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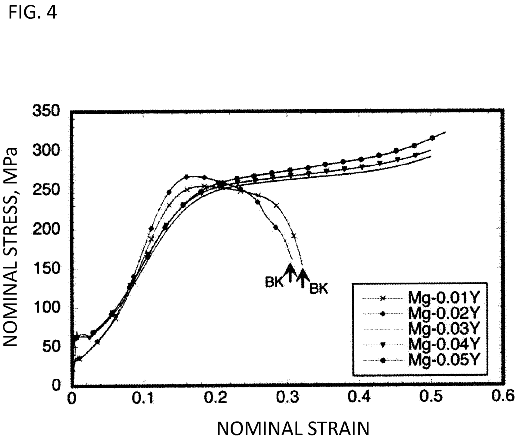
(54) MAGNESIUM ALLOY, MAGNESIUM ALLOY MEMBER AND METHOD FOR MANUFACTURING SAME, AND METHOD FOR USING MAGNESIUM ALLOY

(57) A magnesium alloy of the present invention has the chemical composition that contains 0.02 mol% or more and less than 0.1 mol% of at least one element selected from yttrium, scandium, and lanthanoid rare earth elements, and magnesium and unavoidable impurities accounting for the remainder. A magnesium alloy member of the present invention is produced by hot plastic working of the magnesium alloy in a temperature range of 200°C to 550°C, followed by an isothermal heat treatment performed in a temperature range of 300°C to 600°C. The magnesium alloy is preferred for use in applications such as in automobiles, railcars, and aerospace flying objects. The magnesium alloy and the magnesium alloy member can overcome the yielding stress anisotropy problem, and are less vulnerable to the rising price of rare earth elements.

FIG. 4



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Description

Technical Field

[0001] The present invention relates to magnesium alloys that contain trace amounts of yttrium, scandium, and lanthanoid rare earth elements, and to magnesium alloy members that allow for easy plastic working in cold and room temperature ranges.

[0002] The present invention also relates to a method for manufacturing a magnesium alloy member that allows for easy cold working, and that is preferred for use in applications such as in automobiles, railcars, aerospace flying objects, and housings of electronic devices.

Background Art

[0003] These types of magnesium alloys are desired in applications where light structural members are needed. Examples of such structural member applications include automobiles, railcars, aerospace flying objects, and housings of electronic devices. However, use of magnesium alloys as structural members has not been realized because of the considerable difficulties involved in the plastic working in cold and room temperature ranges. Wrought magnesium alloys produced by processes such as press-rolling and extrusion are also problematic in terms of yielding stress anisotropy, because the basal plane {0001} crystal orientation becomes in line with the working direction, and creates a large difference between the tensile and compression yielding stresses. As used herein, "cold temperature" means ordinary temperature or a temperature below the recrystallization temperature of the material. The cold working temperatures of magnesium alloys are typically 200°C or less.

[0004] PTL 1 and PTL 2 disclose wrought magnesium alloys that contain 0.1 to 1.5 mol% of yttrium. These wrought magnesium alloys advantageously overcome the yielding stress anisotropy problem, and have excellent cold workability. A problem, however, is that these materials contain yttrium, and are vulnerable to the rising price of yttrium.

[0005] PTL 3 and PTL 4 disclose rolled magnesium alloys that contain 0.01 to 0.5 mol% of yttrium. The advantage of these rolled magnesium alloys is the low yttrium content. However, the basal plane is in line with the press-roll direction (PTL 4, FIG. 1), and it is not difficult to imagine that a large difference occurs between the tensile and compression yielding stresses.

[0006] PTL 5 and PTL 6 disclose rolled magnesium alloys that contain only trace amounts of yttrium for easy workability. These rolled magnesium alloys contain 6 to 16 mass% of lithium, and the β phase of the BCC (body-centered cubic lattice) structure is dispersed in the α phase of the HCP (hexagonal close-packed) structure to improve workability. However, the use of the active element lithium severely impairs the corrosion resistance of the material, and poses a safety problem.

[0007] PTL 7 discloses a magnesium alloy in which quasicrystal grains are dispersed in the magnesium matrix in order to reduce yielding stress anisotropy. However, this magnesium alloy is a Mg-Zn-Re alloy, containing rare earth elements in a content of 0.2 to 1.5 mol%. A problem, then, is that the material is vulnerable to the rising price of rare earths. There is indeed a need to reduce the rare earth content.

[0008] PTL 8 discloses a wrought magnesium alloy that contains 0.03 to 0.54 mol% of yttrium. This wrought magnesium alloy has an average magnesium crystal grain diameter of 1.5 μm or less, and a high concentration of yttrium is segregated in the vicinity of the grain boundary to improve material strength. The solute element remains at high concentration in the vicinity of the grain boundary when the size of matrix is fine and the percentage volume of the grain boundary is high. However, the solute element exists in a solid solution state not in the vicinity of the crystal grain boundary but inside the size of matrix in applications where the crystals have coarse grain diameters (for example, 10 μm or more). The material cannot have high strength in this case.

Citation List

Patent Literature

[0009]

PTL 1: WO2010/010965
PTL 2: WO2008/117890
PTL 3: JP-A-2010-13725
PTL 4: JP-A-2008-214668
PTL 5: JP-A-2003-226929
PTL 6: JP-A-9-41066

PTL 7: JP-A-2010-222645
PTL 8: Japanese Patent No. 4840751

Summary of Invention

Technical Problem

[0010] In magnesium alloys, strength and ductility are improved by making fine grains using press-rolling, extrusion, and other processes that apply strain, as with the case of other metallic materials. However, the basal plane {0001} becomes in line with the working direction, specifically a basal plane texture is formed during the hot working for reasons attributed to the magnesium crystal structure. For example, the crystal orientation of the basal plane of press-rolled or extruded magnesium aligns parallel to the press-roll or extrusion direction. This is problematic in terms of yielding stress anisotropy, because the compression yielding stress is only 50% to 60% of the tensile yielding stress. There have been attempts to overcome this problem by dispersing quasicrystal grains (PTL 7) or producing alloys (PTLs 1 to 6). However, all of these techniques involve addition of 0.1 mol% or more of rare earth elements, and are vulnerable to the rising price of rare earths.

Solution to Problem

[0011] According to a first aspect of the present invention, there is provided a magnesium alloy that comprises 0.02 mol% or more and less than 0.1 mol% of yttrium, scandium, or lanthanoid rare earth elements, and Mg and unavoidable impurities accounting for the remainder. The magnesium alloy has a homogenous composition, and a homogenous crystal structure with an average grain size of several micrometers and several ten micrometers.

[0012] According to a second aspect of the present invention, there is provided a magnesium alloy member that is produced by hot plastic working of the magnesium alloy of the chemical composition of the first aspect of the invention in a temperature range of 200°C to 550°C, followed by an isothermal heat treatment performed in a temperature range of 300°C to 600°C. The isothermal heat treatment is a process by which a magnesium alloy sample is placed in a maintained constant temperature bath, maintained for a predetermined time period, and slowly cooled in air outside of the bath. The magnesium alloy member may be a wrought magnesium member such as a plate member, a rod member, and a pipe member.

