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(54) **MAGNESIUM ALLOY HAVING HIGH DUCTILITY AND HIGH TOUGHNESS, AND PREPARATION METHOD THEREOF**

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(57) **ABSTRACT**

A magnesium alloy having high ductility and high toughness, and a preparation method thereof are provided, in which the magnesium alloy includes 1.0-3.5 wt % of tin, 0.05-3.0 wt % of zinc, and the balance of magnesium and inevitable impurities, and a preparation method thereof. Magnesium alloy with a relatively small tin content is added with zinc, and optionally, with one or more alloy elements selected from aluminum, manganese and rare earth metal, at a predetermined content ratio. As a result, the alloy exhibits superior ductility and moderate strength due to the suppression of excessive formation of precipitates and some precipitates hardening effect, respectively. Accordingly, compared to extruded material prepared from conventional commercial magnesium alloys, higher ductility and toughness are provided, so that the alloy can be widely applied over the entire industries including automotive and aerospace industries.

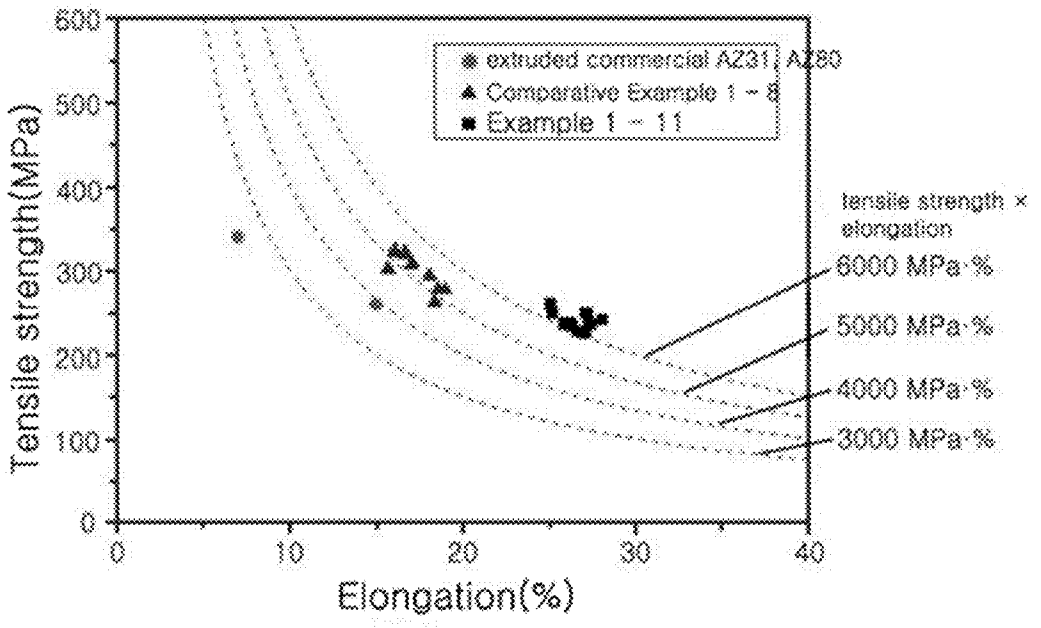


FIG. 1

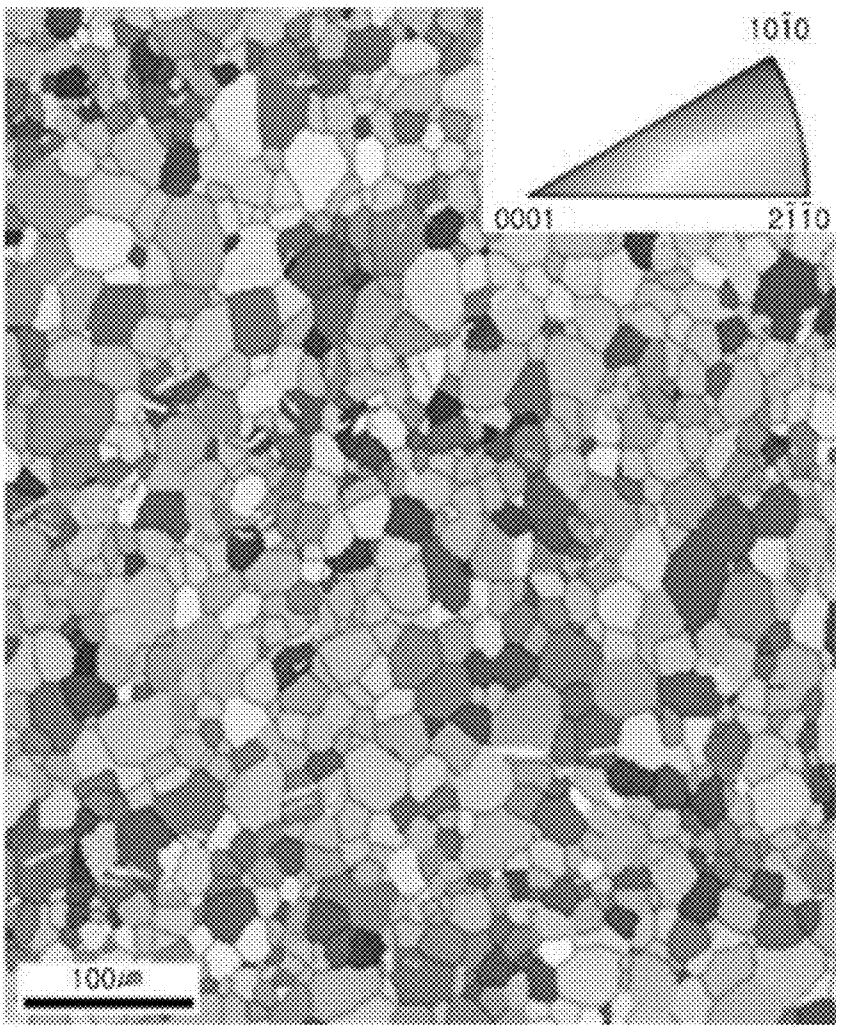


FIG. 2

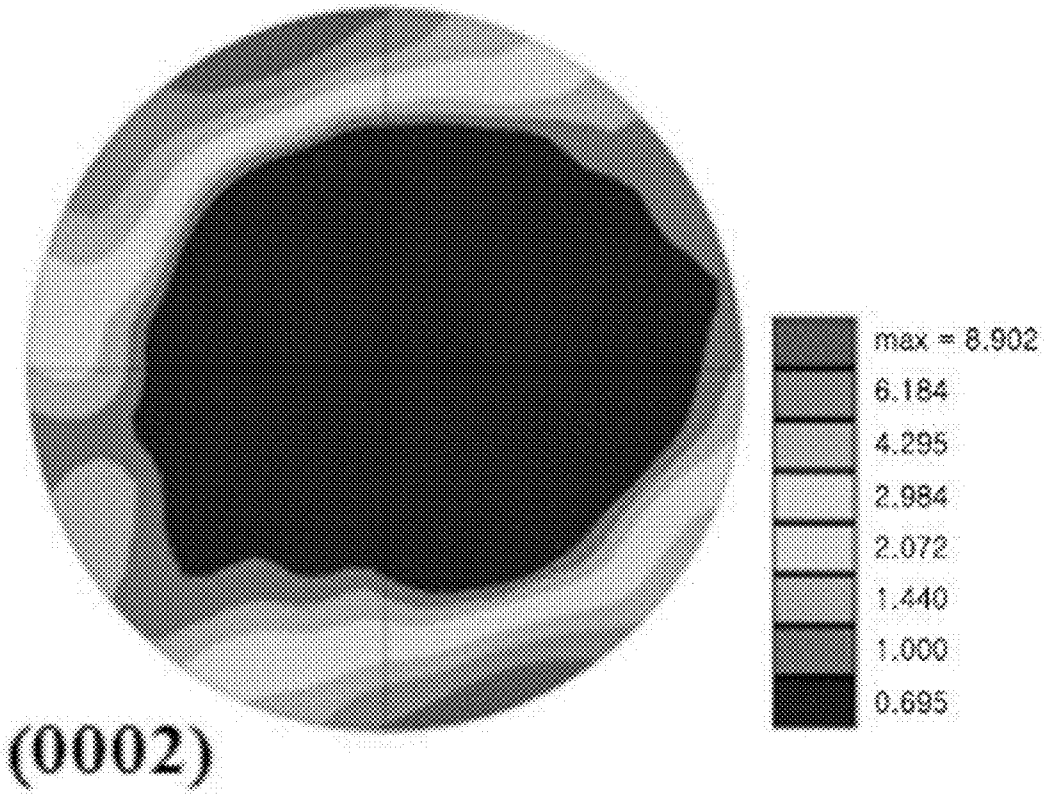


FIG. 3

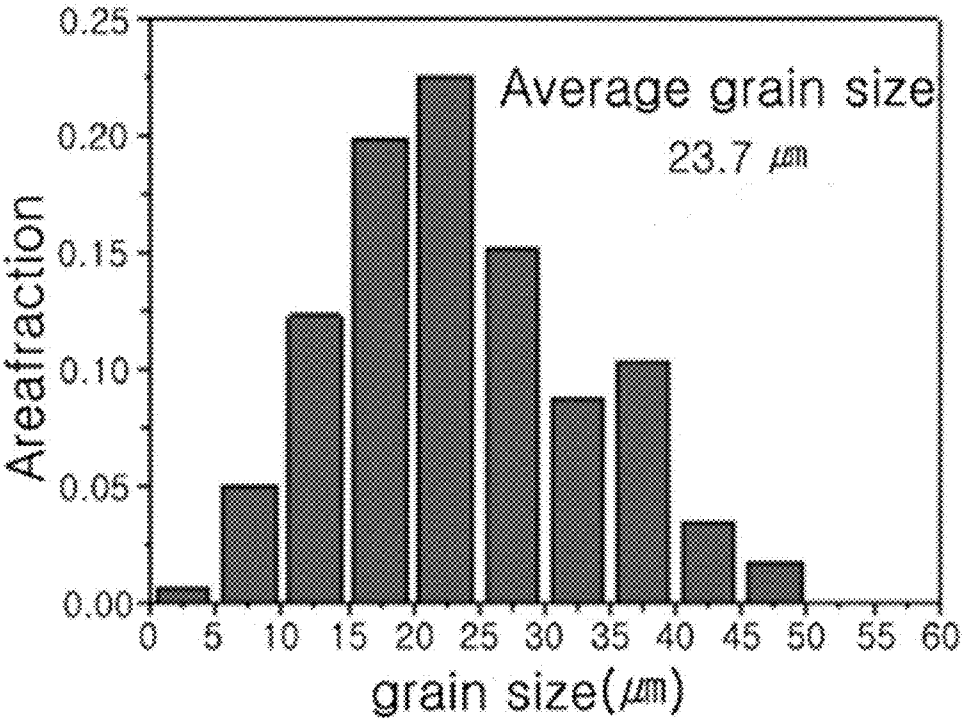

Average grain size
23.7 ㎛
Areafraction
0.25
0.20
0.15
0.10
0.05
0.00
0 5 10 15 20 25 30 35 40 45 50 55 60
grain size(㎛)

