The production method of magnesium-alloy cast product as set forth in claim 13 including, after said solidifying step, a heat-treating step of granulating crystallized substances including Cu in grain boundaries between Mg crystalline grains including Mg.

15. The production method of magnesium-alloy cast product as set forth in claim 14, wherein said heat-treating step is a step in which an age-hardening treatment is carried out at 100-300 °C after carrying out a solution treatment at 400-550 °C.

Fig.1

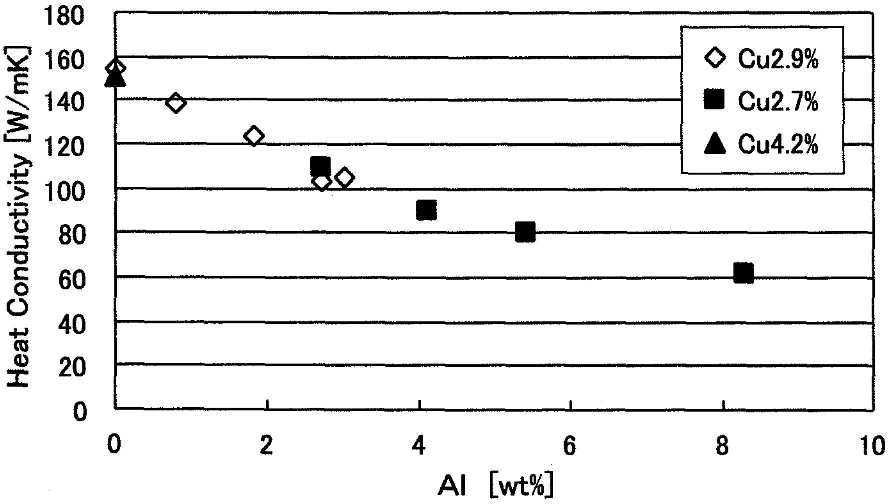

Heat Conductivity [W/mK]
180
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
Al [wt%]
◇ Cu2.9%
■ Cu2.7%
▲ Cu4.2%

Fig.2

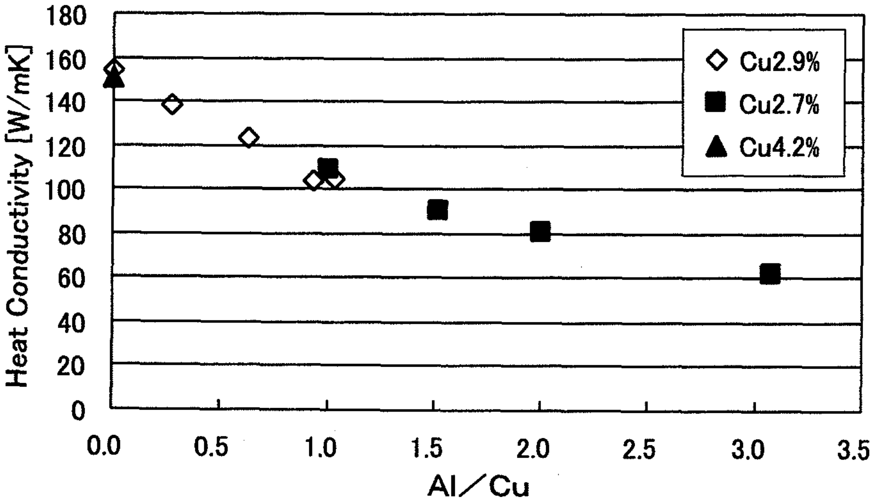

Heat Conductivity [W/mK]
180
160
140
120
100
80
60
40
20
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Al／Cu
◇ Cu2.9%
■ Cu2.7%
▲ Cu4.2%

Fig.3

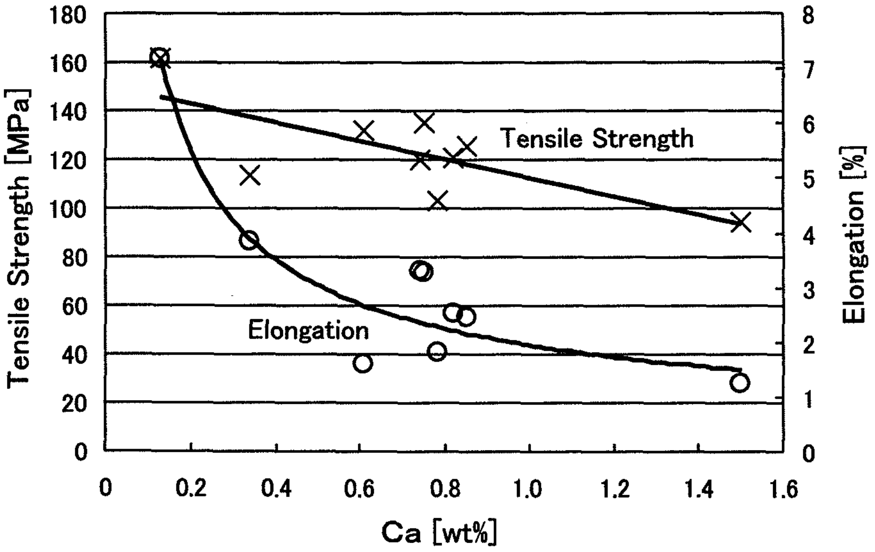

180
160
140
120
100
80
60
40
20
0
Tensile Strength [MPa]
8
7
6
5
4
3
2
1
0
Elongation [%]
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Ca [wt%]
Tensile Strength
Elongation

Fig.4A

Mg-3%Cu-0.5%Ca (#1,#13)