[0013] A third aspect of the present invention is the magnesium alloy member according to the second aspect in which the crystal structure of the member is an equiaxial grain structure with no texture. Equiaxial grain means a three-dimensionally isotropic crystal grain structure that does not stretch or flatten unidirectionally. Texture, or crystal texture as it is also called, refers to a distribution state of the crystal lattice orientation (crystal orientation) of each crystal grain present in a polycrystalline material such as metal. For example, solidifying a cubical crystal metal forms a preferred orientation [100]. In the case of magnesium, the basal plane {0001} tends to align in the strain applying direction, as noted above.

[0014] A fourth aspect of the present invention is the magnesium alloy member according to the second or third aspect in which the average grain size is 10 μm or more.

[0015] A fifth aspect of the present invention is the magnesium alloy members according to any one of the second to fourth aspect in which a compressional nominal strain of 0.4 or more is applied by cold working performed in a temperature range of from room temperature (here and below, room temperature means 15°C to 35°C) to 150°C.

[0016] A sixth aspect of the present invention is the magnesium alloy members according to any one of the second to fifth aspect in which the average grain size of the magnesium alloy after cold working performed in a temperature range of from room temperature to 150°C is 80% or less of the initial average grain size (undeformed magnesium alloy).

[0017] A seventh aspect of the present invention is the magnesium alloy member according to the third aspect in which the strength and hardness of the member after applying nominal strain by cold working performed in a temperature range of from room temperature to 150°C are 15% greater than strength and hardness of the undeformed ones.

[0018] A first method of the present invention is a method for producing a magnesium alloy member, the method comprising: hot plastic working of a magnesium alloy that contains 0.02 mol% or more and less than 0.1 mol% of at least one element selected from yttrium, scandium, and lanthanoid rare earth elements, and Mg and unavoidable impurities accounting for the remainder, the hot plastic working being performed in a temperature range of 200°C to 550°C; and an isothermal heat treatment of the magnesium alloy in a temperature range of 300°C to 600°C after the hot plastic working.

[0019] A second method of the present invention is a method for using a magnesium alloy that contains 0.02 mol% or more and less than 0.1 mol% of at least one element selected from yttrium, scandium, and lanthanoid rare earth elements, and Mg and unavoidable impurities accounting for the remainder, the method comprising using the magnesium alloy as a wrought magnesium member after hot plastic working performed in a temperature range of 200°C to 550°C, and a subsequent isothermal heat treatment performed in a temperature range of 300°C to 600°C.

Advantageous Effects of Invention

[0020] The present invention induces room temperature recrystallization (grain refining) by controlling the dispersion state of one or more elements selected from yttrium, scandium, and lanthanoid rare earth elements in a magnesium alloy. This makes it possible to develop excellent compressional deformation characteristics. The magnesium alloy member of the present invention overcomes the yielding stress anisotropy problem with its random crystal orientation distribution (after working), and has the same yielding stress for the tensile and compressional deformation with the maintained high strength. Further, the magnesium alloy member of the present invention does not break even under a large applied compressional strain in excess of 50%, and has excellent deformability. Because of the considerably low yttrium, scandium, and lanthanoid rare earth element content, the magnesium alloy of the present invention is less vulnerable to the material price of yttrium, scandium, and lanthanoid rare earth elements as compared to conventional rare earth-containing magnesium alloys.

Brief Description of Drawings

[0021]

[FIG. 1] FIG. 1 is a photographic representation showing the appearance of a material when the hot working temperature is in the appropriate range.
[FIG. 2] FIG. 2 represents the nominal stress-nominal strain curve obtained after the room-temperature tensile and compression testing of extruded material Mg-0.05Y and extruded and heat-treated material Mg-0.05Y.
[FIG. 3] FIG. 3 represents the nominal stress-nominal strain curve obtained after the room-temperature compression testing of extruded material Mg-Y alloy.
[FIG. 4] FIG. 4 represents the nominal stress-nominal strain curve obtained after the room-temperature compression testing of extruded and heat-treated material Mg-Y alloy.
[FIG. 5] FIG. 5 represents the nominal stress-nominal strain curve obtained after the room-temperature compression testing of cast and heat-treated material Mg-1 mol% Y.
[FIG. 6] FIG. 6 is a photographic representation of the observed scanning electron micrograph/electron backscatter diffraction image of extruded and heat-treated material Mg-0.03Y.
[FIG. 7] FIG. 7 shows a pole figure image of the region observed in FIG. 5, in which ED and TD are directions parallel to and perpendicular to extrusion direction, respectively.
[FIG. 8] FIG. 8 is a photographic representation of extruded and heat-treated material Mg-0.03Y as observed by scanning electron microscopy/electron backscatter diffraction after applying 20% compressional strain.
[FIG. 9] FIG. 9 is a photographic representation of extruded and heat-treated material Mg-0.03Y as observed by scanning electron microscopy/electron backscatter diffraction after applying 50% compressional strain.
[FIG. 10] FIG. 10 is a photographic representation showing the appearance of a material at a low hot working temperature.

Description of Embodiments

[0022] The magnesium alloy of the present invention contains at least one element selected from yttrium, scandium, and lanthanoid rare earth elements, as mentioned above. A magnesium alloy containing yttrium, and an alloy member of such an alloy will be described below as embodiments of the magnesium alloy and the magnesium alloy member of the present invention.
[0023] For the magnesium alloy member of the present invention to exhibit effect, hot plastic working (hereinafter, also referred to as "hot working") of a magnesium alloy is required to segregate yttrium to a grain boundary, and the yttrium needs to be diffused in the grain interior by isothermal heat treatment. The procedures are as follows.
[0024] For the magnesium alloy member of the present invention to exhibit effect, the magnesium alloy contains yttrium in 0.02 mol% or more and less than 0.1 mol%, and magnesium and unavoidable impurities accounting for the reminder. The yttrium content is preferably 0.025 mol% or more and less than 0.1 mol%, more preferably 0.025 mol% or more and less than 0.05 mol%. When the yttrium content is 0.02 mol%, the yttrium exists at 19.5×10^{-10} m radius intervals. This value corresponds to the magnitude about three times the Burgers vector of magnesium, and represents a value that limits the interactions of lattice defects such as dislocations in terms of atomic binding theory. The grain size that allows the yttrium to homogenously segregate to a grain boundary by the hot working becomes coarser as the yttrium content decreases. It is, however, difficult to obtain the effect because the estimated average grain size after the hot working is 10 μm or more. Here, the Burgers vector represents the distorted direction of atoms around a dislocation line

introduced as a crystallographic linear crystal defect. In edge dislocations, the dislocation line and the Burgers vector are perpendicular to each other, whereas these are parallel to each other in screw dislocations.

[0025] The hot plastic working temperature is preferably 200°C to 550°C, more preferably 250°C to 350°C. When the working temperature is below 200°C, the low working temperature makes dynamic recrystallization less likely to occur.