FIG. 4

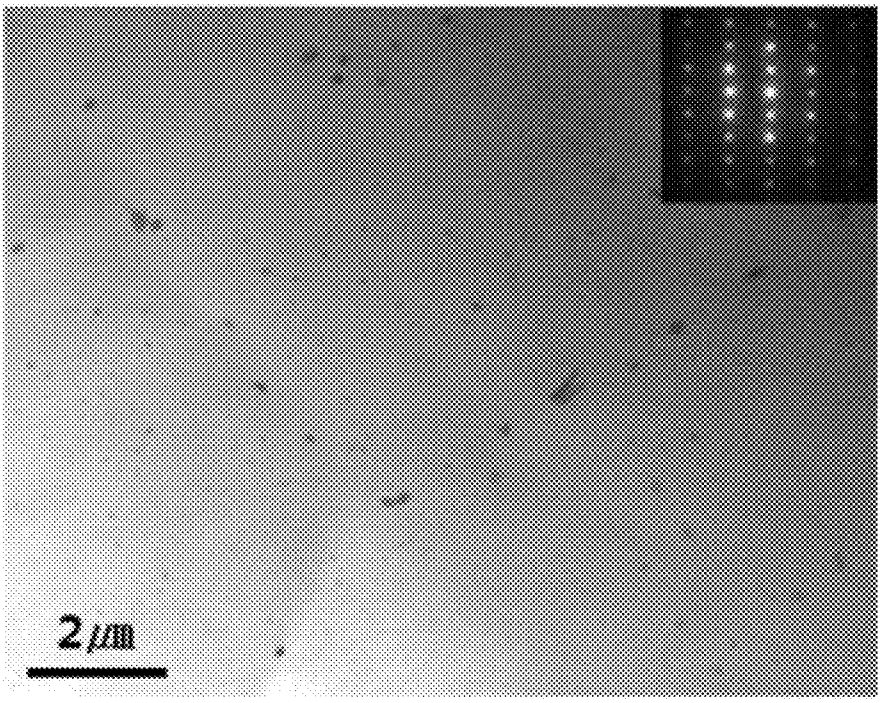
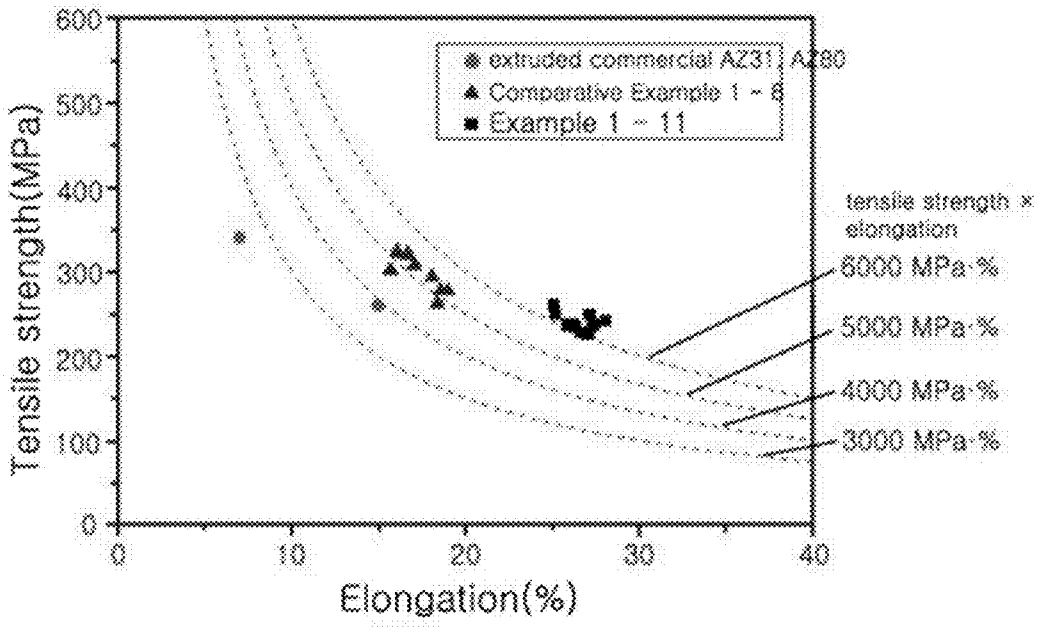


FIG. 5


extruded commercial AZ31
Comparative Example 1 ~ 6
Example 1 ~ 11
tensile strength × elongation
6000 MPa·%
5000 MPa·%
4000 MPa·%
3000 MPa·%
Tensile strength(MPa)
Elongation(%)
0
100
200
300
400
500
600
0
10
20
30
40

MAGNESIUM ALLOY HAVING HIGH DUCTILITY AND HIGH TOUGHNESS, AND PREPARATION METHOD THEREOF

CROSS REFERENCE TO RELATED APPLICATION

[0001] This is a continuation of International Patent Application No. PCT/KR2012/011831, filed Dec. 31, 2012, which claims the benefit Korean Patent Application No. 10-2012-0008995, filed on Jan. 30, 2012. Each of these is incorporated herein by reference in its entirety.

FIELD

[0002] The present invention relates to a magnesium alloy having high ductility and high toughness, and preparation method thereof

BACKGROUND

[0003] Recently, researchers seek ways to further increase energy efficiency of transportation equipments by way of power source development and performance improvement, or light-weighting of parts. Among these efforts, researchers particularly study ways to improve light-weightness and subsequent fuel efficiency, because components of lighter weight can increase energy efficiency at lower cost.

[0004] As a metal material that can be considered for the purpose of light-weighted parts, magnesium alloys are in increasing demand in the transportation machines, portable component-related industry or other area in need of weight reduction, because the magnesium alloys have minimum density (1.8 g/cm^3) among the alloys for structural purpose that have been developed so far, and because these also provide good shielding against electromagnetic waves and vibration absorption.

[0005] However, since magnesium with hexagonal crystalline structure has low formability at room temperature, compared to the other metals with cubic crystalline structure such as copper, iron or aluminum, magnesium has been less considered for extended application in the industries.

[0006] That is, because plastic deformation of a metal is dominantly caused by slip system, the metal with more slip systems in the crystalline structure is more apt to plastic deformation.

[0007] The 'slip' as used herein refers to an irreversible shear displacement of one part of a crystal relative to another in a definite crystallographic direction, which leads into plastic deformation. The slip occurs on a specific crystal plane to a specific crystal direction, and the number of slip systems varies depending on the crystalline structure of a material.

[0008] For example, magnesium with hexagonal close packed (HCP) structure has three (3) slip systems, while the metals such as aluminum, copper or iron with cubic structure have twelve (12) slip systems, thus indicating that magnesium is relatively hardly plastic deformable compared to aluminum, copper or iron.

[0009] Table 1 below lists tensile characteristics of commercial extruded magnesium alloys, indicating that the commercial extruded magnesium alloys developed so far have too low elongation to be applied in the component manufacturing industry considering that this industry generally requires working into a variety of forms.

TABLE 1

Alloy name	Condition	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Tensile strength · elongation (MPa · %)
AZ31	F	200	260	15	3900
	F	250	340	7	2380
AZ80	T5	275	380	7	2660

(In the 'condition' column, letter 'F' denotes extruded material, and T5' denotes extruded material which underwent aging treatment after extrusion.)