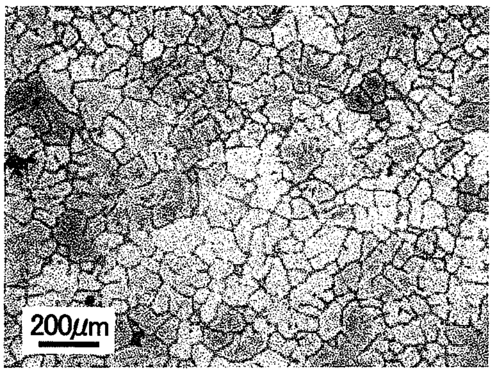


Fig.4B

Mg-3%Cu-0.5%Ca (#1,#13)

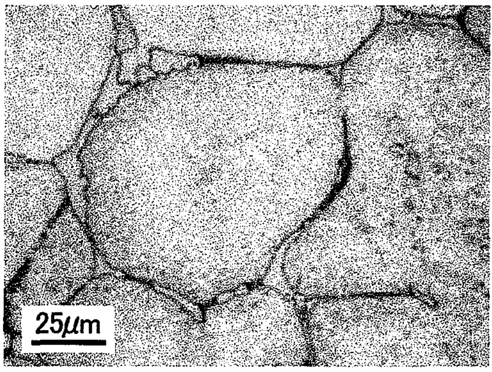


Fig.5A

Mg-3%Cu-0.2%Ca-3%Al (#10)

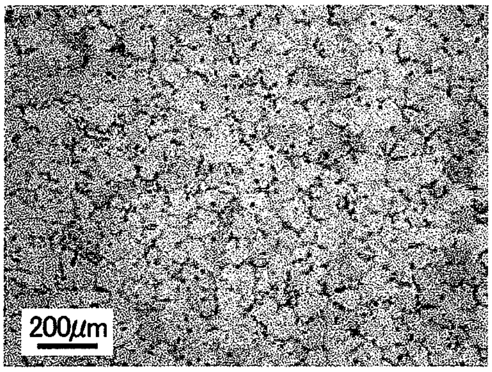


Fig.5B

Mg-3%Cu-0.2%Ca-3%Al (#10)

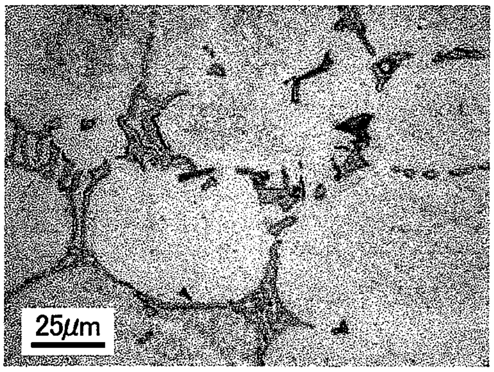


Fig.6A

Mg-3%Cu-3%Ca-3%Al-0.5%Mn

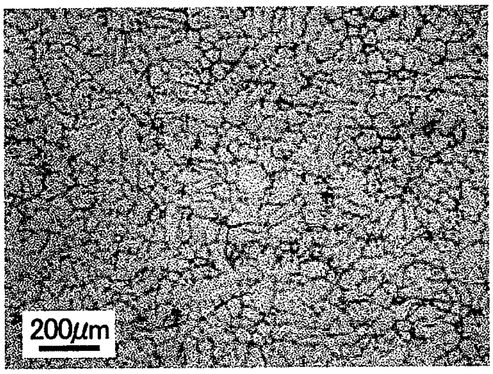


Fig.6B

Mg-3%Cu-3%Ca-3%Al-0.5%Mn

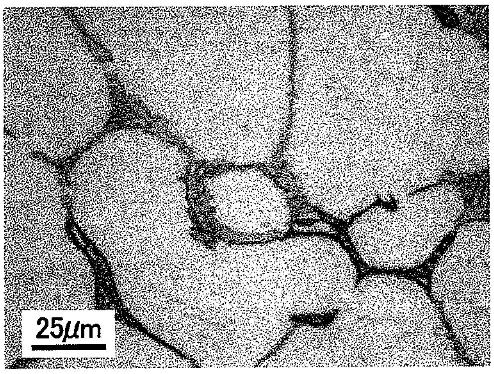


Fig.7

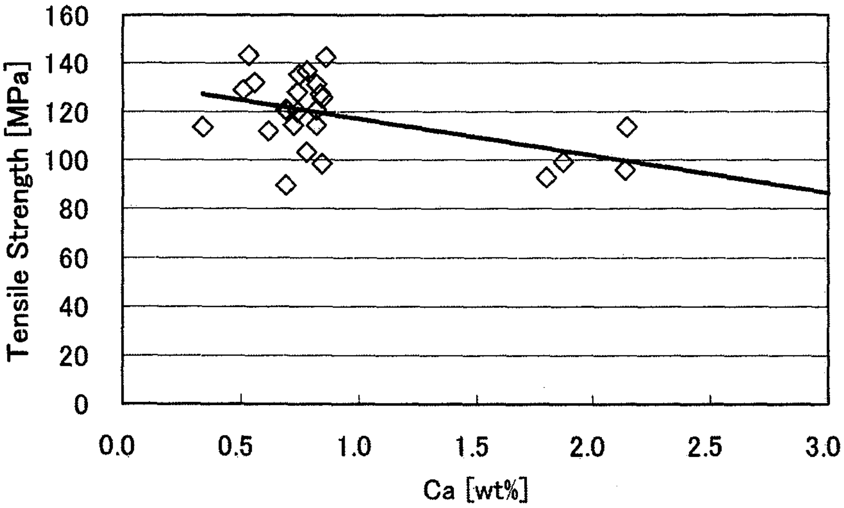

Tensile Strength [MPa]
0
20
40
60
80
100
120
140
160
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Ca [wt%]