[0026] FIG. 1 is a photographic representation showing the appearance of a material when the hot working temperature is in the appropriate range. FIG. 10 is a photographic representation showing the exterior of a material at a low hot working temperature. By comparing FIG. 1 and FIG. 10, it can be seen that an appropriate magnesium alloy member can be produced by setting the hot working temperature in the appropriate temperature range. Above 550°C, the high working temperature makes it difficult to produce an average grain size of 10 μm or less. There is also a potential problem in mold lifetime such as in extrusion. The hot working is typically extrusion, forging, press-rolling, or drawing. However, any plastic working may be used, as long as strain can be applied. The equivalent plastic strain during strain application is 1.5 or more, preferably 2.0 or more. When the equivalent plastic strain is less than 1.5, a sufficient strain cannot be applied, and a mixed structure of coarse grains and fine grains appears, making it difficult to homogenously segregate the yttrium in the vicinity of the grain boundary. With the isothermal heat treatment of a cast material alone without the hot working, the yttrium does not homogenously diffuse and disperse in the grain interior, and fracture occurs at a nominal strain of about 0.3 as shown in FIG. 5. That is, the effects of the present invention cannot be obtained.

[0027] The temperature of the isothermal heat treatment is preferably equal to or greater than the hot working temperature, so that the yttrium segregated at the grain boundary can diffuse in the grain interior. Specifically, temperature of the isothermal heat treatment is preferably 300°C to 600°C, more preferably 350°C to 450°C. A heat treatment temperature above 600°C may cause the material to burn during the heat treatment. The retention time, which varies with the heat treatment temperature, is preferably 3 minutes to 24 hours. A retention time longer than 24 hours has the possibility of causing abnormal grain growth during the heat treatment.

[0028] The magnesium alloy member having an equiaxial grain structure with no texture can be obtained in this manner. It is also possible to obtain a magnesium alloy member having an average grain size of 10 μm or more, for example 30 μm to 50 μm.

[0029] The magnesium alloy member may be subjected to cold plastic working (hereinafter, also referred to as "cold working") in a temperature range of from room temperature to 150°C. For example, a compressional nominal strain of 0.4 or more can be applied. The upper limit is 1.5. The cold working refines the crystal grains of the magnesium alloy member. For example, the size of matrix can be refined to 80% or less of the average grain size of the magnesium alloy member after the cold working. The lower limit is 5%, though it is not particularly limited.

[0030] Refining of the crystal grains by cold working can increase the hardness and strength of the magnesium alloy member. For example, the hardness of the magnesium alloy member can be increased 15% or more after the cold working. The strength of the magnesium alloy member also can be increased 15% or more after the cold working.

[0031] As described above, in the present embodiment, the dispersion state of yttrium is controlled by hot working the magnesium alloy to segregate yttrium at a grain boundary, and performing an isothermal heat treatment to diffuse the yttrium in the grain interior. The subsequent cold working refines the grains, and improves the hardness and strength of the magnesium alloy member.

[0032] Controlling the dispersion state of yttrium induces room temperature recrystallization (grain refining), and excellent compressional deformation characteristics can be developed.

[0033] The foregoing embodiments described the yttrium-containing magnesium alloy, and the alloy member of such a magnesium alloy. However, the present invention is not limited to these embodiments. The present invention also encompasses a magnesium alloy and an alloy member in which some of or all of the yttrium are substituted with scandium or lanthanoid rare earth elements such as lanthanum and cerium, or with scandium and lanthanoid rare earth elements. Scandium, and lanthanoid elements such as lanthanum and cerium belong to the same group as yttrium, and are located above and below yttrium in the periodic table. These elements thus have many similarities in chemical and physical properties, and the present invention can sufficiently exhibit effect even when some of or all of the yttrium are substituted with these elements. The desired effect of the present invention can be more effectively obtained with the yttrium-containing magnesium alloy, and the alloy member of such a magnesium alloy.

Examples

[0034] Yttrium (Y) and pure magnesium (Mg; purity 99.95%) were completely melted in an argon atmosphere, and cast into an iron mold to fabricate five types of Mg-Y alloy cast materials with the target Y contents of 0.01 mol%, 0.02 mol%, 0.03 mol%, 0.04 mol%, and 0.05 mol%. The target Y contents of 0.03 mol%, 0.04 mol%, and 0.05 mol% fall within the range of the present invention (Examples). The target Y contents of 0.01 mol% and 0.02 mol% fall outside of the range of the present invention (Comparative Examples). The Y content, and the concentrations of other composition elements were evaluated by ICP atomic emission spectrometry after a 2-hour solution treatment of the cast material at 500°C. The results of the composition analysis are presented in Table 1. The five alloys were produced by using the following procedures under the following conditions.

[Table 1]

	Y	Fe	Si	Mn	Cu
Mg-0.05Y	0.16 (=0.044)	0.002	0.002	0.003	<0.001
Mg-0.04Y	0.13 (=0.036)	0.002	0.002	0.004	<0.001
Mg-0.03Y	0.09 (=0.025)	0.002	0.002	0.004	<0.001
Mg-0.02Y	0.06 (=0.016)	0.002	0.002	0.003	<0.001
Mg-0.01Y	0.02 (=0.005)	0.002	0.002	0.003	<0.001

Figures in parentheses are mol%. Other figures are mass%.

[0035] The cast material was maintained in a furnace at a temperature of 500°C for 2 hours, and then water cooled as a solution treatment. The product was then machined to produce a columnar extrusion billet measuring 40 mm in diameter and 70 mm in height. The same unit billet was maintained for 30 minutes in a container maintained at the extrusion temperature shown in Table 2, and subjected to a hot strain applying process, which was performed by extruding the material at an extrusion ratio of 25:1. The resulting product will be called "extruded material." The average equivalent plastic strain was 3.7 as determined from the percentage reduction of a cross section. The extruded material was isothermally maintained in a 400°C furnace for 15 minutes, and allowed to cool in air to prepare a sample. This product will be called "extruded and heat-treated material."

[0036]

[Table 2]

	Y concentration, mol%	Extrusion temperature, degrees	Heat treatment temperature, degrees	Heat treatment time, min	grain size, μm	Tys, MPa	Cys, MPa	Fracture strain
Mg-0.05Y	0.044	306	-----	-----	5	278	140	0.15
	0.044	306	400	15	32	91	65	>0.50
Mg-0.04Y	0.036	302	-----	-----	5	252	148	0.15
	0.036	302	400	15	38	91	65	>0.50
Mg-0.03Y	0.025	315	-----	-----	5	207	134	0.14
	0.025	315	400	15	40	85	65	>0.50
Mg-0.02Y	0.016	304	-----	-----	75	94	68	0.17
	0.016	304	400	15	94	84	34	0.31
	0.016	212	-----	-----	5	116	103	0.38
	0.016	212	400	15	44	100	47	0.36
Mg-0.01Y	0.005	317	-----	-----	75	92	47	0.27
	0.005	317	400	15	>100		32	0.32
	0.005	238	-----	-----	30	97	65	0.35
	0.005	238	400	15	65	80	34	0.33

Tys: Tensile yielding stress, Cys: Compressional yielding stress

[0037] Mg-Y alloy samples collected from the extruded materials and the extruded and heat-treated materials were subjected to a room-temperature tensile and compression test at a strain rate of $1 \times 10^{-3}s^{-1}$. All test samples were collected in a direction parallel to the extrusion direction. FIGS. 2 to 4 represent the nominal stress-nominal strain curves obtained after the room-temperature tensile and compression test. It can be seen that fracture occurs in the extruded materials in the nominal strain range of 0.2 to 0.3, irrespective of the amounts of yttrium added. Here, "fracture" is defined as at least 20% reduction in stress, and denoted as BK in the figures. A fracture occurred in the extruded and heat-treated materials Mg-0.01Y and Mg-0.02Y in the nominal strain range of 0.2 to 0.3 as in the extruded materials. However, no fracture occurred in the extruded and heat-treated materials Mg-0.03Y, Mg-0.04Y, and Mg-0.05Y even under the applied nominal strain of 0.5. These results suggest that the extruded and heat-treated materials Mg-0.03Y, Mg-0.04Y, and Mg-0.05Y are highly suited for cold working. As Comparative Example, a Mg-1 mol% Y alloy was fabricated by casting, and subjected to a room-temperature compression test after a solution treatment, without performing hot working.