[0010] To resolve the problems occurring in the conventional art as mentioned above, researchers have been seeking ways to improve specific strength, ductility and toughness of magnesium alloys so as to extend the application area over the entire industries.

[0011] For example, SHIN et al. attempted to improve mechanical characteristic of AM60 magnesium alloy with good toughness characteristic, by adding aluminum (Al), silicon (Si) and calcium (Ca) thereto (SHIN, Gwang-Sun and others,[Influence of Si and Ca addition to gravity cast AM60 magnesium alloy on consolidation behavior], Korea Foundry Society Journal (Casting), Book 18-4,1998, pp. 364 to 372.) Shin et al. found that as the silicon content increases in the magnesium alloy, the tensile strength and yield strength increase, while the elongation is in decreasing pattern overall. The elongation increases when a certain amount of calcium is added to the alloy, or when the aluminum content is decreased. Shin et al. also found that the alloy with the superior characteristic, e.g., the magnesium alloy that undergoes slag formation to optimize alloy reinforcing, shows 193 MPa of tensile strength, 79 MPa of yield strength and 11.2% of elongation. According to Shin et al., although the magnesium alloy has improved tensile characteristic compared to the other commercial magnesium alloys, the magnesium alloy still has limited formability. Additional reference can be found in Korean Patent Publication No. 10-2001-0019353 (Published date: 2002 Oct. 19) which discloses quasi-crystal phase hardened Mg-based alloy exhibiting superior warm and hot formability. Specifically, KR Pat. 10-2001-0019353 discloses magnesium alloy with superior formability, by employing basic alloy composition of magnesium (Mg)-zinc (Zn)-yttrium (Y), having two-phase region of quasi-crystal phase and metal solid solution present therein, and by regulating the same to such an alloy composition in which zinc content is adjusted to a range of 1 at. % to 10 at. %, and yttrium to a range of 0.1 at. % to 3 at. % (KR 10-2001-0019353 A 2002 Oct. 19). However, the above-mentioned effect was mainly due to the presence of quasi-crystal phase, and therefore, it is necessary to increase the amount of zinc to increase the content of quasi-crystal phase. Therefore, the increasing zinc content causes deteriorating ductility of the material, and it can also cause irregular quality of the final form of magnesium alloy depending on areas.

[0012] The present inventors have been in search for magnesium alloy with superior tensile characteristic, and found that it is possible to fabricate magnesium alloy with superior ductility and toughness by adding zinc and also optionally adding one or more alloy elements selected from the group consisting of aluminum, manganese and rare earth metal at appropriate content ratio to magnesium alloy containing a small tin (Sn) content, and then casting, homogenizing and working the same in a way of suppressing excessive forma-

tion of precipitate in the magnesium alloy that can cause deterioration of ductility, and completed the present invention.

DISCLOSURE

Technical Problem

[0013] An objective of the present invention is to provide a magnesium alloy with high ductility and high toughness.

[0014] Another objective of the present invention is to provide a preparation method of magnesium alloy with high ductility and high toughness.

Technical Solution

[0015] To achieve the above-mentioned and other objectives of the present invention, an embodiment provides a magnesium alloy having high ductility and high toughness, containing 1.0 to 3.5 wt % tin (Sn) and 0.05 to 3.0 wt % zinc (Zn), and remainder magnesium and unavoidable impurities.

[0016] Further, the present invention provides a preparation method of magnesium alloy having high ductility and high toughness, including steps of:

[0017] melting magnesium alloy raw material (Step 1);

[0018] casting the melt of magnesium alloy raw material of Step 1 (Step 2);

[0019] homogenizing the cast of magnesium alloy of Step 2 (Step 3); and

[0020] working the homogenized magnesium alloy cast of Step 3 (Step 4).

Advantageous Effects

[0021] The magnesium alloy according to the present invention can be widely applied over the entire industries including transportation equipments due to relatively higher ductility and toughness than the extruded materials prepared from conventional commercial magnesium alloys, because degradation of ductility due to excessive presence of precipitates is minimized and precipitate hardening effect is provided, by adding zinc and optionally adding one or more species selected from the group consisting of aluminum, manganese and rare earth metal at a predetermined content ratio to a magnesium alloy which has a small tin content and which can have precipitate hardening, thus limiting formation of micro precipitate phase to a small amount.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIG. **1** is inverse pole figure map, as measured by electron back scattered diffraction (EBSD), of TZ22 alloy according to the present invention (FIG. **1**: Example 3).

[0023] FIG. **2** is (0002) basal pole figure, as measured by EBSD, of TZ22 alloy according to the present invention (FIG. **2**: Example 3).

[0024] FIG. **3** is grain size distribution, as measured by EBSD, of TZ22 alloy according to the present invention (FIG. **3**: Example 3).

[0025] FIG. **4** is TEM image of TZ22 alloy according to the present invention (FIG. **4**: Example 3).

[0026] FIG. **5** is a graph showing tensile strength and elongation of the magnesium alloy according to the present invention (FIG. **5**: Examples 1 to 11; Comparative Examples 1 to 8; Commercial AZ31 extrusion material; commercial AZ80 extrusion material).

DETAILED DESCRIPTION

[0027] Prior to explaining the present invention in detail, it is defined that a phrase 'A to B' is understood as a range of 'A or above and less than B'.

[0028] According to the present invention, a magnesium alloy having high ductility and high toughness is provided, which contains 1.0 to 3.5 wt % tin (Sn) and 0.05 to 3.0 wt % zinc (Zn), remainder magnesium (Mg) and unavoidable impurities.

[0029] Further, the present invention provides a preparation method of magnesium alloy having high ductility and high toughness, including steps of:

[0030] melting magnesium alloy raw material (Step 1);

[0031] casting the melt magnesium alloy raw material at Step 1 (Step 2);

[0032] homogenizing the cast of magnesium alloy of Step 2 (Step 3); and

[0033] working the homogenized magnesium alloy cast of Step 3 (Step 4).

[0034] The present invention will be explained in greater detail below.

[0035] Before explaining the present invention in detail, it is noted that the enhanced mechanical characteristic of the magnesium alloy according to the present invention will be explained based on the following principles which are applicable in the pertinent field of art.