Fig.8

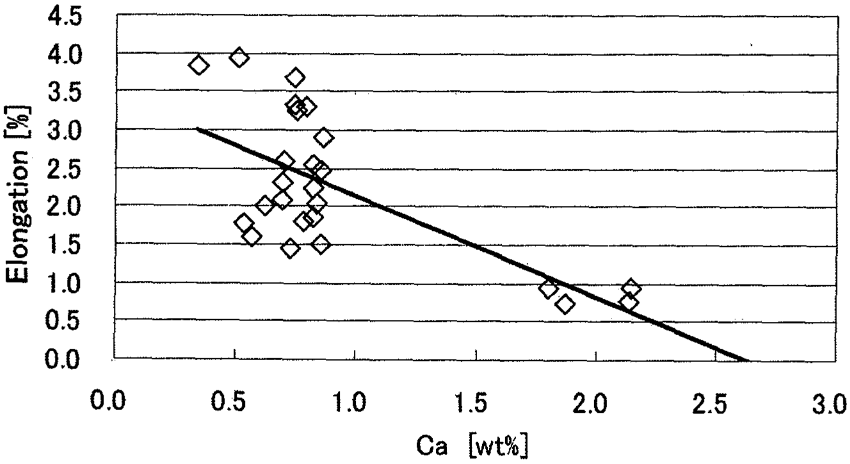

Elongation [%]
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Ca [wt%]

Fig.9

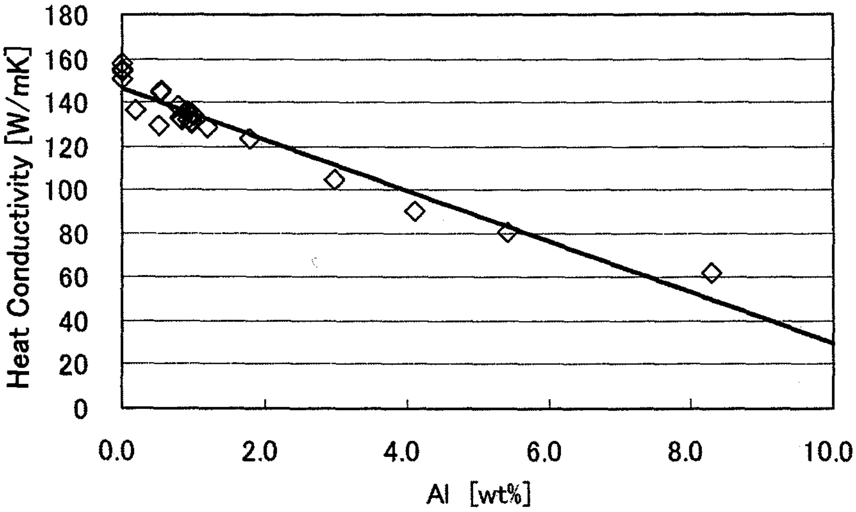

Heat Conductivity [W/mK]
180
160
140
120
100
80
60
40
20
0
0.0
2.0
4.0
6.0
8.0
10.0
Al [wt%]

Fig.10

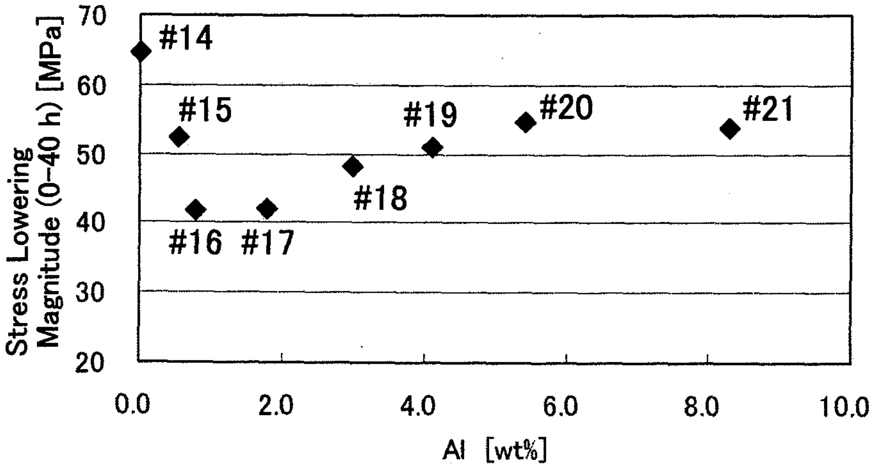

Stress Lowering Magnitude (0-40 h) [MPa]
70
60
50
40
30
20
#14
#15
#16
#17
#18
#19
#20
#21
0.0
2.0
4.0
6.0
8.0
10.0
Al [wt%]

Fig.11A

Mg-3%Cu-1%Ca-0.5%Al (#15)

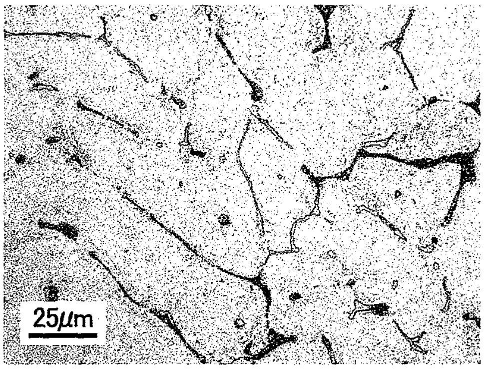


Fig.11B

Mg-3%Cu-1%Ca-2%Al (#17)