The result is shown in FIG. 5. It can be seen that fracture occurs at a nominal strain as low as about 0.3, despite the high yttrium content. The post-casting hot strain applying process can thus be said as essential for the present invention to exhibit effect.

[0038] FIG. 6 shows an example of the observed scanning electron micrograph/electron backscatter diffraction image of the extruded and heat-treated material Mg-0.03Y. The symbols ED and TD represent directions parallel and perpendicular to the extrusion direction, respectively. It can be seen that the material does not tensile in the extrusion direction: ED, and has an equiaxial structure. The average diameter of grains with 15° or greater misorientation was 40 μm. FIG. 7 shows a pole figure image of the region observed in FIG. 6. Each point corresponds to the crystal orientation of the measured crystal grain. It can be seen that the material has a random texture without accumulation of basal plane in the specific direction (extrusion direction).

[0039] FIG. 8 shows an example of the microstructure of the extruded and heat-treated material Mg-0.03Y observed by scanning electron microscopy/electron backscatter diffraction after applying 20% compressional nominal strain (= 0.20). In contrast to the undeformed material of FIG. 6, refining of the grains can be observed. The average diameter of the grains with 15° or greater misorientation was 30 μm, 75% of the initial grain diameter before the room temperature recrystallization. In the figure, the symbol "LG" represents a low-angle grain boundary with less than 15° misorientation. This is considered to be largely due to the room temperature recrystallization forming a low-angle boundary of about 5° in the grains. FIG. 9 shows an example of the microstructure of the extruded and heat-treated material Mg-0.03Y observed by scanning electron microscopy/electron backscatter diffraction after applying 50% compressional nominal strain (= 0.50). In contrast to the undeformed material of FIG. 6, refining of the grains can be observed. The average diameter of the crystal grains with 15° or greater misorientation was 11 μm, 25% of the initial grain diameter.

[0040] Hardness measurement was performed for the extruded and heat-treated material Mg-0.03Y (undeformed sample) and the sample to which 50% compressional nominal strain (= 0.50) was applied. Hardness was 30.5 Hv for the undeformed sample, and 36.5 Hv for the 50% deformed sample. The improved hardness over the undeformed material is attributed to the finer grain size imparted after the room temperature working. It can be seen from these results that the material of the present invention improves hardness and strength after the room-temperature plastic working.

Comparative Example

[0041] When the working temperature is below 200°C, the low working temperature makes dynamic recrystallization less likely to occur. FIG. 10 is a photographic representation showing the appearance of the material of Comparative Example, representing the situation where dynamic recrystallization is limited by low working temperature. The limited dynamic recrystallization makes the material of Comparative Example less usable in producing a good material.

Industrial Applicability

[0042] The present invention induces room temperature recrystallization (grain refining), and develops excellent compressional deformation characteristics by controlling the dispersion state of one or more elements selected from yttrium, scandium, and lanthanoid rare earth elements in a magnesium alloy. The magnesium alloy member of the present invention has a random crystal orientation distribution (after working), and the same yielding stress for the tensile and compressional deformation with the maintained high strength. The magnesium alloy member of the present invention can thus be used as a wrought magnesium member such as a plate member, a rod member, and a pipe member. In a three-dimensional structure using such a wrought magnesium member, any external force acting on the structure deforms the magnesium alloy member near isotropically, and the strengths against the locally acting tensile and compressional loads become essentially the same. Further, the magnesium alloy member of the present invention does not break even under a large applied compressional strain in excess of 50%, and has excellent deformability. The magnesium alloy member of the present invention can thus be used as a structural member or a shock absorbing material in applications such as automobiles, railcars, aerospace flying objects, and portable electronic devices.

Claims

1. A magnesium alloy comprising 0.02 mol% or more and less than 0.1 mol% of at least one element selected from yttrium, scandium, and lanthanoid rare earth elements, and Mg and unavoidable impurities accounting for the remainder.

2. A magnesium alloy member produced by hot plastic working of the magnesium alloy of the chemical composition of claim 1 in a temperature range of 200°C to 550°C, followed by an isothermal heat treatment performed in a

temperature range of 300°C to 600°C.

3. The magnesium alloy member according to claim 2, wherein the crystal structure of the member is an equiaxial grain structure with no texture.

4. The magnesium alloy member according to claim 2 or 3, wherein the average grain size is 10 μm or more.

5. The magnesium alloy member according to any one of claims 2 to 4, wherein a compressional nominal strain of 0.4 or more is applied by cold working performed in a temperature range of from room temperature to 150°C.

6. The magnesium alloy member according to any one of claims 2 to 5, wherein the average grain size of the magnesium alloy after cold working performed in a temperature range of from room temperature to 150°C is 80% or less of the average grain size of an unworked magnesium alloy.

7. The magnesium alloy member according to claim 3, wherein the strength and hardness of the member after applying nominal strain by cold working performed in a temperature range of from room temperature to 150°C are 15% greater than strength and hardness of the undeformed ones.

8. A method for producing a magnesium alloy member, the method comprising:

   hot plastic working of a magnesium alloy that contains 0.02 mol% or more and less than 0.1 mol% of at least one element selected from yttrium, scandium, and lanthanoid rare earth elements, and Mg and unavoidable impurities accounting for the remainder, the hot plastic working being performed in a temperature range of 200°C to 550°C; and
   an isothermal heat treatment of the magnesium alloy in a temperature range of 300°C to 600°C after the hot plastic working.

9. A method for using a magnesium alloy that contains 0.02 mol% or more and less than 0.1 mol% of at least one element selected from yttrium, scandium, and lanthanoid rare earth elements, and Mg and unavoidable impurities accounting for the remainder,
the method using the magnesium alloy as a wrought magnesium member after hot plastic working performed in a temperature range of 200°C to 550°C, and a subsequent isothermal heat treatment performed in a temperature range of 300°C to 600°C.

