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

(11) EP 2 492 365 A2

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

(43) Date of publication:
29.08.2012 Bulletin 2012/35

(21) Application number: **11830869.1**

(22) Date of filing: **04.10.2011**

(51) Int Cl.:
C22C 23/00 $^{(2006.01)}$ ***B22D 21/04*** $^{(2006.01)}$
C22C 23/02 $^{(2006.01)}$ ***C22C 23/04*** $^{(2006.01)}$

(86) International application number:
PCT/KR2011/007298

(87) International publication number:
WO 2012/046984 (12.04.2012 Gazette 2012/15)

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

(30) Priority: **05.10.2010 KR 20100096709**
16.03.2011 KR 20110023260

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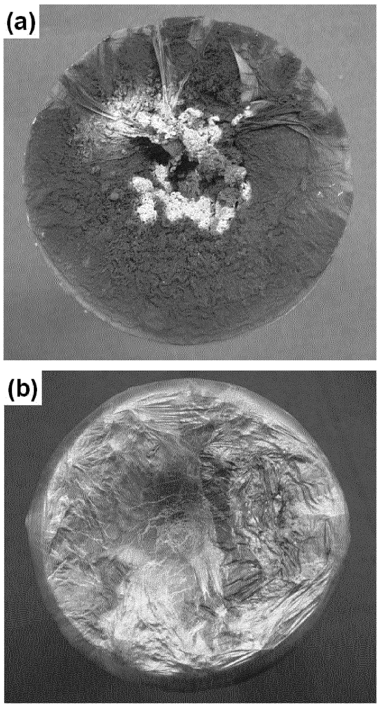
(54) FLAME RETARDANT MAGNESIUM ALLOY WITH EXCELLENT MECHANICAL PROPERTIES, AND PREPARATION METHOD THEREOF

(57) A magnesium alloy that has excellent ignition resistance and is excellent in both strength and ductility. The magnesium alloy includes, by weight, 1.0% or greater but less than 7.0% of Al, 0.05% to 2.0% of Ca, 0.05% to 2.0% of Y, greater than 0% but not greater than 6.0% of Zn, and the balance of Mg, and the other unavoidable impurities. The total content of the Ca and the Y is equal to or greater than 0.1 % but less than 2.5% of the total weight of the magnesium alloy. The Mg alloy forms a dense composite oxide layer that acts as a protective film. Thus the Mg alloy has very excellent oxidation resistance and ignition resistance, can be melted, cast and machined in the air or a common inert atmosphere (Ar or N_2), and can reduce the spontaneous ignition of chips that are accumulated during the process of machining.

Fig.1



Printed by Jouve, 75001 PARIS (FR)

Description

[Technical Field]

[0001] The present invention relates to a magnesium alloy having excellent ignition resistance or nonflammability, and more particularly, to a magnesium alloy that can be melted and cast in the air as well as in a common inert atmosphere due to the presence of a stable protective film formed on the surface of the molten metal, has excellent ignition resistance or nonflammability in order to prevent spontaneous ignition of chips, and is excellent in both strength and ductility.

[Background Art]

[0002] Magnesium alloys, which have a high specific strength, are the lightest of alloys, are applicable in a variety of casting and machining processes, and have a wide range of application, and are thereby used in almost all fields in which light weight is required, such as parts for vehicles and electronic parts. However, magnesium (Mg) is a metallic element that has a low electrochemical potential and is very active. Mg still has limitations in terms of the stability and reliability of the material, since it undergoes a strong reaction when it comes into contact with oxygen or water, and sometimes causes fires. Therefore, the fields in which Mg can be applied are still limited compared to its potential applicability. In particular, it cannot be used in applications in which safety is important.

[0003] Because of this activity of Mg alloys, it is necessary to create an inert atmosphere using an inert mixture gas, such as a flux or CO_2 + SF_6. Since the flux that is used in melting and refining is a chlorinated substance, there is a problem in that chlorine atoms reside inside a material, thereby significantly decreasing corrosion resistance when the conditions for processing the molten metal are not fulfilled. In order to solve this problem, it is effective to perform melting and casting in an atmosphere in which SF_6, CO_2 and air are mixed, instead of using the flux. However, SF_6 is classified as a greenhouse gas, the global-warming potential (GWP) of which is 24 times that of CO_2, so that the use thereof is expected to be regulated in the future time.

[0004] In order to more fundamentally solve this problem, studies for improving the oxidation resistance of Mg alloys, in particular, studies intended to increase the ignition temperature of Mg alloys by adding Ca, Be or rare-earth metals, have been carried out. Traditionally, Ca has been a main choice among the alloying elements that are added to Mg alloys that are oxidation resistant because Ca is cheaper than other rare-earth metals, is nontoxic, and greatly increases the ignition temperature in consideration of the amount that is added.

[0005] According to previous studies on magnesium alloys that contain Ca, it is known that the ignition temperature increases by about 250˚C when 3wt% or greater of Ca is added. Therefore, in order to realize an ignition temperature of 700˚C or higher, at which casting is possible in the condition of being exposed to the air without a protective gas, or an ignition temperature of 650˚C or higher, at which casting is possible in the condition of including the protective gas, Ca must be added to Mg alloys, preferably in an amount of 3wt% or greater, and in a minimum amount of 2wt% or greater. However, when Ca is added in an amount greater than 2wt%, the tensile properties of Mg alloys are generally degraded, with the decrease in elongation being particularly significant. This is because a great quantity of coarse and brittle eutectic phases is formed, thereby resulting in cracks. As such, increasing the amount of Ca that is added has the merit of increasing the ignition resistance, but also has a drawback in that the tensile properties are significantly degraded. Therefore, there is the demand for the development of a magnesium alloy that can satisfy both the ignition resistance and the tensile properties.

[Disclosure]

[Technical Problem]

[0006] Therefore, an object of the present invention is to provide a magnesium alloy that is intended to solve the foregoing problem of the related art.

[0007] Specifically, an object of the present invention is to provide a magnesium alloy that contains Ca therein, and more particularly, has excellent ignition resistance and excellent tensile properties.

[0008] In addition, an object of the present invention is to provide a magnesium alloy that enables an environment-friendly manufacturing process, which uses a minimum amount of Ca and does not use a protective gas such as SF_6, which is an environmental pollutant.

[Technical Solution]

[0009] In order to realize the foregoing object, according to the present invention, provided is a magnesium (Mg) alloy, which is manufactured by melt casting. The Mg alloy includes, by weight, 1.0% or greater but less than 7.0% of Al, 0.05%

to 2.0% of Ca, 0.05% to 2.0% of Y, greater than 0% but not greater than 6.0% of Zn, and the balance of Mg, and the other unavoidable impurities. The total content of the Ca and the Y is equal to or greater than 0.1 % but less than 2.5% of the total weight of the magnesium alloy.

[0010] In addition, it is preferable that the content of the Ca range, by weight, from 0.2% to 1.5%.

[0011] Furthermore, it is preferable that the content of the Y range, by weight, from 0.1 % to 1.5%.

[0012] In addition, it is preferable that the contents of the Ca and the Y range from 0.3% to 2.0% of a total weight of the magnesium alloy.

[0013] Furthermore, it is preferable that the magnesium alloy further include, by weight, greater than 0% but not greater than 1.0% of Mn.

[0014] In addition, it is preferable that the magnesium alloy further include, by weight, 0.1 % to 1.0% of Zr.

[0015] According to the present invention, provided is a method of manufacturing a magnesium alloy. The method includes the following steps of: forming a magnesium alloy molten metal, which contains Mg, Al and Zn; adding raw materials of Ca and Y into the magnesium alloy molten metal; producing a magnesium alloy cast material from the magnesium alloy molten metal, in which the raw materials of Ca and Y are added, using a fusion casting method. A magnesium alloy produced as described above includes, by weight, 1.0% or greater but less than 7.0% of Al, 0.05% to 2.0% of Ca, 0.05% to 2.0% of Y, greater than 0% but not greater than 6.0% of Zn, the balance of Mg, and the other unavoidable impurities.

[0016] In addition, it is preferable that the step of adding the raw materials of Ca and Y into the magnesium alloy molten metal include the step of adding the raw materials of Ca and Y at a temperature higher than 800˚C.