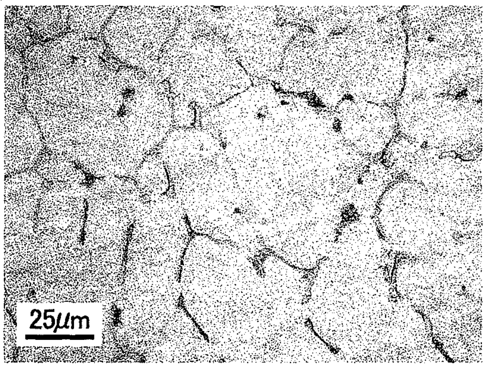


Fig.11C

Mg-3%Cu-1%Ca-4%Al (#19)

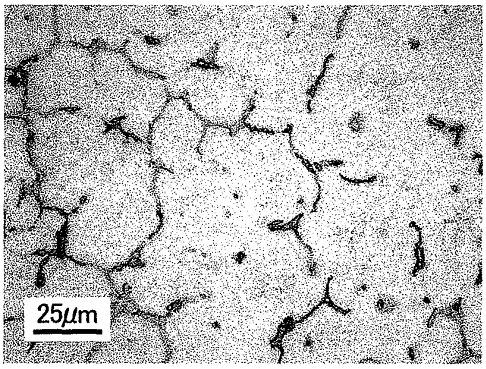


Fig.11D

Mg-3%Cu-1%Ca-8%Al

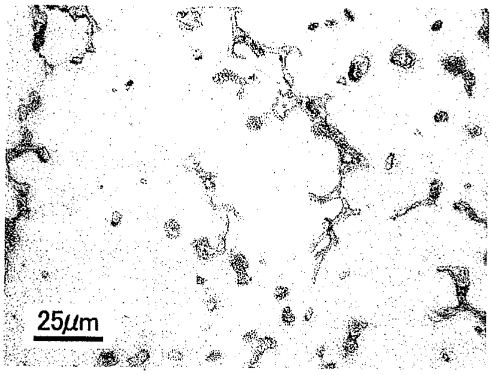


Fig.12

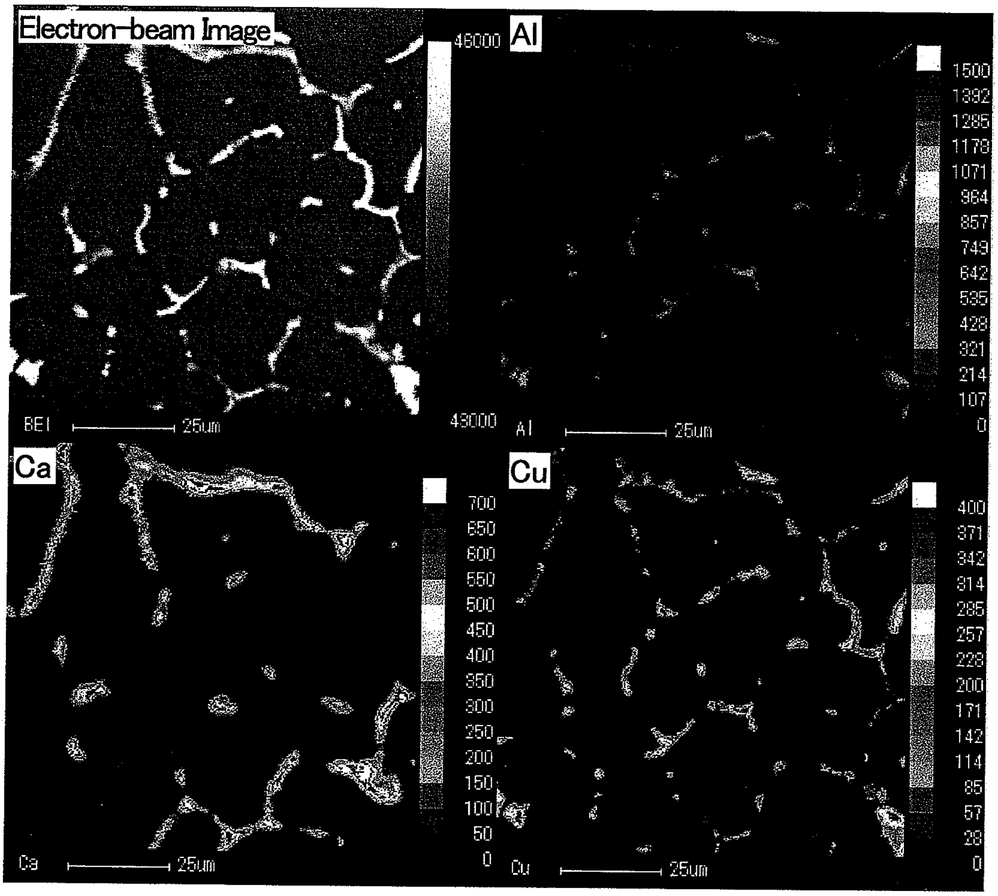


Fig.13

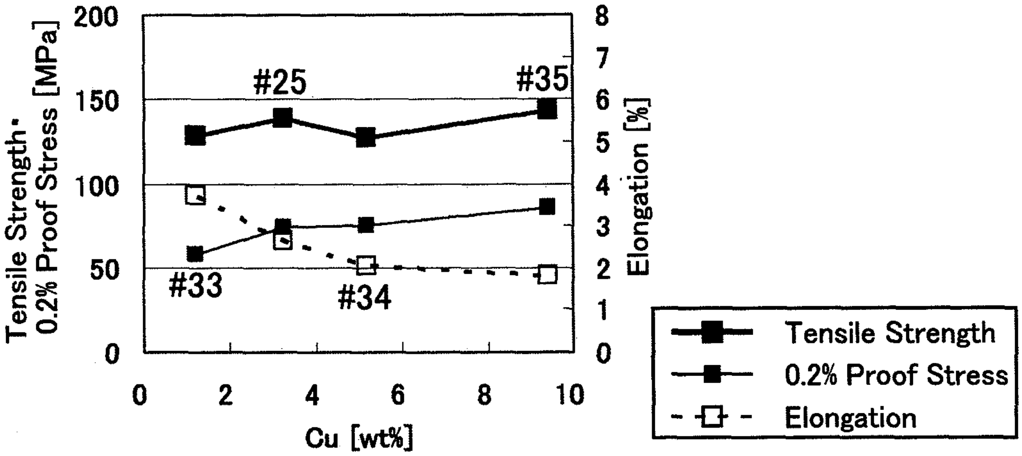

Tensile Strength·
0.2% Proof Stress [MPa]
200
150
100
50
0
#25
#35
#33
#34
0
2
4
6
8
10
Cu [wt%]
8
7
6
5
4
3
2
1
0
Elongation [%]
Tensile Strength
0.2% Proof Stress