[0036] Generally, an alloy becomes stronger than pure metal form when solute atom incorporates into lattice of solvent atom for solid solution. For example, when different metal such as tin, zinc, aluminum, manganese and rare earth metal penetrates into crystal lattice of magnesium metal, or substituted with some of the magnesium atoms, the original mechanical characteristic of the magnesium can alter.

[0037] To be specific, because of the presence of second metal of different size in the atom lattice of the magnesium metal either in interstitial or substitutional manner, the magnesium lattice deforms from the original lattice form, thus altering mechanical characteristic of magnesium itself. This process is called 'solid solution strengthening'.

[0038] The solid solution strengthening can enhance yield strength, tensile strength and hardness of pure metal, and also can enhance resistance at high temperature.

[0039] However, because enhancement of mechanical characteristics such as yield strength, tensile strength and hardness by solid solution strengthening alone is limited, additional metal hardening can be employed, which precipitates second phase from super saturated solid solution with heat treatment, and the resultant alloy with such effects is referred to as 'precipitate hardening alloy'.

[0040] The solvent atoms and solute atoms (second phase) in the precipitate hardening alloy have difference in solid solubility depending on temperatures thereof, and the metal hardens as the temperature decreases and thus the second phase solid solubility decreases to precipitate.

[0041] According to the present invention, the magnesium alloy containing tin has enhanced mechanical characteristic, by additionally including zinc and selectively, aluminum, manganese, cerium, yttrium and gadolinium, according to a predetermined composition ratio.

[0042] The present invention will be explained in detail based on the principles explained above.

[0043] The present invention provides magnesium alloy having high ductility and high toughness, containing 1.0 to

3.5 wt % tin (Sn) and 0.05 to 3.0 wt % zinc (Zn), remainder magnesium (Mg) and unavoidable impurities.

[0044] In the magnesium alloy according to the present invention, the tin has maximum solubility limit of 14.5 wt % in the magnesium matrix at 561° C., and it forms Mg2Sn precipitate phase upon heat treatment to thus show age hardening behavior. The magnesium alloy containing less than 1.0 wt % tin has insufficient amount of Mg2Sn precipitate phase upon extrusion so that the final form of magnesium alloy has insufficient precipitate hardening effect and decreasing strength. On the contrary, the magnesium alloy containing 3.5 wt % or more tin therein has excessive formation of Mg2Sn precipitate phase so that increasing precipitate size causes the final form of magnesium alloy to have deteriorated ductility.

[0045] Further, in the magnesium alloy according to the present invention, zinc is the element that can increase precipitate strengthening effect when added to magnesium-tin alloy, and also enhance strength of the alloy via solid solution strengthening. The magnesium alloy containing less than 0.05 wt % of zinc can hardly have enhanced strength of the alloy by precipitate hardening and solid solution strengthening, while the magnesium alloy containing 3.0 wt % or more zinc can hardly have homogenization at temperature exceeding 360° C. due to low solidus line temperature of the magnesium alloy, resulting in increasing Mg2Sn phase fraction in the structure and subsequently deteriorating elongation of the magnesium alloy.

[0046] Further, the magnesium alloy according to the present invention may additionally include one or more elements selected from the group consisting of aluminum (Al), manganese (Mn) and rare earth metal.

[0047] The magnesium alloy according to the present invention contains the aluminum in an amount of 0.05 to 3.0 wt % with respect to the total weight of the magnesium alloy.

[0048] The aluminum addition to magnesium-tin alloy can enhance precipitate hardening effect and also increase strength of the alloy by way of solid solution. Further, the aluminum combines with manganese to form a variety of dispersion particles, leading to an enhancement of alloy's strength by way of particle strengthening and grain refining. The magnesium alloy containing less than 0.05 wt % aluminum can hardly have the effects mentioned above, while the magnesium alloy containing 3.0 wt % or more aluminum can hardly homogenize at a temperature exceeding 380° C. due to low solidus line temperature of the magnesium alloy, and therefore, subsequently deteriorating elongation of the magnesium alloy.

[0049] Furthermore, the magnesium alloy according to the present invention may preferably include the manganese at an amount of 0.05 to 1.5 wt % with respect to total weight of the magnesium alloy.

[0050] The manganese is the alloy element that brings about not only the solid solution strengthening effect, but also enhanced alloy strength and corrosion resistance by combining with the aluminum mentioned above to form a variety of dispersion particles. The magnesium alloy containing less than 0.05 wt % of manganese can hardly have the effects mentioned above, while the magnesium alloy containing manganese at an amount exceeding 1.5 wt % can have deteriorated elongation of the final form of magnesium alloy due to the presence of coarse manganese particles which are formed in magnesium alloy melt at temperatures below 750° C.

[0051] Further, the magnesium alloy according to the present invention may preferably include the rare earth metal at an amount of 0.05 to 1.5 wt % with respect to total weight of the magnesium alloy.

[0052] The magnesium alloy according to the present invention may additionally include one or more rare earth elements from the group consisting of cerium (Ce), yttrium (Y) and gadolinium (Gd).

[0053] The rare earth element in larger atom size (approximately, 180 pm) than magnesium atom (approximately, 160 pm) coexists with the other elements with a smaller atom size (approximately, 120 pm to 140 pm) such as tin, zinc, aluminum and manganese in the magnesium alloy, and matches well with the magnesium atoms to provide an effect of generating slip plane within the alloy crystal to allow easy deformation during plastic working and also to provide an effect of providing crystal nucleus during solidification to thus form fine cast microstructure. The magnesium alloy containing less than 0.05 wt % of rare earth metal has deteriorating yield strength of the alloy and can have insufficient work hardening effect and corrosion resistance, while the magnesium alloy containing rare earth metal at an amount of 1.5 wt % or more has excessive presence of intermetallic compounds, thus having deteriorated ductility and formability.

[0054] Accordingly, the magnesium alloy according to the present invention can have enhanced elongation, without compromising tensile characteristic thereof, which leads into superior toughness and ductility than the commercial magnesium alloys, by the addition of zinc and by selective addition of one or more elements selected from the group consisting of aluminum, manganese and rare earth metal, to a magnesium-tin alloy base, according to the composition ratio mentioned above.