[0017] According to the present invention, provided is a method of manufacturing a magnesium alloy. The method includes the following steps of: forming a magnesium alloy molten metal, which contains Mg, Al and Zn; forming a master alloy ingot, which contains Mg, Al, Zn, Ca and Y, and is soluble at 750˚C or lower; inputting the master alloy ingot, which is soluble at 750˚C or lower, into the magnesium alloy molten metal; and producing a magnesium alloy cast material from the molten metal, which contains the master alloy ingot, using a fusion casting method. A magnesium alloy produced as described above includes, by weight, 1.0% or greater but less than 7.0% of Al, 0.05% to 2.0% of Ca, 0.05% to 2.0% of Y, greater than 0% but not greater than 6.0% of Zn, the balance of Mg, and the other unavoidable impurities.

[0018] In addition, it is preferable that the master alloy ingot, which contains Mg, Al, Zn, Ca and Y, is soluble at 750˚C or lower, and is input into the magnesium alloy molten metal at a temperature lower than 750˚C.

[0019] According to the present invention, provided is a method of manufacturing a magnesium alloy. The method includes the following steps of: forming a magnesium alloy molten metal, which contains Mg, Al and Zn; adding a Ca compound and a Y compound into the magnesium alloy molten metal; and producing a magnesium alloy cast material from the magnesium alloy molten metal, in which the Ca compound and the Y compound are added, using a fusion casting method. A magnesium alloy produced as described above includes, by weight, 1.0% or greater but less than 7.0% of Al, 0.05% to 2.0% of Ca, 0.05% to 2.0% of Y, greater than 0% but not greater than 6.0% of Zn, the balance of Mg, and the other unavoidable impurities.

[0020] In addition, it is preferable that the step of inputting the raw materials of Ca and Y, the master alloy ingot, which contains Mg, Al, Zn, Ca and Y, or the Ca compound and the Y compound into the magnesium alloy molten metal further include the step of periodically stirring the magnesium alloy molten metal.

[0021] Furthermore, it is preferable that the casting method be one selected from the group consisting of mold casting, sand casting, gravity casting, squeeze casting, continuous casting, strip casting, die casting, precision casting, lost foam casting, spray casting, and semi-solid casting.

[0022] In addition, it is preferable that the method further include the step of carrying out hot working on the magnesium alloy cast material produced by the casting method.

[0023] The reasons why the content of respective components in the magnesium alloy of the present invention is limited are as follows.

Aluminum (Al)

[0024] Al is an element that increases the strength, flowability and solidification range of a magnesium alloy, thereby improving castability. In general, the fraction of the eutectic phase increases in response to an increase in the content of Al that is added. In addition, as will be described later, according to the results of experiments of the present invention, it can be appreciated that the ignition resistance increases in response to an increase in the content of Al when Al is added in combination with other alloying elements. When the content of Al is less than 1wt%, the effect of the increased strength and ignition resistance does not occur, and when the content of Al is equal to or greater than 7wt%, tensile properties are degraded due to a coarse $Mg_{17}Al_{12}$ eutectic phase. Therefore, it is preferred that Al is contained in the range equal to or greater than 1wt% and less than 7wt%.

Calcium (Ca)

[0025] Ca improves the strength and thermal resistance properties of a Mg-Al-based alloy by forming an intermetallic compound as well as reducing the oxidation of a molten metal by forming a thin and dense oxide layer of CaO on the surface of the molten metal, thereby improving the ignition resistance of the Mg alloy. However, when the content of Ca is less than 0.05wt%, the effect of the improved ignition resistance is not significant. On the other hand, when the content of Ca is greater than 2wt%, the castability of the molten metal decreases, hot cracking occurs, die sticking increases, and elongation significantly decreases, which are problematic. Therefore, in the Mg alloy of the present invention, Ca is added in an amount ranging preferably from 0.05wt% to 2.0wt%, and more preferably from 0.2wt% to 1.5wt%.

Yttrium (Y)

[0026] Y is generally used as an element that increases high-temperature creep resistance due to precipitation strengthening, since it has a high solubility limit. When Y is added in combination with Ca to the magnesium alloy, the fraction of the coarse Ca-containing eutectic phase decreases. When Y is added in an amount of 0.5wt% or greater, there is an effect in that Al_2Y particles, which form microscopic grains of a cast material, are formed, thereby improving tensile properties. In addition, an oxide layer of Y_2O_3 is formed on the surface of a molten metal to form a mixed layer with MgO and CaO, thereby increasing ignition resistance. When Y is contained in an amount of less than 0.05wt% in the Mg alloy, the increase in the ignition temperature is not significant. When Y is contained in an amount greater than 2wt%, the price of the Mg alloy rises, and the effect of micronization is lost due to the coarsening of Al_2Y particles. Therefore, in the Mg alloy of the present invention, Y is included in an amount ranging preferably from 0.05wt% to 2.0wt%, and more preferably from 0.1wt% to 1.5wt%.

Zinc (Zn)

[0027] Zn has an effect of refining grains and increasing strength when added together with Al. In addition, the maximum solubility limit of Zn in the Mg alloy is 6.2wt%. When an amount of Zn greater than this limit is added, a coarse eutectic phase that is created during casting weakens the mechanical properties of the cast material, and a considerable amount of coarse eutectic phase resides even after homogenization heat treatment, thereby becoming a factor that weakens the mechanical properties, in particular, elongation. Therefore, it is preferred that Zn be added in an amount equal to or less than 6wt%.

Manganese (Mn)

[0028] In the Mg-Al-based alloy, Mn improves corrosion resistance due to its bonding with Fe, which is an impurity element that impedes corrosion resistance, and increases strength by forming an Al-Mn intermetallic compound at a rapid cooling speed. However, when Mn is added in an amount greater than 1.0wt%, a coarse β-Mn or Al_8Mn_5 phase is formed in the Mg alloy, thereby deteriorating the mechanical properties. Therefore, it is preferred that Mn be included in an amount equal to or less than 1.0wt%.

Zirconium (Zr)

[0029] Zr is generally added for the purpose of micronization of grains due to the nonhomogeneous nucleation of Mg crystals in primary Zr because the primary Zr, the crystal lattice of which is very similar to Mg crystals, is created during solidification when Zr is added to a Mg alloy that does not contains some elements, such as Al and Mn. When Zr is added in an amount less than 0.1wt%, its effect is not sufficient. When Zr is added in an amount that is greater than 1.0wt%, elongation decreases due to the formation of the coarse primary Zr. Therefore, it is preferred that Zr be added in an amount ranging from 0.1wt% to 1.0wt%.

Other Unavoidable Impurities

[0030] The Mg alloy of the present invention may contain impurities that are unavoidably mixed from raw materials thereof or during the process of manufacture. Among the impurities that can be contained in the Mg alloy of the invention, iron (Fe), silicon (Si) and nickel (Ni) are components that particularly worsen the corrosion resistance of the Mg alloy. Therefore, it is preferred that the content of Fe be maintained at 0.004wt% or less, the content of Si be maintained at 0.04wt% or less, and the content of Ni be maintained at 0.001wt% or less.

Total Amount of Ca and Y

[0031] When Ca and Y are added in combination, a dense combined oxide layer of CaO/Y_2O_3 is formed on the surface of a solid or liquid Mg alloy, so that the ignition resistance of the Mg alloy is superior to that of a Mg alloy to which Ca or Y is separately added. In addition, when Ca or Y is separately added, an amount of 3wt% or greater is generally added in order to obtain excellent ignition resistance. In this case, however, there is a problem in that the tensile properties are greatly degraded because a coarse intermetallic compound is formed. In contrast, the addition of Ca and Y in combination can advantageously improve tensile properties by decreasing the fraction and size of the intermetallic compound while obtaining excellent ignition resistance. When Ca and Y are added to the Mg alloy such that the total content thereof is less than 0.1wt%, the effect of the combined addition of Ca and Y does not appear. This results in a low ignition temperature of 650˚C, thereby making it impossible to perform melting in the air or a common inert gas atmosphere. In addition, when the total content of Ca and Y is 2.5wt% or greater, an increase in the cost of the alloy results without any significant advantage related to the additional increase in the ignition temperature. Therefore, in the Mg alloy of the invention, it is preferred that the total content of Ca and Y that are added be in the range preferably equal to or greater than 0.1wt% and less than 2.5wt, and more preferably from 0.2wt% to 2.0wt%.