Elongation

Fig.14

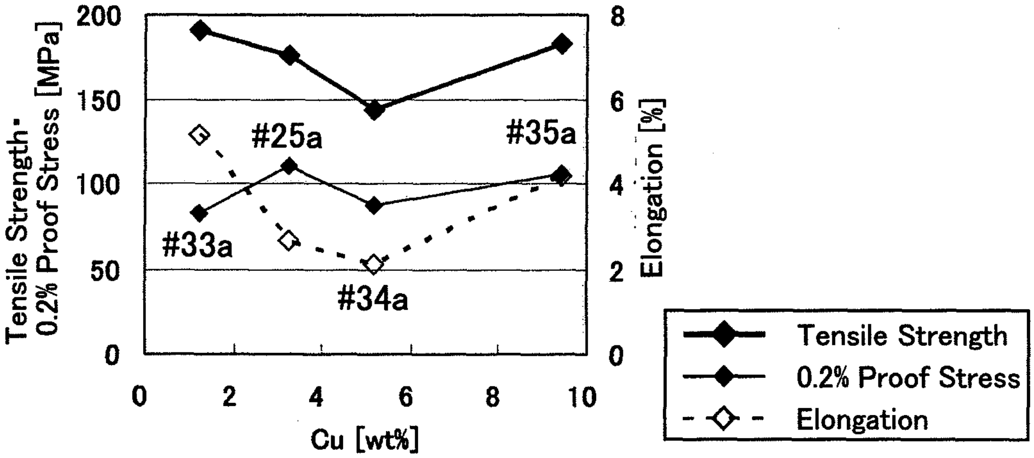

Tensile Strength·
0.2% Proof Stress [MPa]
200
150
100
50
0
#25a
#35a
#33a
#34a
0
2
4
6
8
10
Cu [wt%]
8
6
4
2
0
Elongation [%]
Tensile Strength
0.2% Proof Stress
Elongation

Fig.15

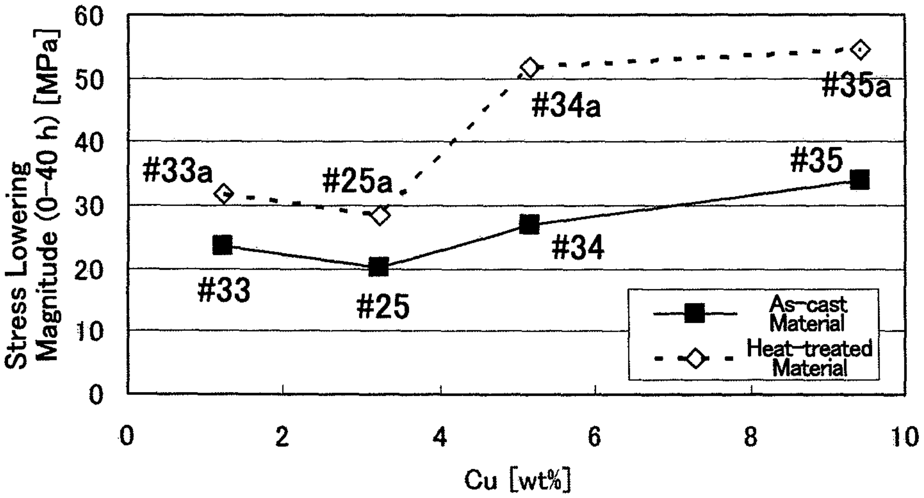

Stress Lowering Magnitude (0–40 h) [MPa]
60
50
40
30
20
10
0
0
2
4
6
8
10
Cu [wt%]
#33a
#25a
#34a
#35a
#33
#25
#34
#35
As-cast Material
Heat-treated Material