[0055] Further, the present invention provides a preparation method of magnesium alloy having high ductility and high toughness, including steps of:

[0056] melting magnesium alloy raw material (Step 1);

[0057] casting the melt of magnesium alloy raw material of Step 1 (Step 2);

[0058] homogenizing the cast of magnesium alloy of Step 2 (Step 3); and

[0059] working the homogenized magnesium alloy cast of Step 3 (Step 4).

[0060] The preparation method of magnesium alloy having high ductility and high toughness according to the present invention will be explained below step by step.

[0061] According to the preparation method of magnesium alloy of the present invention, Step 1 involves melting magnesium alloy raw material.

[0062] The magnesium alloy raw material may include 1.0 to 3.5 wt % tin (Sn) and 0.05 to 3.0 wt % zinc (Zn), remainder magnesium and unavoidable impurities.

[0063] Further, the magnesium alloy raw material may additionally include one or more alloying elements selected from the group consisting of 0.05 to 3.0 wt % aluminum, 0.05 to 1.5 wt % manganese, and 0.05 to 1.5 wt % rare earth metal.

[0064] For the rare earth metal, one or more selected from the group consisting of cerium (Ce), yttrium (Y) and gadolinium (Gd) may be selected and used, but not limited thereto.

[0065] According to the preparation method of magnesium alloy of the present invention, the magnesium alloy raw material may include tin, zinc, aluminum, manganese and rare

earth metal which may bring about the effects mentioned above, at specific composition ratios mentioned above for the reasons mentioned above.

[0066] According to the preparation method of magnesium alloy of the present invention, the magnesium alloy raw material may use each of the pure metals or an alloy containing a combination of the metals, but not limited thereto. Accordingly, any preparation method may be employed provided that it allows easy regulation of the composition of the magnesium alloy mentioned above.

[0067] Further, according to the preparation method of magnesium alloy of the present invention, Step 2 relates to casting the melt of magnesium alloy raw material of Step 1.

[0068] The melt of magnesium alloy raw material of Step 1, i.e., the melt of magnesium alloy may preferably be cast at a temperature range of 650° C. to 750° C. The magnesium alloy can hardly be cast at a temperature lower than 650° C. because of low flow rate of the magnesium alloy melt, while the magnesium alloy melt exceeding 750° C. is abruptly oxidized, thus generating oxide (i.e., impurities) which can then ingress in the melt during casting.

[0069] Further, the casting at Step 2 may use gravity casting, continuous casting, sand casting or pressure casting, but not limited thereto. Accordingly, any other generally used method in the pertinent field may be used.

[0070] Further, the melt of magnesium alloy of Step 2 may preferably be formed into billets by casting, but not limited thereto. Accordingly, the melt of magnesium alloy may be cast into a variety of forms depending on use or convenience of person skilled in the art.

[0071] Furthermore, according to the preparation method of magnesium alloy of the present invention, Step 3 homogenizing the cast of magnesium alloy of Step 2.

[0072] The homogenization can change irregular structure caused by segregation of alloying elements formed during casting to homogenized structure, and also improve hot workability and mechanical characteristics of the magnesium alloy.

[0073] The homogenization of the magnesium alloy cast may be performed by heat treatment at a temperature range of 400° C. to 550° C. for a duration of 0.5 hr to 96 hr, followed by quenching. The magnesium alloy cast homogenized at a temperature lower than 400° C. can have insufficient tin content dissolved in the magnesium matrix, which can lead into a decrease of strengthening effect of alloy acquired by the dynamic precipitation occurring during hot plastic working. Further, since the coarse Mg2Sn phase generated at the segregation portion of the cast is not sufficiently eliminated in the heat treatment, ductility of the resultant magnesium alloy can deteriorate. Further, when the homogenization of the magnesium alloy cast is done at a temperature exceeding 550° C., homogenizing at higher heat treatment temperatures than the solidus line temperature of magnesium alloy causes partial melting of the magnesium alloy cast and thus causes irregular structure of the processed material.

[0074] Further, when the homogenization of the magnesium alloy cast is performed at the above-mentioned temperature range for the duration shorter than 0.5 hr, the effect acquired from the heat treatment can be insufficient. When the homogenization of the magnesium alloy cast is performed at the above-mentioned temperature range for the duration exceeding 96 hr, the enhancement effect is not so great compared to the time taken, so that the working is not economical.

[0075] In the homogenization of the magnesium alloy, the magnesium alloy cast may preferably be heat treated and then cooled by water quenching according to the method explained above, but not limited thereto. Accordingly, any quenching may be applied, provided that the quenching does not require a long quenching time which will cause precipitation of coarse Mg2Sn phase during quenching and subsequent deterioration of strengthening effect due to reduced dynamic precipitation during working.

[0076] Further, the operation at Step 3 may additionally include, before the homogenization, a step of pre-heating at a temperature range of 250° C. to 350° C. for the purpose of suppressing local melting phenomenon of second phase due to abrupt temperature rise.

[0077] Further, according to the preparation method of magnesium alloy of the present invention, Step 4 involves working the homogenized magnesium alloy cast of Step 4.

[0078] According to the present invention, to facilitate the working of the magnesium alloy, Step 4 may additionally include a step of pre-heating at a temperature range of 200° C. to 450° C. When the pre-heating temperature is lower than 200° C., the working of the homogenized magnesium alloy cast cannot be performed efficiently, while when the pre-heating temperature exceeds 450° C., such high temperature can deteriorate the strength of the final form of the magnesium alloy due to the grain growth of the magnesium alloy during the working process of the homogenized magnesium alloy cast.

[0079] Further, the working may generally employ extrusion, although not limited thereto. Accordingly, a variety of methods may be employed properly, depending on use or purpose of a worker.

[0080] When extrusion is adopted for the working of the magnesium alloy cast, direct or indirect or continuous extrusion may be employed, although not limited thereto. Accordingly, any method may be properly used to suit use or purpose of a worker.

[0081] Furthermore, the preparation method of the magnesium alloy according to the present invention may additionally include a step of aging treatment after Step 4.

[0082] By the aging treatment, the solute atoms contained in the solvent atoms, e.g., alloy atoms other than magnesium contained in the magnesium matrix, precipitate on the grain boundary or dislocation, thus restraining motion of dislocations to further increase the strength of the magnesium alloy.