[Advantageous Effects]

[0032] The Mg alloy according to the invention forms a dense composite oxide layer that acts as a protective film. Thus the Mg alloy has very excellent oxidation and ignition resistance, can be melted, cast and machined in the air or a common inert atmosphere (Ar or N_2), and can reduce the spontaneous ignition of chips that are accumulated during the process of machining.

[0033] In addition, the Mg alloy according to the invention is adapted to reduce costs, protect the health of workers, and prevent environmental pollution since it does not use a protective gas such as SF_6.

[0034] Furthermore, the Mg alloy according to the invention is applicable as a material for structural components, since its ignition resistance is superior to that of common alloys, with the ignition temperature thereof being 50˚C higher than the melting point thereof, and it also has excellent strength and ductility.

[0035] Moreover, the Mg alloy according to the invention can be variously used as a processing material or a cast material, and in particular, can be manufactured as an extruded material, a sheet material, a forged material, a cast material, and the like, which can be practically applied to next-generation vehicles, high-speed rail systems, and the like, in which high-strength, high-elongation and safety characteristics are required.

[Description of Drawings]

[0036]

FIG. 1 (a) is a picture showing the surface of an alloy cast material according to comparative example 1, which is manufactured in the air according to an exemplary embodiment of the invention;

FIG. 1 (b) is a picture showing the surface of an alloy cast material according to comparative example 2, which is manufactured in the air according to an exemplary embodiment of the invention;

FIG. 2 is a view illustrating a method of measuring the ignition temperature of a magnesium alloy, which is manufactured according to an exemplary embodiment of the invention;

FIG. 3 is a view showing the results of electron probe micro-analysis (EPMA) on an oxide layer on the surface of a molten metal after a magnesium alloy according to example 5, which was cast according to an exemplary embodiment of the invention, was maintained at 670˚C for 10 minutes;

FIG. 4 is a view schematically showing the structure of double composite oxide layers formed on the surface of a solid or liquid phase in an alloy in which Ca and Y are added in combination, the double composite oxide layers serving to block the penetration of external oxygen;

FIG. 5 (a) is an optical picture showing the microscopic structure of an alloy of comparative example 3, which is cast according to an exemplary embodiment of the invention;

FIG. 5 (b) is an optical picture showing the microscopic structure of an alloy of example 2, which is cast according to an exemplary embodiment of the invention;

FIG. 6 (a) is an optical picture showing the microscopic structure of an alloy of comparative example 1, which is extruded according to an exemplary embodiment of the invention;

FIG. 6 (b) is an optical picture showing the microscopic structure of an alloy of comparative example 2, which is extruded according to an exemplary embodiment of the invention;

FIG. 6 (c) is an optical picture showing the microscopic structure of an alloy of comparative example 3, which is extruded according to an exemplary embodiment of the invention;

FIG. 6 (d) is an optical picture showing the microscopic structure of an alloy of example 1, which is extruded according to an exemplary embodiment of the invention;

FIG. 7 is a picture showing variation in the ignition temperature depending on the total amount of Ca and Y that is added in the comparative examples and examples, which are manufactured according to an exemplary embodiment of the invention; and

FIG. 8 is a picture showing variations in the value of tensile strength × uniform elongation depending on the total amount of Ca and Y that is added in the comparative examples and examples, which are manufactured according to an exemplary embodiment of the invention.

[Best Mode]

[0037] Reference will now be made in detail to exemplary embodiments of a Mg alloy and a method of manufacturing the same according to the present invention. However, it is to be understood that the following embodiments are illustrative but do not limited the invention.

[0038] As the results of studies that were carried out on a thermodynamically calculated alloy design in order to solve the foregoing problem of the related art and realize the object of the invention, the inventors of the invention found that, when Ca and Y are added in combination to a Mg-Al-based alloy or a Mg-Al-Zn-based alloy, as presented in Table 1 below, the fraction of a hard eutectic phase (eutectic phase I) significantly decreases compared to the case in which Ca is added alone, and at the same time, the formation of a Al_2Y phase, i.e. particles that form micronized grains, is induced, so that not only ignition resistance but also tensile strength can be improved.

Table 1

	Al_2Y	Eutectic phase I (Al_2Ca, Mg_2Ca)	Eutectic phase II ($Mg_{17}CAL_{12}$)
Mg-3Al-1Zn-1Ca	-	2.241	
Mg-3Al-1Zn-2Ca	-	3.733	
Mg-3Al-1Zn-1Ca-0.6Y	0.845	2.169	
Mg-6Al-1Zn-1Ca	-	2.303	4.183
Mg-6Al-1Zn-2Ca	-	4.600	1.776
Mg-6Al-1Zn-1Ca-0.6Y	0.890	2.272	3.505

[0039] The inventors of the invention manufactured Mg alloys having a variety of compositions based on the above data. The method of manufacturing a Mg alloy according to an exemplary embodiment of the invention is as follows.

[0040] First, raw materials that include Mg (99.9%), Al (99.9%), Zn (99.99%), Ca (99.9%), Y (99.9%) and selectively Mn (99.9%) were prepared, and were then melted. Then, Mg alloy cast materials having the alloy compositions described in example 1 to example 17 and comparative example 1 to comparative example 9 in Table 2 below were formed from the raw materials using a gravity casting method. Specifically, the temperature of a molten metal was increased up to a temperature between 850˚C and 900˚C, so that these elements were completely melted, in order to produce an alloy by directly inputting Ca and Y, which have high melting points of 842˚C and 1525˚C, respectively, into the molten metal. After that, the molten metal was gradually cooled down to a casting temperature, and then the Mg alloy cast materials were produced by casting the molten metal.

[0041] Alternatively, according to an exemplary embodiment of the invention, it is possible to manufacture a Mg alloy by a variety of methods in addition to the method in which casting is performed after a molten metal is formed by simultaneously melting raw materials including Mg (99.9%), Al (99.9%), Zn (99.99%), Ca (99.9%) and Y (99.9%). In an example, it is possible to first form a Mg alloy molten metal using the raw materials of Mg, Al and Zn or alloys thereof, input the raw materials of Ca and Y, or a Ca compound and a Y compound into the Mg alloy molten metal, and then produce a Mg alloy cast material by a suitable casting method. It is also possible to produce a Mg alloy cast material by preparing a Mg, Al, Zn, Ca and Y alloy (master alloy ingot) of which the contents of Ca and Y are higher than final target values, forming a Mg alloy molten metal using raw materials of Mg, Al and Zn or alloys thereof, and then inputting the master alloy ingot into the Mg alloy molten metal. This method is particularly advantageous in that the master alloy ingot can be input at a temperature that is lower than the temperature at which the raw materials of Ca and Y are directly input into the Mg alloy molten metal, since the melting point of the master alloy ingot is lower than those of the raw materials of Ca and Y. In addition, the formation of a Mg alloy according to the invention can be realized by a variety of methods, and all methods of forming a Mg alloy that are well-known in the art to which the invention belongs are included as part of the invention.

[0042] In this embodiment, a graphite crucible was used for induction melting, and a mixture gas of SF_6 and CO_2 was applied on the upper portion of the molten metal, so that the molten metal did not come into contact with the air, in order to prevent the molten metal from being oxidized before the alloying process was finished. In addition, after the melting was completed, mold casting was performed using a steel mold without a protective gas. A sheet-shaped cast material having a width of 100mm, a length of 150mm and a thickness of 15mm was manufactured for a rolling test, a cylindrical billet having a diameter of 80mm and a length of 150mm was manufactured for an extrusion test, and a cylindrical billet having a diameter of 55mm and a length of 100mm was manufactured for an ignition test of the alloy cast material. Although the Mg alloy was cast by a mold casting method in this embodiment, a variety of casting methods, such as sand casting, gravity casting, squeeze casting, continuous casting, strip casting, die casting, precision casting, spray casting, semi-solid casting, and the like, may also be used. Although the Mg alloy according to the invention is not necessarily limited to a specific casting method, fusion casting is more preferable.

[0043] Afterwards, the slabs that were prepared above were subjected to homogenization heat treatment at 400˚C for 15 hours. In sequence, the materials of comparative example 1 to comparative example 6 and example 1 to example 7 in Table 2, which were subjected to homogenization heat treatment, were machined into sheet materials having a final thickness of 1 mm via hot working, in which the respective materials were rolled under conditions of a roll temperature of 200˚C, a roll diameter of 210mm, a roll speed of 5.74mpm, and reduction ratios of each roll of 30%/pass and 72%/pass. Here, when the reduction ratio of each roll was 30%/pass, rolling was performed a total of 7 times until the final thickness of 1 mm was realized.