FIG. 1

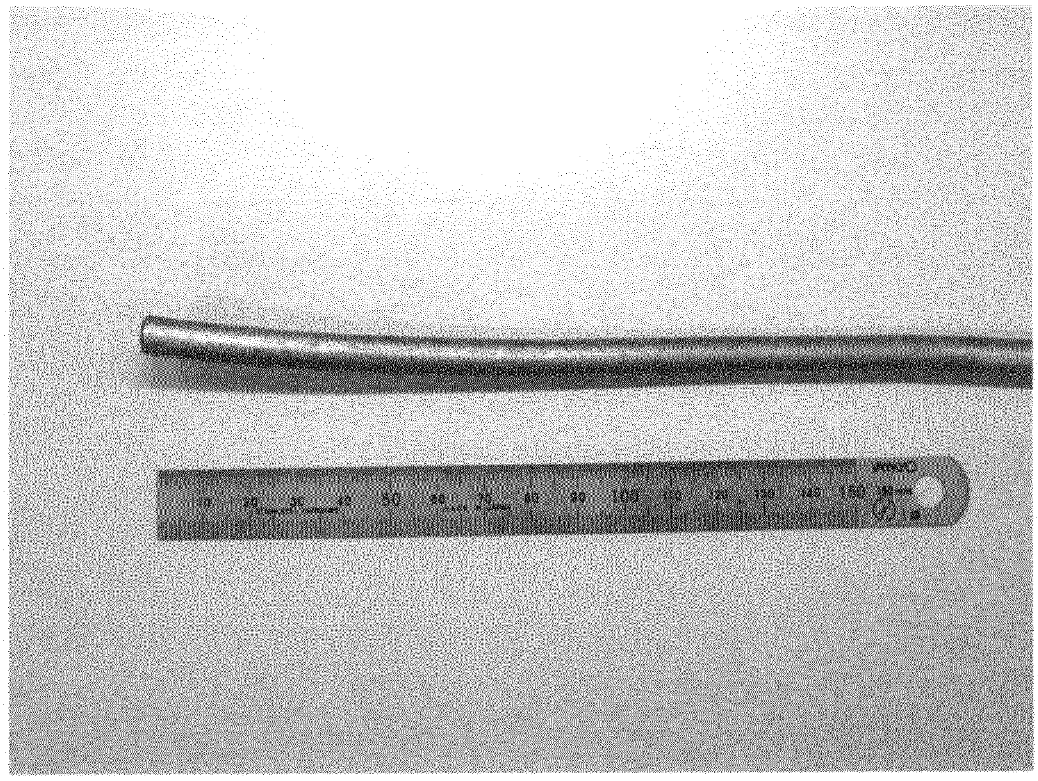

10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
150mm
MADE IN JAPAN

FIG. 2

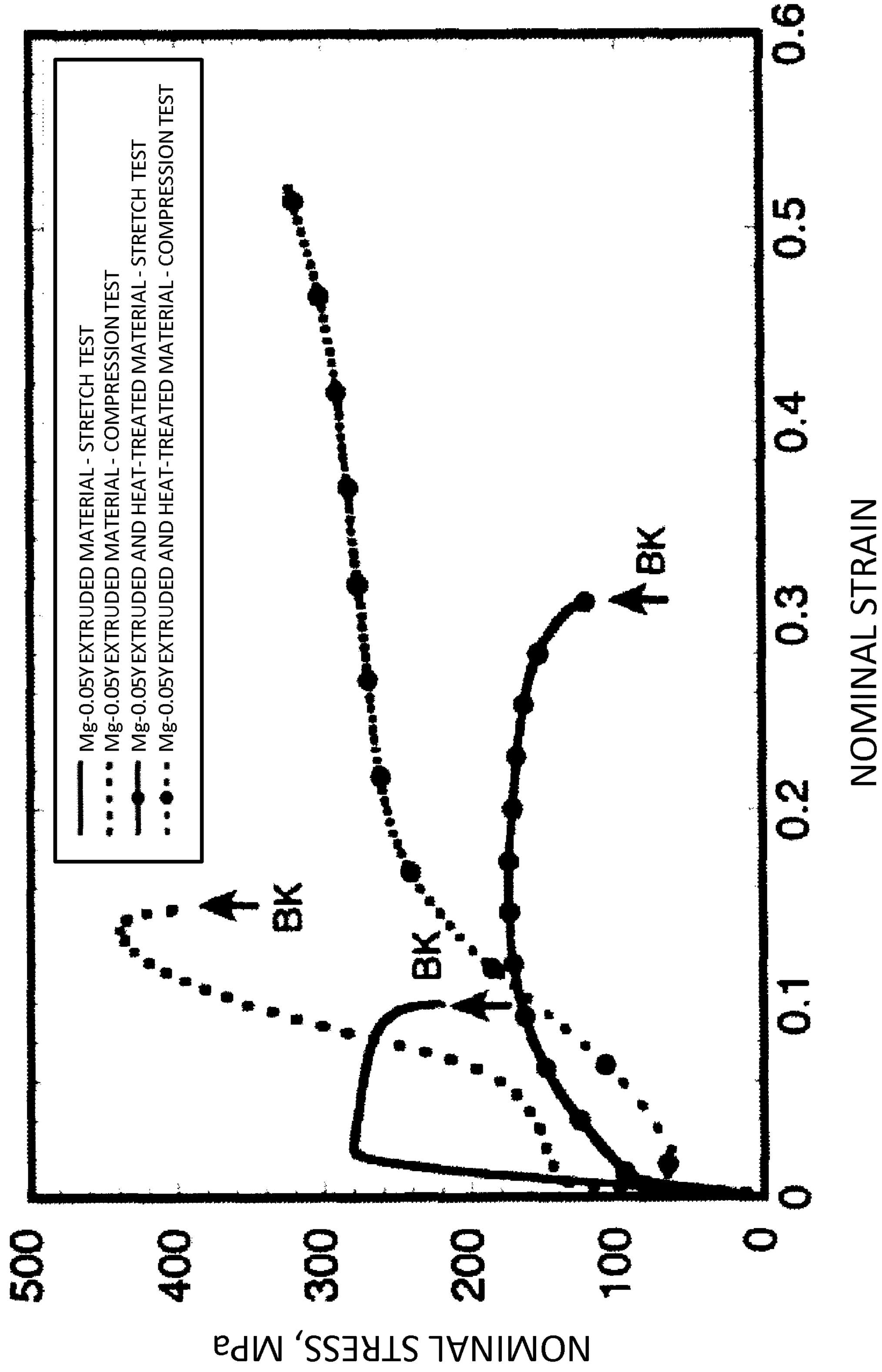

Mg-0.05Y EXTRUDED MATERIAL - STRETCH TEST
Mg-0.05Y EXTRUDED MATERIAL - COMPRESSION TEST
Mg-0.05Y EXTRUDED AND HEAT-TREATED MATERIAL - STRETCH TEST
Mg-0.05Y EXTRUDED AND HEAT-TREATED MATERIAL - COMPRESSION TEST
BK
BK
BK
NOMINAL STRESS, MPa
0
100
200
300
400
500
NOMINAL STRAIN
0
0.1
0.2
0.3
0.4
0.5
0.6