Fig.16

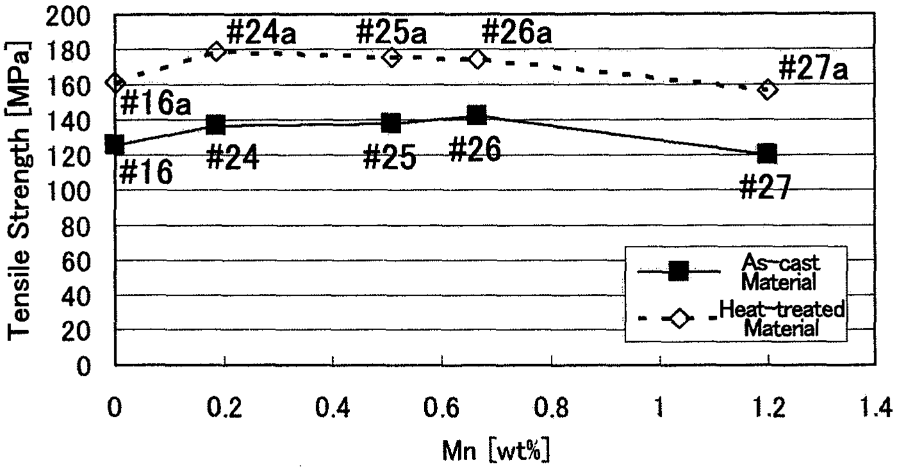

Tensile Strength [MPa]
200
180
160
140
120
100
80
60
40
20
0
#24a
#25a
#26a
#27a
#16a
#16
#24
#25
#26
#27
As-cast Material
Heat-treated Material
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Mn [wt%]

Fig.17

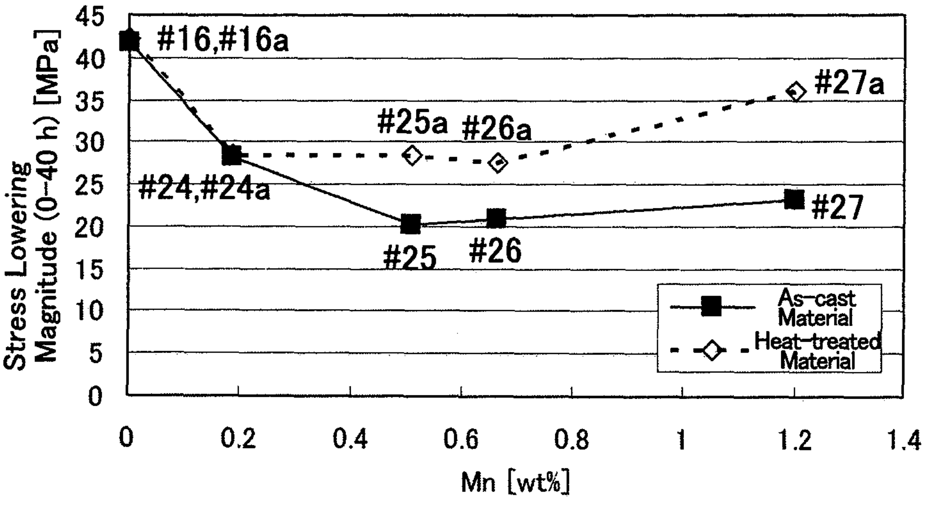

Stress Lowering Magnitude (0-40 h) [MPa]
45
40
35
30
25
20
15
10
5
0
#16,#16a
#27a
#25a
#26a
#24,#24a
#27
#25
#26
As-cast Material
Heat-treated Material
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Mn [wt%]

Fig.18A

Mg-3%Cu-1%Ca (#14)

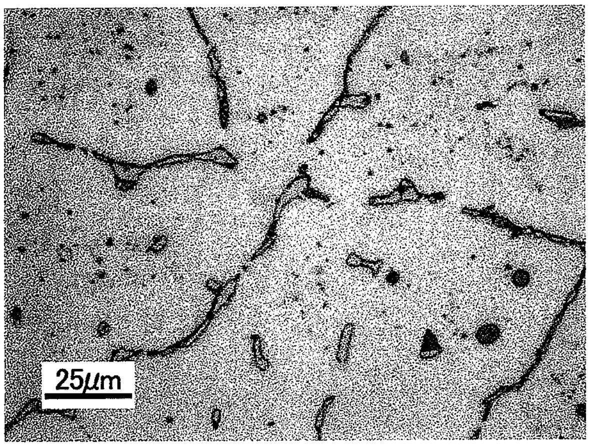


Fig.18B

Mg-3%Cu-1%Ca (#14)