[0044] In addition, in comparative example 7, comparative example 8 and example 8 in Table 2, rod-shaped extruded materials having a final diameter of 16mm were manufactured by extruding the materials that were subjected to homogenization heat treatment under conditions including an extrusion speed of 5m/min, an extrusion ratio of 25:1, and an extrusion temperature of 250. The extruded materials had a good surface state.

[0045] Although rolling and extrusion were performed after casting and homogenization heat treatment in this embodiment, the materials may be manufactured by a variety of machining methods, such as forging and drawing, without being necessarily limited to a specific machining method.

Measurement of Ignition Temperature of Mg Alloy

[0046] In order to measure the ignition temperature of the Mg alloys, chips having a predetermined size were produced by machining the outer portion of the cylindrical billets, which were manufactured above, in conditions including a depth of 0.5mm, a pitch of 0.1 mm, and a constant speed of 350rpm. 0.1 g chips that were produced by the foregoing method were heated by loading them at a constant speed into a heating furnace, which was maintained at 1000˚C. The temperatures at which a sudden rise in temperature begins during this process were determined as ignition temperatures, as shown in FIG. 3, and the results are presented in Table 2.

[0047] As can be seen from comparative example 1 to comparative example 6 in Table 2, the ignition temperature of Mg alloys suddenly increases in response to the addition of Ca. When the same amount of Ca was added, the ignition temperature of the alloys tends to increase in response to an increase in the content of Al therein.

Table 2

	Alloy Symbol	Alloy Composition (wt%)						Ignition Temp (˚C)	Test Atm.
		Al	Zn	Ca	Y	Mn	Zr		
Comp. Ex. 1	AZ31	3	1					490	Air
								554	Air + Ar
Comp. Ex. 2	AZX311	3	1	1				708	Air
Comp. Ex. 3	AZX312	3	1	2				747	Air
Comp. Ex. 4	AZ61	6	1					507	Air
								602	Air + Ar
Comp. Ex. 5	AZX611	6	1	1				703	Air
Comp. Ex. 6	AZX612	6	1	2				755	Air
Comp. Ex. 7	ZX61		6	1				672	Air
Comp. Ex. 8	ZX62		6	2				704	Air
Comp. Ex. 9	ZK60		5.5				0.45	553	Air

(continued)

	Alloy Symbol	Alloy Composition (wt%)						Ignition Temp (˚C)	Test Atm.
		Al	Zn	Ca	Y	Mn	Zr		
Example 1	Alloy 1	3	0.8	1	1	0.3		807	Air
Example 2	Alloy 2	3	1	1	0.6			768	Air
								776	Air + Ar
Example 3	Alloy 3	3	1	0.7	0.6			714	Air
								707	Air + Ar
Example 4	Alloy 4	3	0.8	0.3	0.3	0.25		698	Air
								705	Air + Ar
Example 5	Alloy 5	6	1	1	0.6			774	Air
Example 6	Alloy 6	6	1	0.7	0.6			745	Air
								749	Air + Ar
Example 7	Alloy 7	6	1	0.3	0.3			705	Air
								717	Air + Ar
Example 8	Alloy 8	6	1	0.1	0.1			677	Air
Example 9	Alloy 9	6	2	1	0.6			783	Air
Example 10	Alloy 10	4	4	0.7	0.6			658	Air
								711	Air + Ar
Example 11	Alloy 11	4	4	0.1	0.1			771	Air
Example 12	Alloy 12	1	6	1	1			653	Air
								676	Air + Ar
Example 13	Alloy 13	1	6	0.7	0.6			744	Air
Example 14	Alloy 14	1	6	1	0.3			689	Air
Example 15	Alloy 15	2	6	1	1			659	Air
Example 16	Alloy 16	1	6	0.7	0.6		0.2	755	Air
Example 17	Alloy 17							698	Air

[0048] In Table 2, comparing each ignition temperature of example 2 and example 5 with the respective ignition temperature of comparative example 2 and comparative example 5, it can be appreciated that the ignition temperature is much higher when Y was also added to the Mg alloys than when Ca was added alone to the Mg alloys. This is because a mixed layer of CaO and Y_2O_3 was formed in the portion that was in contact with molten metal due to the addition of Y, as can be seen from the result of electron probe micro-analysis (EPMA) of FIG. 4, and that this layer was able to effectively reduce the oxygen in the air from penetrating into and reacting with the molten metal. In addition, a mixed layer of CaO and MgO was present in the outer portion of the mixed layer of CaO and Y_2O_3. These double mixed layers help the molten metal remain stable even at high temperatures.

[0049] In addition, comparing comparative example 3 with example 2 and comparative example 6 with example 5, it can be appreciated that the ignition temperature was higher when Ca and Y were added in combination than when Ca was added alone, even though the total content of Ca and Y was less than the content of Ca. This shows that a more excellent effect can be realized in terms of increasing ignition resistance when Ca and Y are added in combination than when Ca is used alone in order to increase the ignition temperature of the Mg alloy.

[0050] In addition, Table 2 presents that the Mg alloy according to example 1 has a very high ignition temperature of 807˚C. This is because Y has a very high content of 1wt%. Thus, it can be appreciated that ignition resistance can significantly increase in response to an increase in the content of Y that is added. Furthermore, in Table 2, the Mg alloy according to example 8 has a very high ignition resistance of 811˚C. This shows that the ignition temperature of the Mg alloy, in which 6wt% of Zn is added, significantly increases when Ca and Y are added respectively in an amount of 1wt%.

Evaluation of Tensile Properties of Mg Alloy

[0051] The sheet materials, which were manufactured by the above-described method, were heat-treated at 250˚C for 30 minutes, and then sub-size sheet-shaped samples according to the ASTM-E-8M standard, in which the length of a gauge was 25mm, were produced. A tensile test was carried out at room temperature under a strain of $1\times10^{-3}s^{-1}$ using a common tensile tester, and the results are presented in Table 3.

[0052] In addition, samples of a rod-shaped extruded material, in which the length of a gauge was 25mm, were manufactured, and tensile test was carried out under the same conditions as for the sheet-shaped samples.

[0053] As presented in Table 3, comparing comparative example 2 with comparative example 3, comparative example 5 with comparative example 6, and comparative example 7 with comparative example 8, it can be appreciated that the yield strength and tensile strength increased but elongation significantly decreased in response to the increase in the content of Ca from 1wt% to 2wt%. This decrease in the elongation is because the fraction of a microscopic precipitate phase of Al_2Ca as well as the fraction of a coarse and hard ternary eutectic phase of Mg-Al-Ca increased, as shown in FIG. 5 (a), when the content of Ca that was added was increased to 2wt%. In contrast, as shown in FIG. 5 (b), when the content of Ca that was added was 1wt%, even though 0.6wt% of Y was included, no coarse and hard ternary eutectic phase of Mg-Al-Ca was observed and thus elongation was not decreased. Likewise, comparing the microscopic structures of the extruded materials of comparative example 1 to comparative example 3 and example 1 with reference to FIG. 6, when the content of Ca that was added was increased to 1wt% and 2wt%, large amounts of black second phases, indicated by the arrows in FIG. 6 (b) and FIG. 6 (c), respectively, were observed, and elongation decreased since the hard second phases were vulnerable to defects.