FIG. 3

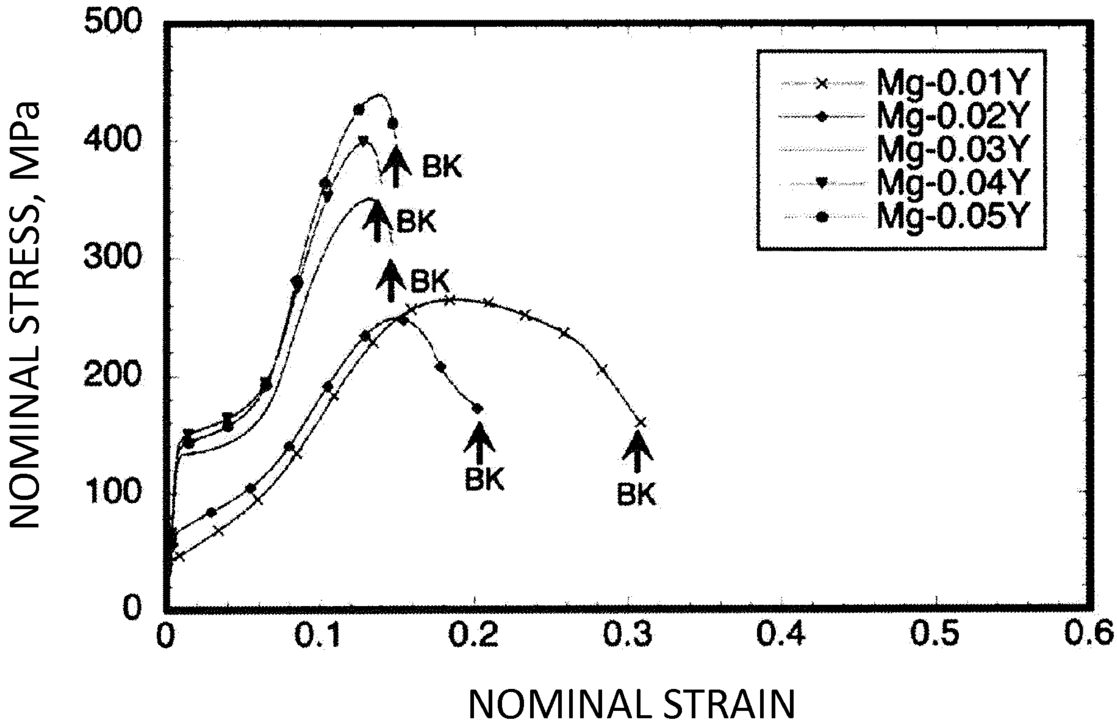

NOMINAL STRESS, MPa
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
NOMINAL STRAIN
Mg-0.01Y
Mg-0.02Y
Mg-0.03Y
Mg-0.04Y
Mg-0.05Y
BK
BK
BK
BK
BK

FIG. 4

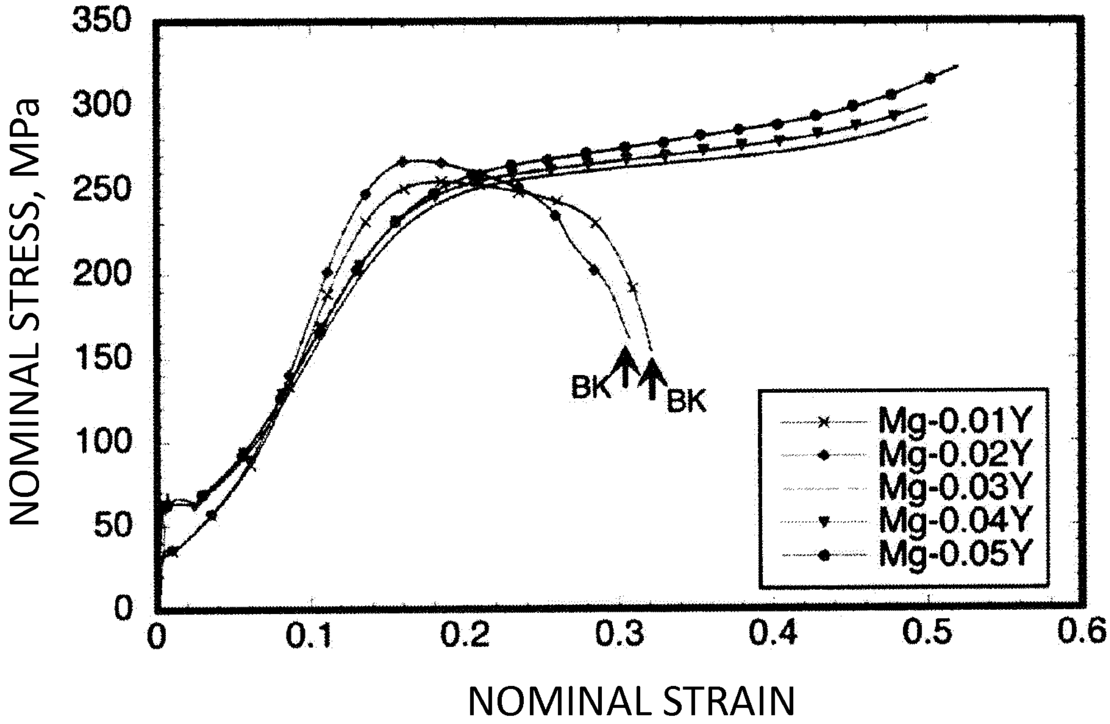

350
300
250
200
150
100
50
0
NOMINAL STRESS, MPa
0
0.1
0.2
0.3
0.4
0.5
0.6
NOMINAL STRAIN
BK
BK
Mg-0.01Y
Mg-0.02Y
Mg-0.03Y
Mg-0.04Y
Mg-0.05Y