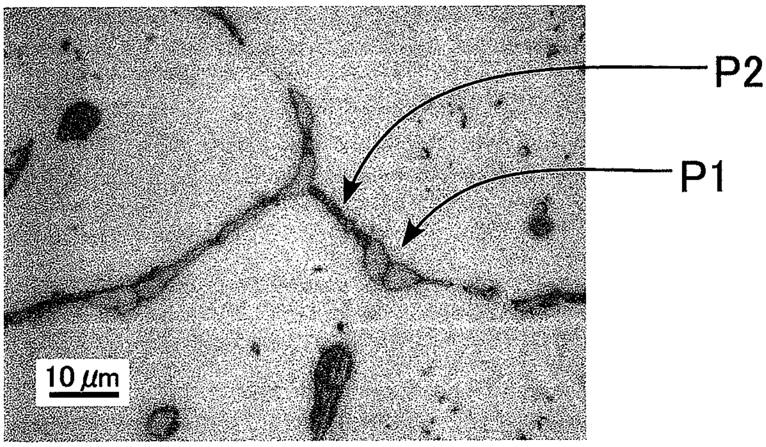


Fig.19

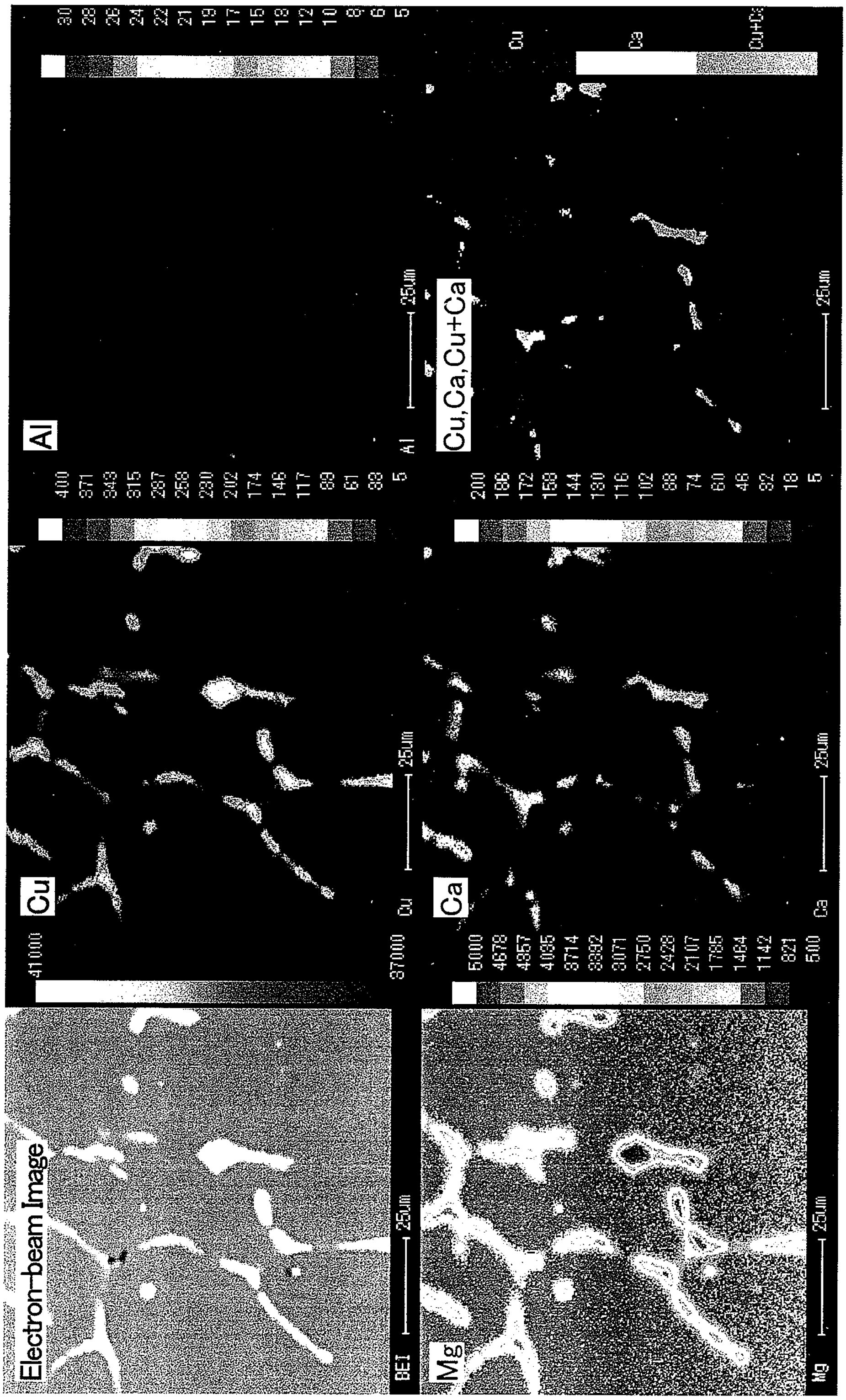

Electron-beam Image
BEI
25um
Cu
41000
37000
Cu
25um
Al
400
371
343
315
287
258
230
202
174
146
117
89
61
33
5
Al
25um
30
28
26
24
22
21
19
17
15
13
12
10
8
6
5
Mg
Mg
25um
Ca
5000
4678
4357
4035
3714
3392
3071
2750
2428
2107
1785
1464
1142
821
500
Ca
25um
Cu,Ca,Cu+Ca
200
186
172
158
144
130
116
102
88
74
60
46
32
18
5
25um
Cu
Ca
Cu+Ca

Fig.20

Mg-3%Cu-1%Ca (#14a)