Table 3

	Alloy Symbol	Tensile Properties					
		YS1) (MPa)	TS2) (MPa)	El3) (%)	UEl4) (%)	TS X UEl (MPa•%)	Remarks
Comp. Ex. 1	AZ31	176.4	274.5	25.2	17.4	4788	RAM5)
		176.8	270.4	26.0	15.3	4142	EM6)
Comp. Ex. 2	AZX311	191.1	276.1	24.3	16.9	4658	RAM
		239.4	294.5	17.1	11.8	3479	EM
Comp. Ex. 3	AZX312	255.2	303.6	16.5	9.7	2943	RAM
		346.0	355.4	9.0	5.8	2045	EM
Comp. Ex. 4	AZ61	218.7	324.0	22.0	17.2	5565	RAM
		166.5	298.1	26.4	21.1	6292	EM
Comp. Ex. 5	AZX611	204.4	306.2	19.7	16.0	4909	RAM
		150.8	276.9	21.2	19.3	5337	EM
Comp. Ex. 6	AZX612	230.0	321.0	16.7	14.1	4536	RAM
		169.9	275.6	19.2	16.4	4533	EM
Comp. Ex. 7	ZX61-F	191.4	268.1	25.4	17.2	4606	EM
Comp. Ex. 8	ZX62-F	294.9	298.5	13.7	9.4	2791	EM
Comp. Ex. 9	ZK60-F	238.4	318.4	24.1	13.5	4298	EM
Example 2	Alloy 2	175.8	265.2	24.7	18.4	4880	RAM
Example 3	Alloy 3	171.1	264.3	26.5	18.4	4856	RAM
Example 4	Alloy 4	175.1	267.4	27.8	16.8	4483	EM
Example 5	Alloy 5	225.7	323.4	19.6	15.5	5020	RAM
Example 8	Alloy 8	156.3	297.6	26.8	22.6	6738	EM
Example 9	Alloy 9	242.1	337.0	16.8	15.3	5157	RAM
Example 10	Alloy 10	215.1	340.2	21.7	19.5	6633	EM
Example 11	Alloy 11	152.0	302.1	33.5	29.1	8780	EM
Example 12	Alloy 12	189.8	323.7	27.3	22.7	7338	EM

(continued)

	Alloy Symbol	Tensile Properties					
		YS1) (MPa)	TS2) (MPa)	El3) (%)	UEl4) (%)	TS X UEl (MPa•%)	Remarks
Example 13	Alloy 13	161.5	276.1	26.8	22.4	6196	RAM
Example 14	Alloy 14	165.9	288.3	30.3	25.9	7467	EM
Example 15	Alloy 15	167.5	280.8	31.3	23.9	6711	EM
Example 16	Alloy 16	175.3	285.7	26.5	22.3	6363	EM
Notes) YS1): Yield Strength, TS2): Tensile Strength, El3): Elongation, UEl4): Uniform Elongation, RAM5): Rolled and Annealed Material, EM6): Extruded Material							

[0054] On the other hand, as shown in FIG. 6 (d), no hard second phase that decreases elongation was observed in the extruded material of an alloy in which each of Ca and Y was added in an amount of 1wt%. This result is more apparent when comparing example 2 with comparative example 3, example 5 with comparative example 6, and example 13 with comparative example 8. Specifically, it can be appreciated that, even though only 1wt% of Ca and 0.6wt% of Y were added in example 2 and example 5, their elongation was very high and their ignition resistance and tensile strength were at levels similar to those of comparative example 3 and comparative example 6, in which 2wt% of Ca was added. Likewise, in example 13, it can be appreciated that the ignition resistance was greatly increased and that the tensile properties, particularly the value of tensile strength × uniform elongation, were greatly increased when 1wt% of Ca and 1wt% of Y were added to the Mg-6Zn-1Al alloy. That is, due to the addition of a small amount of Y, it was possible to produce a Mg alloy of this embodiment in which the content of Ca was maintained low, on the order of 1wt%, but in which the fraction of the coarse and hard ternary eutectic phase was greatly decreased, such that both strength and elongation were improved.

[0055] In addition, comparing example 2 with comparative example 2 and example 5 with comparative example 5, it can be appreciated that example 2 and example 5 contain the same content of Ca that was added in relation to the addition of Y, and have ignition resistance that is superior to that of the case in which Y was not added. At the same time, the value of tensile strength × uniform elongation is further increased.

[0056] This tendency can be appreciated from FIG. 7 and FIG. 8, which show variations in the ignition temperature and tensile properties thereof in response to the total amount of Ca and Y that was added. As shown in FIG. 7, the ignition temperature tends to gradually increase in response to an increase in the total amount of Ca and Y that was added. In particular, it can be appreciated that the slope of the increase in the ignition temperature is further increased when Y is added than when Y is not added. In contrast, as shown in FIG. 8, when Ca is added alone, the value of tensile strength × uniform elongation tends to greatly decrease in response to an increase in the content of Ca that is added, irrespective of the type of hot working. However, when both Ca and Y are added, the mechanical strength thereof is improved more than that of an alloy in which neither Ca nor Y is added. From these results, it can be appreciated that the ignition resistance is greatly increased, and at the same time that tensile properties are greatly improved due to the addition of a small content of Ca and Y at the same time.

[0057] The Mg alloy and the method of manufacturing the same according to exemplary embodiments of the present invention have been described above in detail with reference to the accompanying drawings. However, it will be apparent to a person having ordinary skilled in the art to which the present invention belongs that the foregoing embodiments are merely examples of the invention and various modifications and variations are possible. Therefore, it should be understood that the scope of the invention shall be defined only by the appended claims.

Claims

1. A magnesium alloy manufactured by melt casting, the magnesium alloy comprising, by weight, 1.0% or greater but less than 7.0% of Al, 0.05% to 2.0% of Ca, 0.05% to 2.0% of Y, greater than 0% but not greater than 6.0% of Zn, a balance of Mg, and other unavoidable impurities,
   wherein a total content of the Ca and the Y is equal to or greater than 0.1% but less than 2.5% of a total weight of the magnesium alloy.

2. The magnesium alloy of claim 1, wherein a content of the Ca ranges, by weight, from 0.2% to 1.5%.

3. The magnesium alloy of claim 1, wherein a content of the Y ranges, by weight, from 0.1 % to 1.5%.

4. The magnesium alloy of any one of claims 1 to 3, wherein contents of the Ca and the Y range from 0.3% to 2.0% of a total weight of the magnesium alloy.

5. The magnesium alloy of any one of claims 1 to 3, further comprising, by weight, greater than 0% but not greater than 1.0% of Mn.

6. The magnesium alloy of any one of claims 1 to 3, further comprising, by weight, 0.1 % to 1.0% of Zr.

7. A method of manufacturing a magnesium alloy, comprising:

forming a magnesium alloy molten metal, which contains Mg, Al and Zn;
adding raw materials of Ca and Y into the magnesium alloy molten metal;
producing a magnesium alloy cast material from the magnesium alloy molten metal, in which the raw materials of Ca and Y are added, using a fusion casting method,
wherein a magnesium alloy, which is produced by the above process, comprises, by weight, 1.0% or greater but less than 7.0% of Al, 0.05% to 2.0% of Ca, 0.05% to 2.0% of Y, greater than 0% but not greater than 6.0% of Zn, a balance of Mg, and other unavoidable impurities.

8. The method of claim 7, wherein adding the raw materials of Ca and Y into the magnesium alloy molten metal comprises adding the raw materials of Ca and Y at a temperature higher than 800˚C.

9. A method of manufacturing a magnesium alloy, comprising:

forming a magnesium alloy molten metal, which contains Mg, Al and Zn;
forming a master alloy ingot, which contains Mg, Al, Zn, Ca and Y, and is soluble at 750˚C or lower;
inputting the master alloy ingot, which is soluble at 750˚C or lower, into the magnesium alloy molten metal; and
producing a magnesium alloy cast material from the molten metal, which contains the master alloy ingot, using a fusion casting method,
wherein a magnesium alloy produced as described above comprises, by weight, 1.0% or greater but less than 7.0% of Al, 0.05% to 2.0% of Ca, 0.05% to 2.0% of Y, greater than 0% but not greater than 6.0% of Zn, a balance of Mg, and other unavoidable impurities.

10. The method of claim 9, wherein the master alloy ingot, which contains Mg, Al, Zn, Ca and Y, is soluble at 750˚C or lower, and is input into the magnesium alloy molten metal at a temperature lower than 750˚C.

11. A method of manufacturing a magnesium alloy, comprising:

forming a magnesium alloy molten metal, which contains Mg, Al and Zn;
adding a Ca compound and a Y compound into the magnesium alloy molten metal; and
producing a magnesium alloy cast material from the magnesium alloy molten metal, in which the Ca compound and the Y compound are added, using a fusion casting method,
wherein a magnesium alloy produced by the above process comprises, by weight, 1.0% or greater but less than 7.0% of Al, 0.05% to 2.0% of Ca, 0.05% to 2.0% of Y, greater than 0% but not greater than 6.0% of Zn, a balance of Mg, and other unavoidable impurities.