FIG. 5

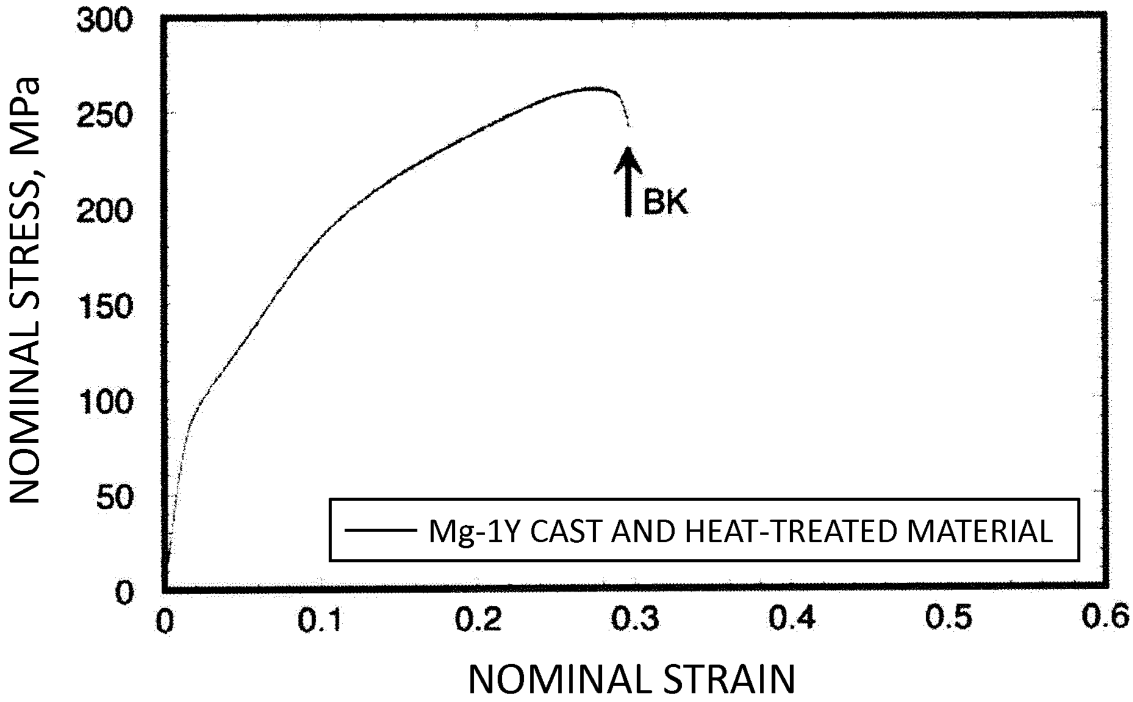

NOMINAL STRESS, MPa
300
250
200
150
100
50
0
0
0.1
0.2
0.3
0.4
0.5
0.6
NOMINAL STRAIN
BK
Mg-1Y CAST AND HEAT-TREATED MATERIAL