[0083] According to the preparation method of magnesium alloy of the present invention, the aging treatment may preferably be performed at a temperature range of 150° C. to 250° C. for a duration of 1 hr to 360 hr. When the aging treatment is performed at a temperature lower than 150° C., time for the magnesium alloy to reach maximum strength is lengthy, which is uneconomical. When the aging treatment is performed at a temperature exceeding 250° C., time for the magnesium alloy to reach the maximum strength can be reduced, but the size of the precipitates increases due to high temperature, so that the strength of the magnesium alloy is eventually deteriorated.

[0084] Further, when the aging treatment is performed at the above-mentioned temperature range for less than 1 hr, the effect acquired from the aging treatment can be insufficient, while when the aging treatment is performed for longer than 360 hr, it is not economical compared to the effect as obtained.

[0085] Accordingly, the magnesium alloy according to the present invention, which includes tin-containing magnesium alloy added with zinc and optionally with one or more elements selected from the group consisting of aluminum, manganese and rare earth metal, at the composition ratio mentioned above, can provide higher ductility and toughness than the conventional tin-containing magnesium alloys or commercial magnesium alloys.

MODE FOR INVENTION

[0086] The present invention will be explained below in detail with reference to Examples. However, the Examples are provided only for the purpose of illustration, and should not be construed as limiting the invention.

EXAMPLES 1 TO 11

Preparation of Extruded Magnesium Alloy Material 1 to 11

Step 1. Melting Magnesium Alloy Raw Material

[0087] Using pure Mg(99.9 wt %), pure Sn(99.9 wt %), pure Zn(99.995 wt %), pure Al(99.9 wt %), Mg—Mn master alloy(Mn:3.17 wt %), pure Ce(99.9 wt %), pure Y(99.9 wt %) and pure Gd(99.9 wt %), the magnesium alloy with the composition as listed in Table 2 below was melt in graphite crucible using high frequency induction melting furnace. A mixed gas of SF6 and CO2 was applied to the top of the melt, to prevent oxidization by isolating the melt from possible exposure to air.

TABLE 2

		Alloying composition(wt %)							
	Alloy	Sn	Zn	Al	Mn	Ce	Y	Gd	Mg
Example 1	TZ20	2	0.5	—	—	—	—	—	Bal.
Example 2	TZ21	2	1	—	—	—	—	—	Bal.
Example 3	TZ22	2	2	—	—	—	—	—	Bal.
Example 4	TZA211	2	1	1	—	—	—	—	Bal.
Example 5	TZA212	2	1	2	—	—	—	—	Bal.
Example 6	TZM210	2	1	—	0.5	—	—	—	Bal.
Example 7	TZAM2110	2	1	1	0.5	—	—	—	Bal.
Example 8	TZ21-Ce	2	1	—	—	0.5	—	—	Bal.
Example 9	TZ21-Y	2	1	—	—	—	0.5	—	Bal.
Example 10	TZ-Gd	2	1	—	—	—	—	0.5	Bal.
Example 11	TZA211-Gd	2	1	1	—	—	—	0.5	Bal.

Step 2. Casting Magnesium Alloy

[0088] The melt of magnesium alloy of Step 1 was maintained at 700° C. for 10 min, and then formed into billet which has 80 mm in diameter and 200 mm in length by pouring into a steel mold pre-heated at 200° C.

Step 3. Homogenization

[0089] The billet of Step 2 was pre-heated under inert atmosphere at 330° C. for 2 hr, and then underwent elevation of temperature at a rate of 1° C./min to 500° C. and heat treatment at 500° C. for 4 hr. To restrain formation of coarse precipitate in the quenching process of billet, water quenching was conducted with room temperature water after the heat treatment.

Step 4. Working

[0090] To work the magnesium alloy, indirect extruder (max extrusion force: 500 tonf) was used to extrude 16 mm rod of the magnesium alloy material (Extrusion condition: billet and die temperature 250° C., extrusion ratio 25, ram speed 1.3 mm/s).

Example 12

Preparation of Extruded Magnesium Alloy Material 12

[0091] The extruded magnesium alloy material was prepared in the same manner as Example 2, except for difference that the extruded magnesium alloy material prepared at Example 2 additionally underwent aging treatment at 200° C. for 144 hr.

Comparative Examples 1 to 8

Preparation of Extruded Magnesium Alloy Material 13 to

[0092] The extruded magnesium alloy material was prepared in the same manner as Example 1, except for the difference of using the magnesium alloy composition as listed in Table 3 below in Step 1.

TABLE 3

		Alloying composition(wt %)				
	Alloy	Sn	Zn	Al	Mn	Mg
Comparative Example 1	TZ51	5	1	—	—	Bal.
Comparative Example 2	TZ52	5	2	—	—	Bal.
Comparative Example 3	TZA511	5	1	1	—	Bal.
Comparative Example 4	TZA513	5	1	3	—	Bal.
Comparative Example 5	TZ81	8	1	—	—	Bal.
Comparative Example 6	TZ82	8	2	—	—	Bal.
Comparative Example 7	TZA813	8	1	3	—	Bal.
Comparative Example 8	TZAM8111	8	1	1	1	Bal.

Experimental Example 1

Microstructure Analysis

[0093] In order to analyze the microstructure of the magnesium alloy fabricated according to the present invention, electron back scattered diffraction (EBSD) and transmission electron microscope (TEM) were used, and the following results were obtained (see FIGS. **1** to **4**).

[0094] Referring to FIGS. **1** to **3**, the magnesium alloy fabricated according to the present invention shows isotropic microstructure, with its basal plane being in parallel arrangement along the direction of extrusion, and average grain size being 23.7 μm.

[0095] Further, referring to FIG. **4**, the extruded magnesium alloy material fabricated according to the present invention has a small amount of fine second-phase (approximately, 50 to 500 nm in size) along the grain boundary and within the grain.

[0096] From the result shown in FIG. **4**, it is concluded that the fine second-phases dispersed along the grain boundary and within the grain of the extruded magnesium alloy material are the Mg2Sn phase formed by dynamic precipitation

during the extrusion process of the magnesium alloy, which will induce precipitate hardening effect of the magnesium alloy.