12. The method of any one of claims 7 to 11, wherein inputting the raw materials of Ca and Y, the master alloy ingot, which contains Mg, Al, Zn, Ca and Y, or the Ca compound and the Y compound into the magnesium alloy molten metal further comprises periodically stirring the magnesium alloy molten metal.

13. The method of any one of claims 7 to 11, wherein the casting method comprises one selected from the group consisting of mold casting, sand casting, gravity casting, squeeze casting, continuous casting, strip casting, die casting, precision casting, lost foam casting, spray casting, and semi-solid casting.

14. The method of any one of claims 7 to 11, further comprising carrying out hot working on the magnesium alloy cast material produced by the casting method.

Fig.1

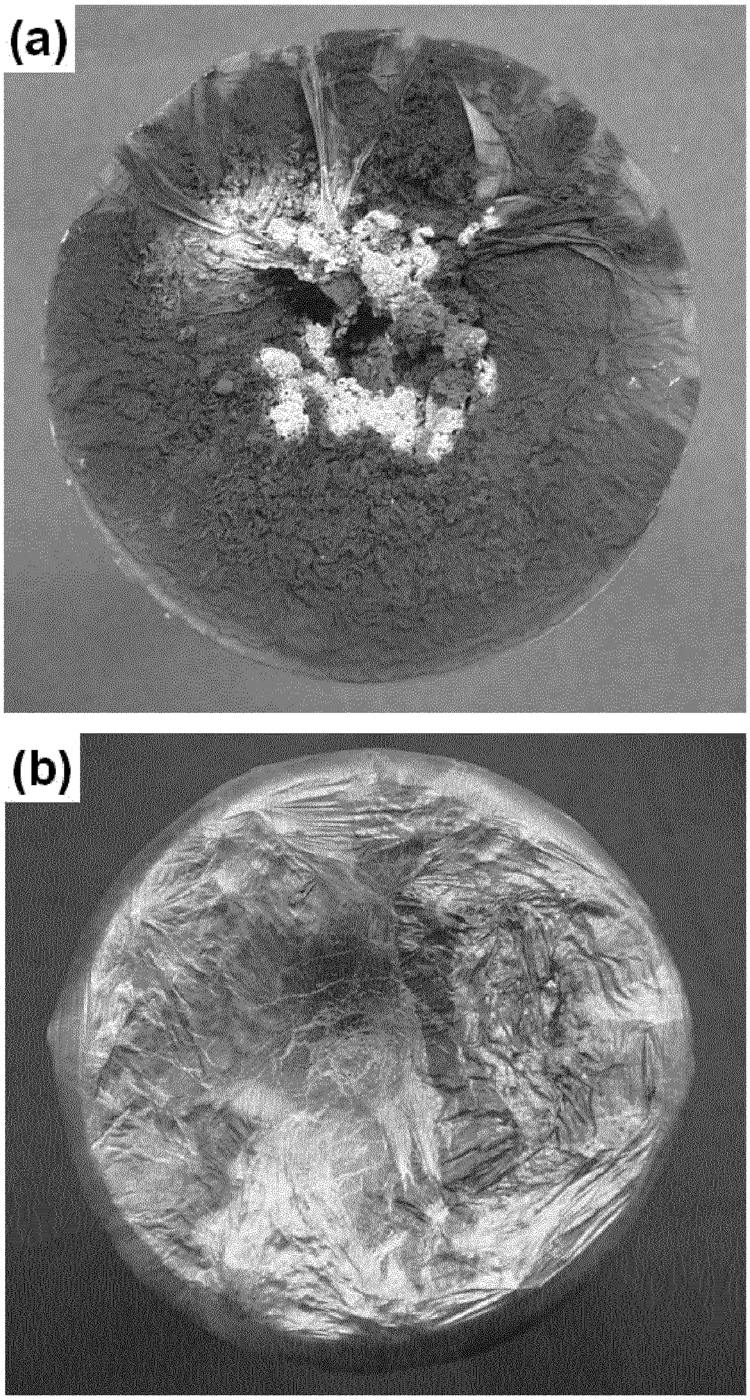


Fig. 2

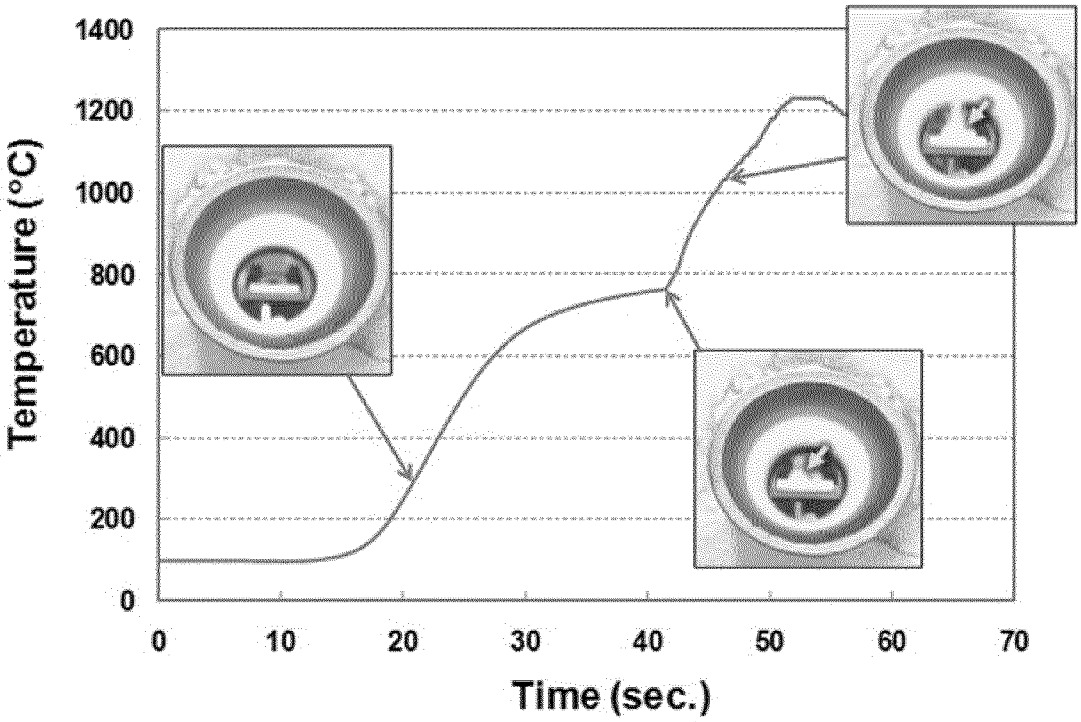

1400
1200
1000
800
600
400
200
0
Temperature (°C)
0
10
20
30
40
50
60
70
Time (sec.)