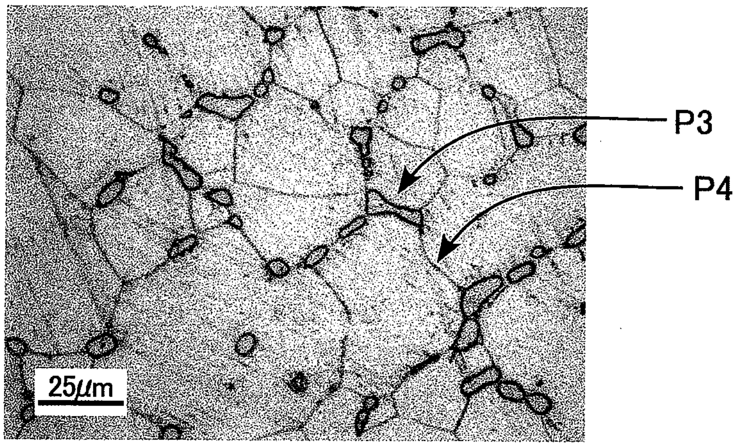
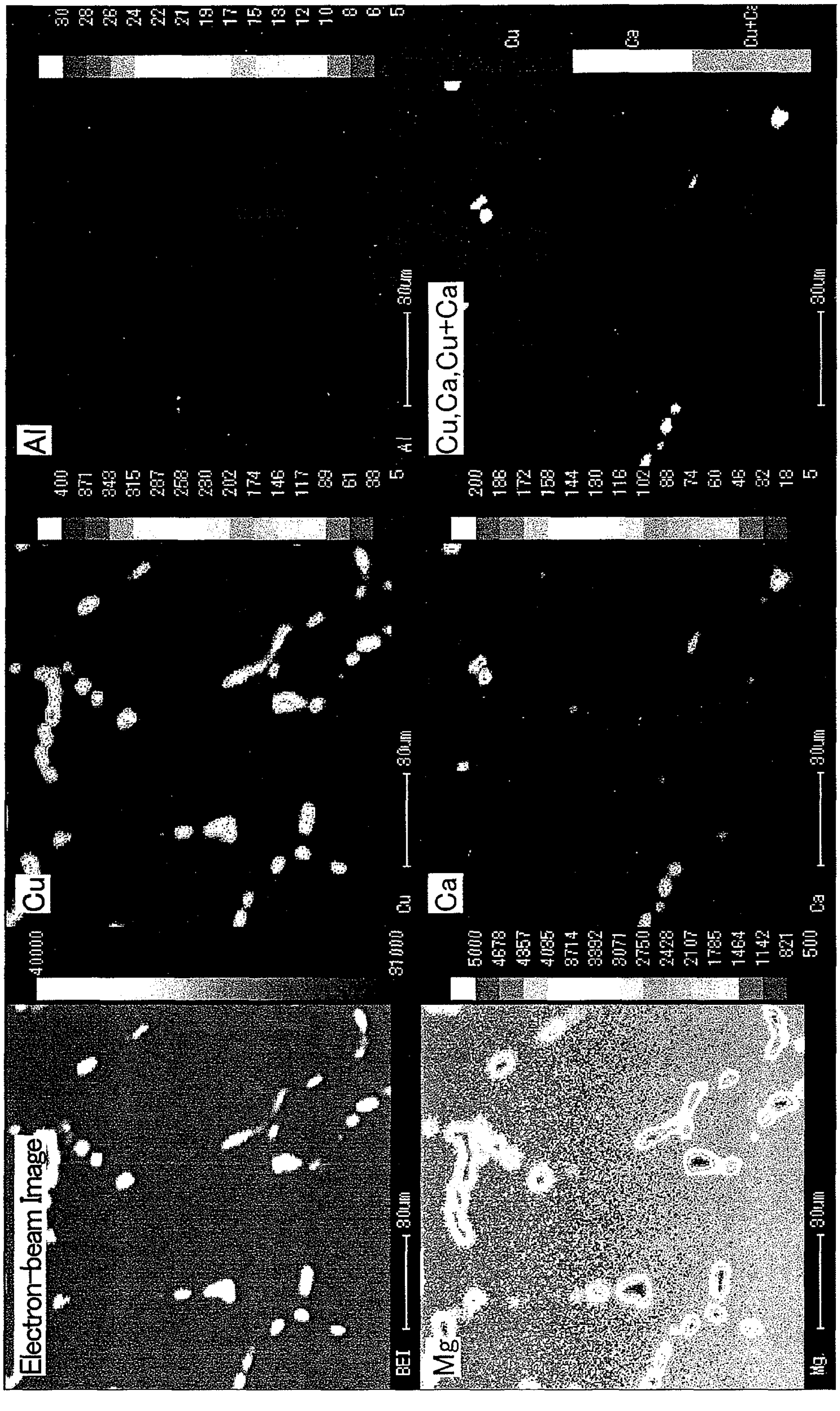


Fig.21


Electron-beam Image
BEI
30μm
Cu
40000
31000
Al
400
371
343
315
287
258
230
202
174
146
117
89
61
33
5
30
28
26
24
22
21
19
17
15
13
12
10
8
6
5
Mg
Ca
5000
4678
4357
4035
3714
3392
3071
2750
2428
2107
1785
1464
1142
821
500
Cu,Ca,Cu+Ca
200
186
172
158
144
130
116
102
88
74
60
46
32
18
5
Cu
Ca
Cu+Ca

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2007/071756

A. CLASSIFICATION OF SUBJECT MATTER
C22C23/00(2006.01)i, *C22C23/02*(2006.01)i, *C22F1/06*(2006.01)i, *F02B39/00*(2006.01)i, *F02F1/00*(2006.01)i, *F02F1/24*(2006.01)i, *F04D29/02*(2006.01)i

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)
C22C23/00-C22C23/06, C22F1/06, F02B39/00, F02F1/00, F02F1/24, F04D29/02

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2008
Kokai Jitsuyo Shinan Koho	1971-2008	Toroku Jitsuyo Shinan Koho	1994-2008

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.
A	JP 7-11374 A (Ube Industries, Ltd., Nissan Motor Co., Ltd.), 13 January, 1995 (13.01.95), Claims; Par. Nos. [0001], [0015], [0027]; tables 3, 6 & US 5681403 A & GB 2296256 A	1-15
A	JP 6-25790 A (Mitsui Mining & Smelting Co., Ltd., Metallgesellschaft AG.), 01 February, 1994 (01.02.94), Claims; Par. Nos. [0001], [0016] (Family: none)	1-15

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

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"E" earlier application or patent but published on or after the international filing date
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"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
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 28 January, 2008 (28.01.08)	Date of mailing of the international search report 05 February, 2008 (05.02.08)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

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REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2005054233 A **[0003]**