Experimental Example 2

Mechanical Characteristic Evaluation

[0097] In order to evaluate tensile characteristics of the extruded magnesium alloy material fabricated according to the present invention, cylindrical tensile samples were prepared (gauge length: 25 mm, gauge diameter: 6 mm), and tensile properties were tested at room temperature with a strain rate of 1×10-3 s-1 using tensile testing equipment (INSTRON 4206), and the results are shown in Table 4 below and FIG. **5** (FIG. **5**: Examples 1 to 11; Comparative Examples 1 to 8; extruded commercial AZ31 alloy material; extruded commercial AZ80 alloy material).

[0098] Generally, a metallic material has decreasing tensile strength when the elongation increases, and has decreasing elongation when the tensile strength increases. That is, when the tensile strength and elongation, which are in inverse relationship with each other, are multiplied by each other, the resultant value, i.e., 'tensile strength×elongation (MPa·%)' can be used as a reference to compare the tensile properties of metallic materials in view of two aspects (i.e., strength and ductility), so that a greater 'tensile strength×elongation' is considered to be indicative of better tensile properties. Additionally, since the above value is in proportional relationship with the energy that can be absorbed by the metallic material during fracture, the higher value also indicates higher toughness.

TABLE 4

	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Tensile strength × elongation (MPa · %)
Example 1	149	227	26.7	6061
Example 2	144	226	27.1	6125
Example 3	136	233	26.4	6151
Example 4	146	236	27.4	6466
Example 5	154	249	27.2	6773
Example 6	170	249	25.2	6275
Example 7	177	260	25.1	6526
Example 8	155	236	26.3	6207
Example 9	155	235	27.3	6416
Example 10	158	236	25.9	6112
Example 11	149	241	28.1	6772
Comparative Example 1	188	262	18.4	4821
Comparative Example 2	191	277	18.6	5152
Comparative Example 3	190	277	19.0	5263
Comparative Example 4	195	308	17.1	5267
Comparative Example 5	241	294	18.1	5321
Comparative Example 6	238	302	15.7	4741
Comparative Example 7	221	323	16.1	5200
Comparative Example 8	264	320	16.7	5344

[0099] Referring to Table 4 above, the magnesium alloys fabricated according to the present invention shows 24% enhancement of elongation compared to the conventional high-strength magnesium alloys, without considerably compromising the strength thereof.

[0100] Accordingly, the magnesium alloys fabricated according to the present invention have superior combination of strength and ductility (with tensile strength×elongation value exceeding 6000 MPa·%) and thus exhibit improved tensile properties than commercial magnesium alloys in Table 1 (tensile strength×elongation value lower than 4000 MPa·%) or magnesium alloys of Comparative Examples 1 to 8 (tensile strength×elongation value lower than 5500 MPa·%).

[0101] From the above findings, it is confirmed that the magnesium alloy fabricated according to the present invention can provide superior ductility and toughness without considerably compromising strength when compared with conventional magnesium alloys, and thus the magnesium alloy can be applied to the weight lightening of the components across the entire industries including automotive, aerospace, or the like.

We claim:

1. A magnesium alloy having high ductility and high toughness comprising 1.0 to 3.5 wt % tin (Sn), 0.05 to 3.0 wt % zinc (Zn), remainder magnesium (Mg) and unavoidable impurities.

2. The magnesium alloy as set forth in claim **1**, wherein the magnesium alloy further comprises one or more alloying elements selected from the group consisting of aluminum (Al), manganese (Mn) and rare earth metal.

3. The magnesium alloy as set forth in claim **2**, wherein the aluminum is contained in an amount of 0.05 to 3.0 wt %.

4. The magnesium alloy as set forth in claim **2**, wherein the manganese is contained in an amount of 0.05 to 1.5 wt %.

5. The magnesium alloy as set forth in claim **2**, wherein the rare earth metal is contained in an amount of 0.05 to 1.5 wt %.

6. The magnesium alloy as set forth in claim **2**, wherein the rare earth metal is one or more selected from the group consisting of cerium (Ce), yttrium (Y) and gadolinium (Gd).

7. A preparation method of a magnesium alloy having high ductility and high toughness, comprising:

melting magnesium alloy raw material (Step 1);

casting the melt of magnesium alloy raw material of Step 1 (Step 2);

homogenizing the cast of magnesium alloy of Step 2 (Step 3); and

working the homogenized magnesium alloy cast of Step 3 (Step 4).

8. The preparation method as set forth in claim **7**, wherein the magnesium alloy raw material of Step 1 comprises 1.0 to 3.5 wt % tin (Sn), 0.05 to 3.0 wt % zinc (Zn), remainder magnesium (Mg) and unavoidable impurities.

9. The preparation method as set forth in claim **7**, wherein the magnesium alloy raw material of Step 1 further comprises: 0.05 to 3.0 wt % aluminum (Al); 0.05 to 1.5 wt % manganese (Mn); and 0.05 to 1.5 wt % rare earth metal.

10. The preparation method as set forth in claim **9**, wherein the rare earth metal is one or more selected from the group consisting of cerium (Ce), yttrium (Y) and gadolinium (Gd).

11. The preparation method as set forth in claim **7**, wherein the casting of Step 2 is performed at a temperature range of 650° C. to 750° C.

12. The preparation method as set forth in claim **7**, wherein the homogenizing of Step 3 comprises heat treatment at a temperature range of 400° C. to 550° C. for a duration of 0.5 hr to 96 hr, and quenching.

13. The preparation method as set forth in claim **12**, wherein the homogenizing of Step 3 is performed after pre-heating at a temperature range of 250° C. to 350° C.

14. The preparation method as set forth in claim **7**, wherein the working of Step 4 is performed after pre-heating at a temperature range of 200° C. to 450° C.

15. The preparation method as set forth in claim **7**, wherein the preparation method further comprises a step of performing aging treatment after Step 4.

16. The preparation method as set forth in claim **15**, wherein the aging treatment is performed at a temperature range of 150° C. to 250° C. for a duration of 1 hr to 360 hr.

17. A magnesium alloy having high ductility and high toughness prepared by the method as set forth in claim **7**.

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