Fig. 3

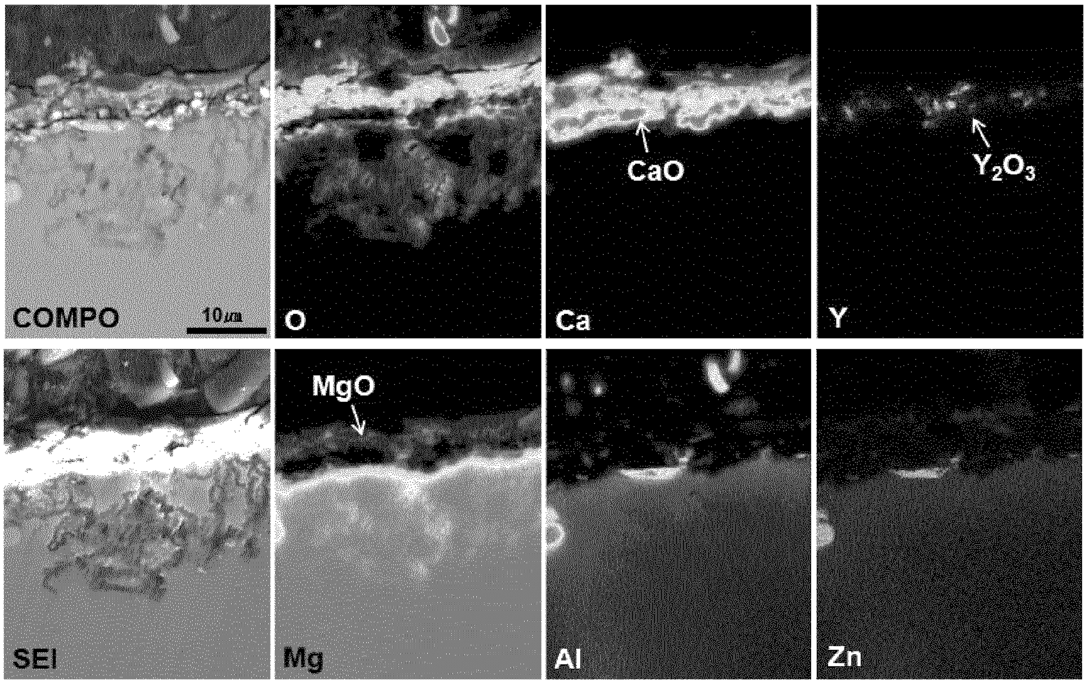

COMPO
10㎛
O
Ca
CaO
Y
Y_2O_3
SEI
MgO
Mg
Al
Zn

Fig. 4

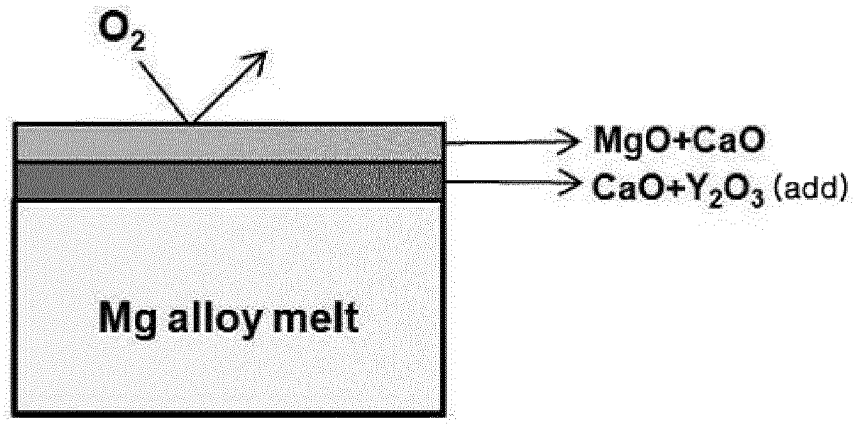

O_2
MgO+CaO
$CaO+Y_2O_3$ (add)
Mg alloy melt

Fig. 5

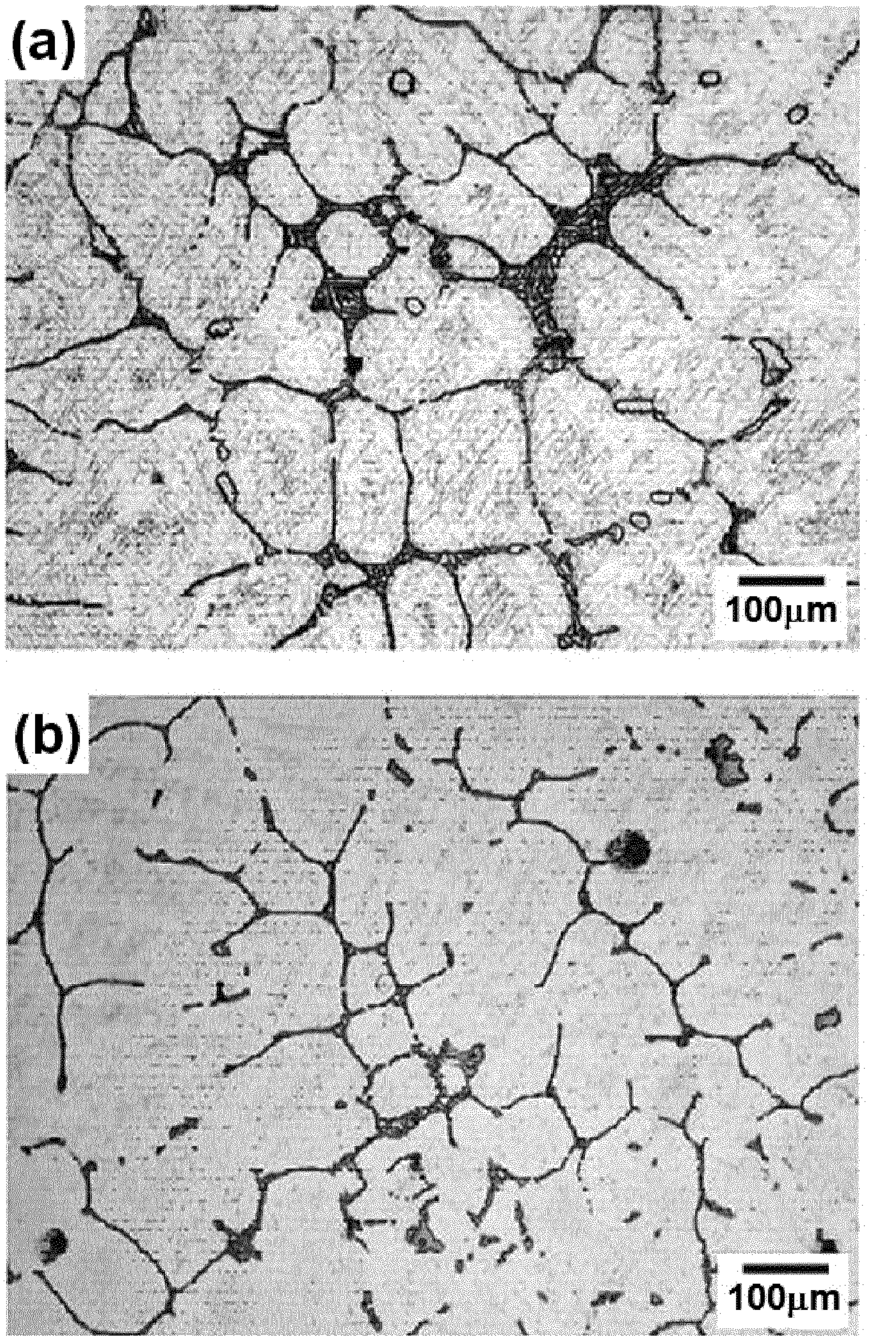


Fig. 6

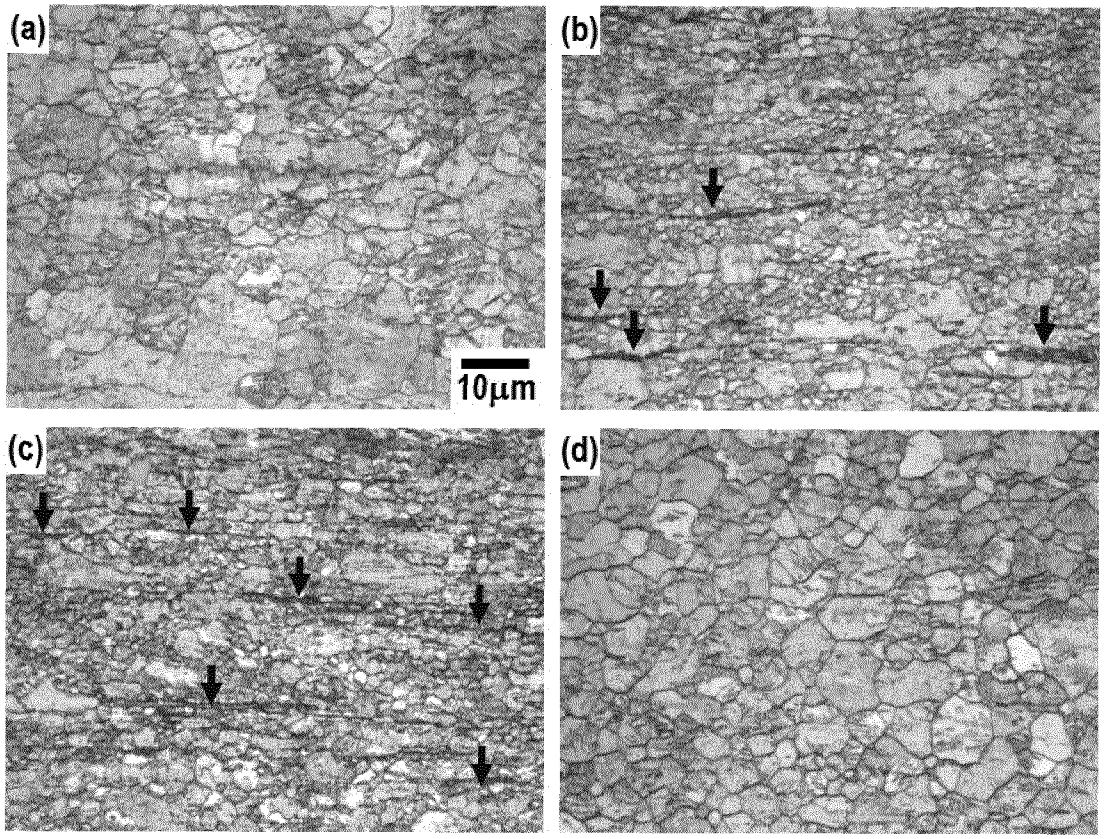


Fig. 7

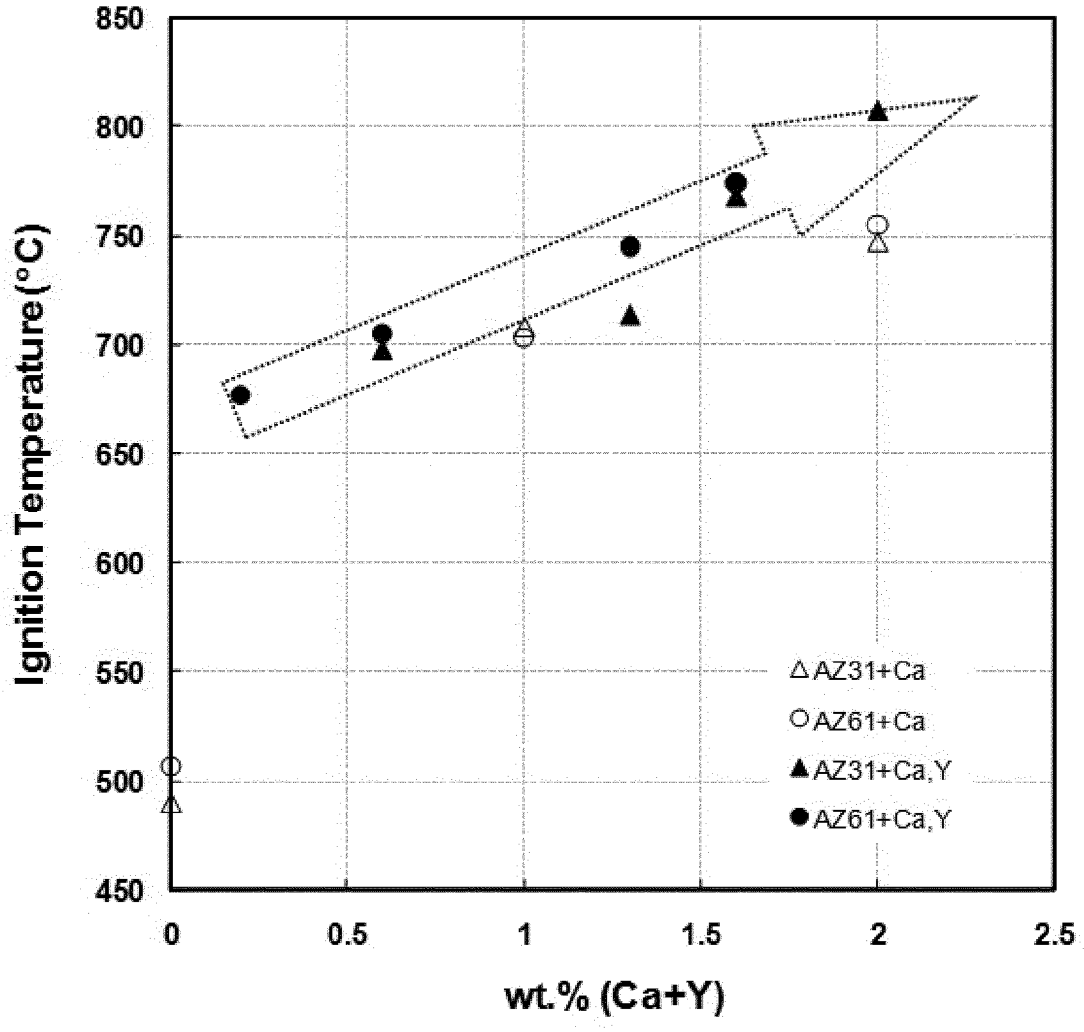
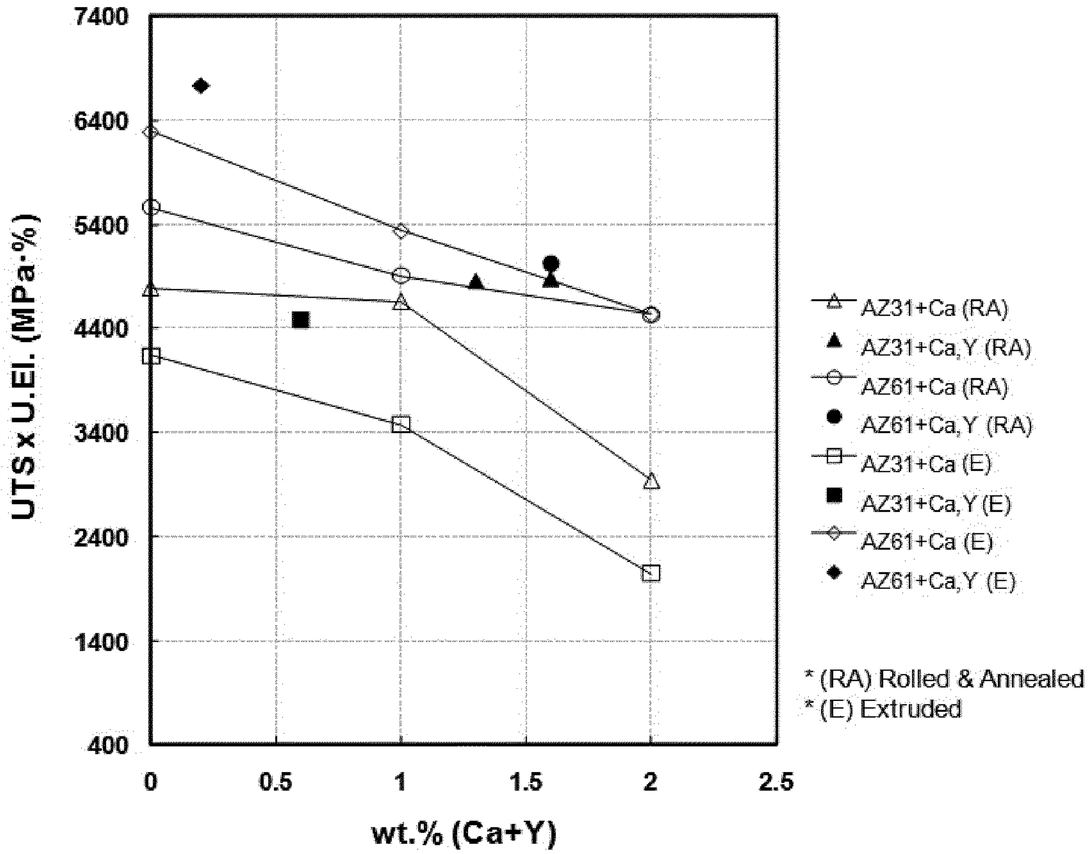

850
800
750
700
650
600
550
500
450
Ignition Temperature(°C)
0
0.5
1
1.5
2
2.5
wt.% (Ca+Y)
△ AZ31+Ca
○ AZ61+Ca
▲ AZ31+Ca,Y
● AZ61+Ca,Y

Fig. 8


7400
6400
5400
4400
3400
2400
1400
400
0
0.5
1
1.5
2
2.5
UTS x U.El. (MPa·%)
wt.% (Ca+Y)
AZ31+Ca (RA)
AZ31+Ca,Y (RA)
AZ61+Ca (RA)
AZ61+Ca,Y (RA)
AZ31+Ca (E)
AZ31+Ca,Y (E)
AZ61+Ca (E)
AZ61+Ca,Y (E)
* (RA) Rolled & Annealed
* (E) Extruded