FIG. 6

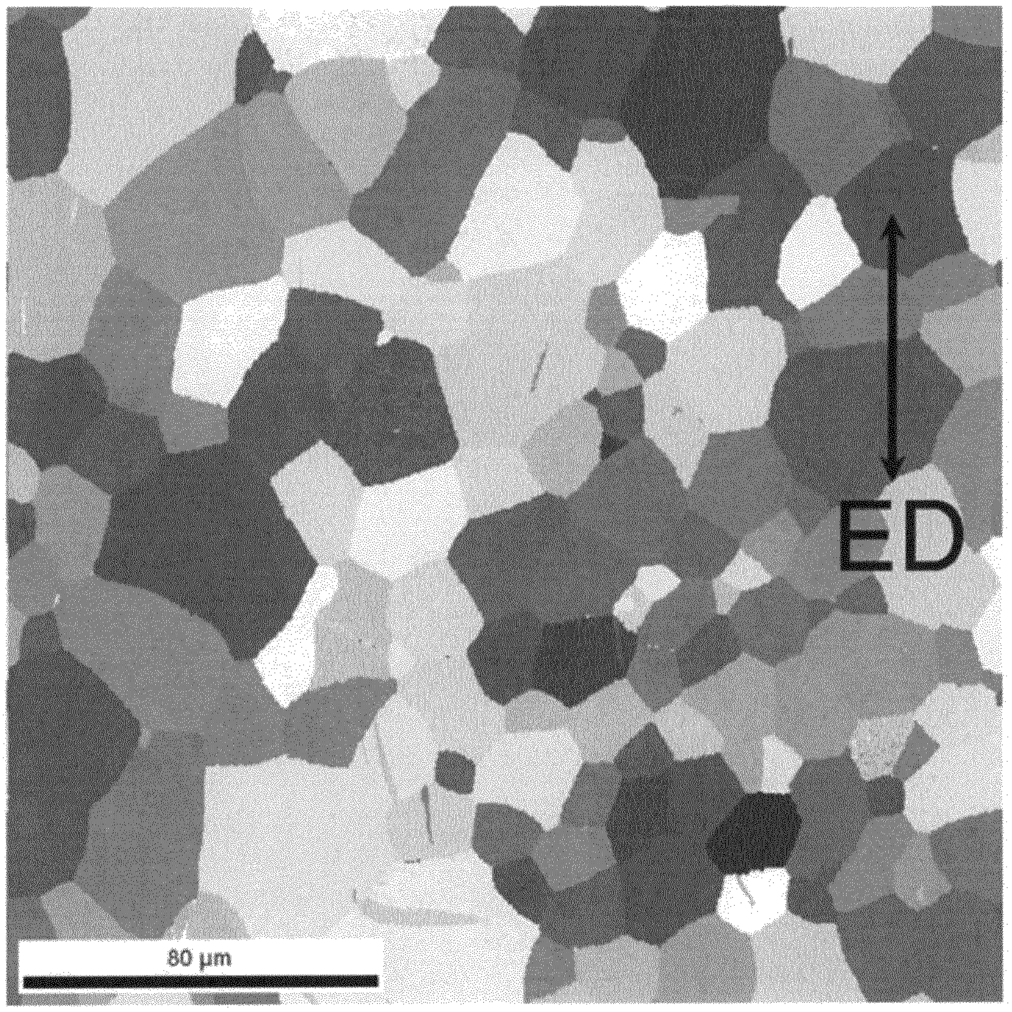


FIG. 7

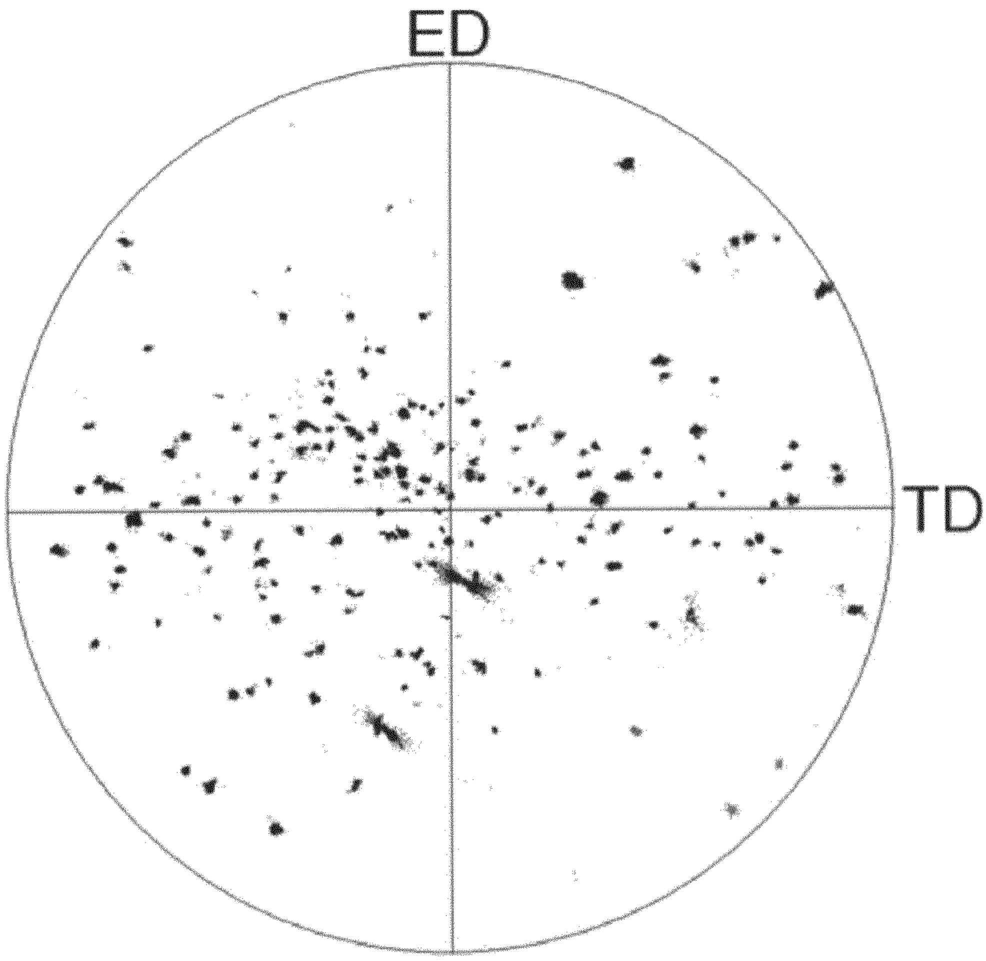


FIG. 8

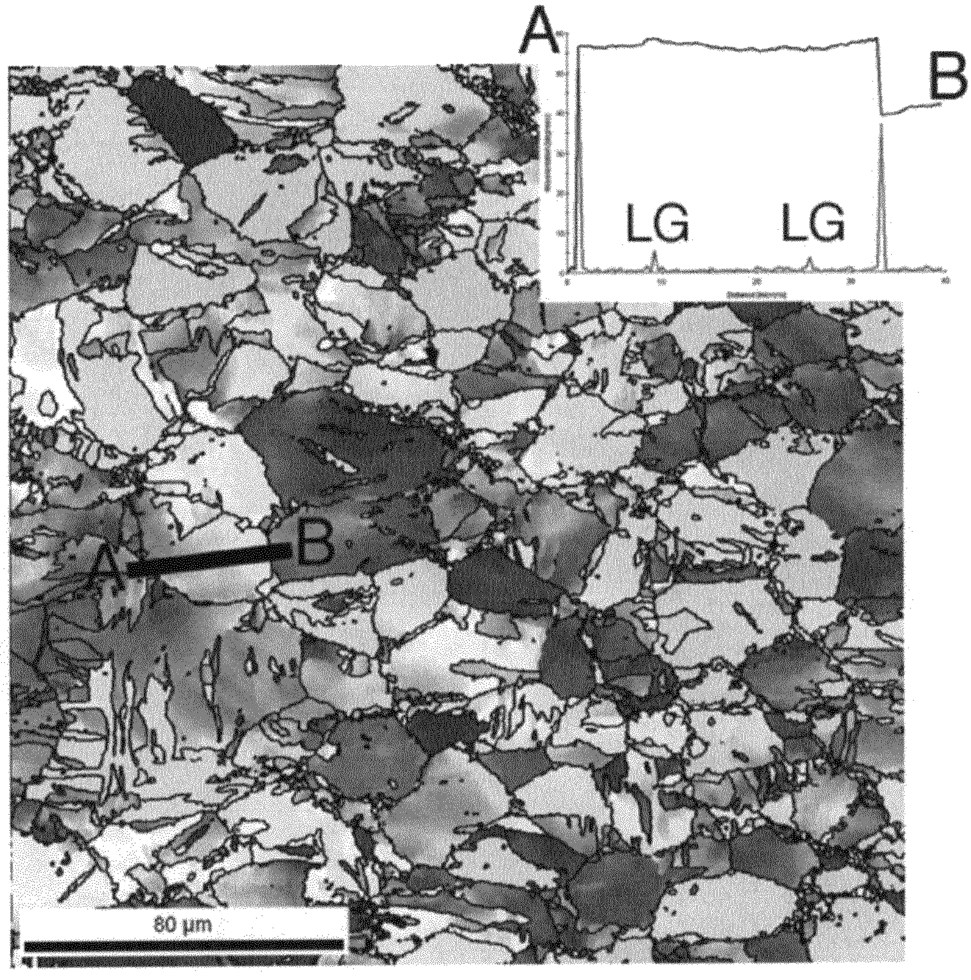


FIG. 9

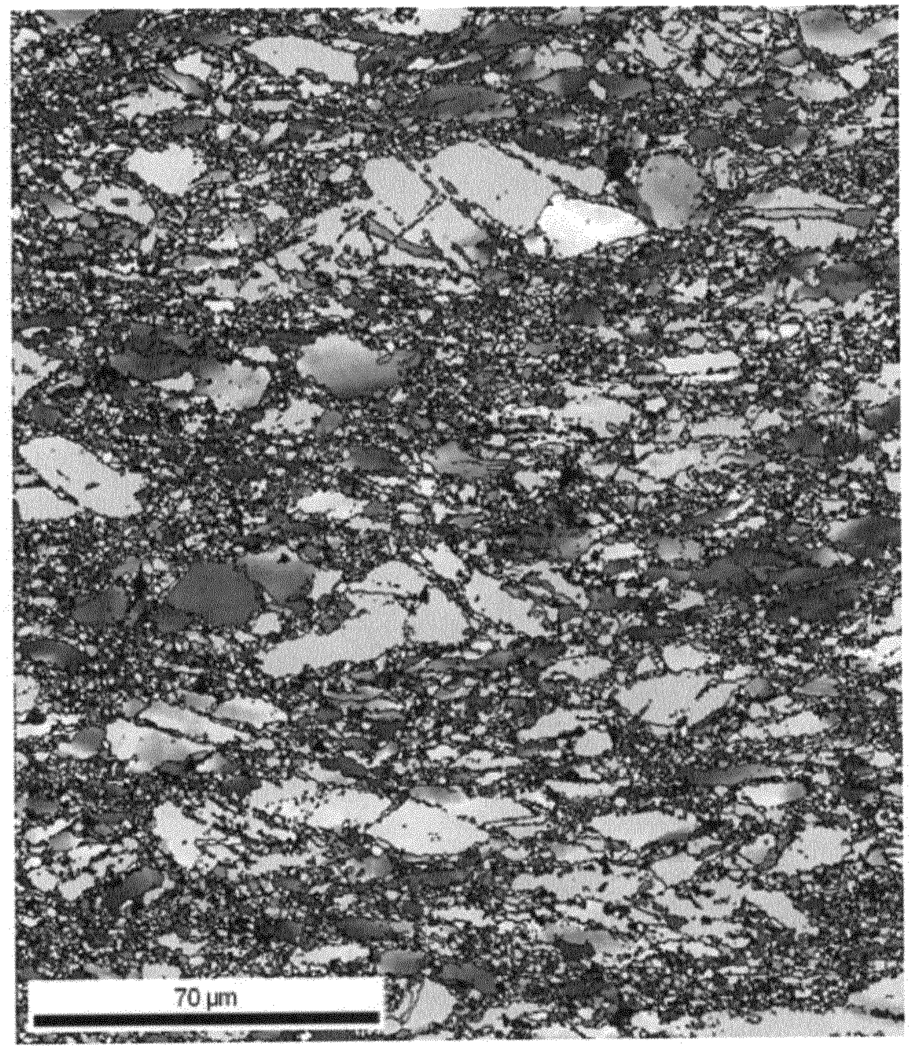
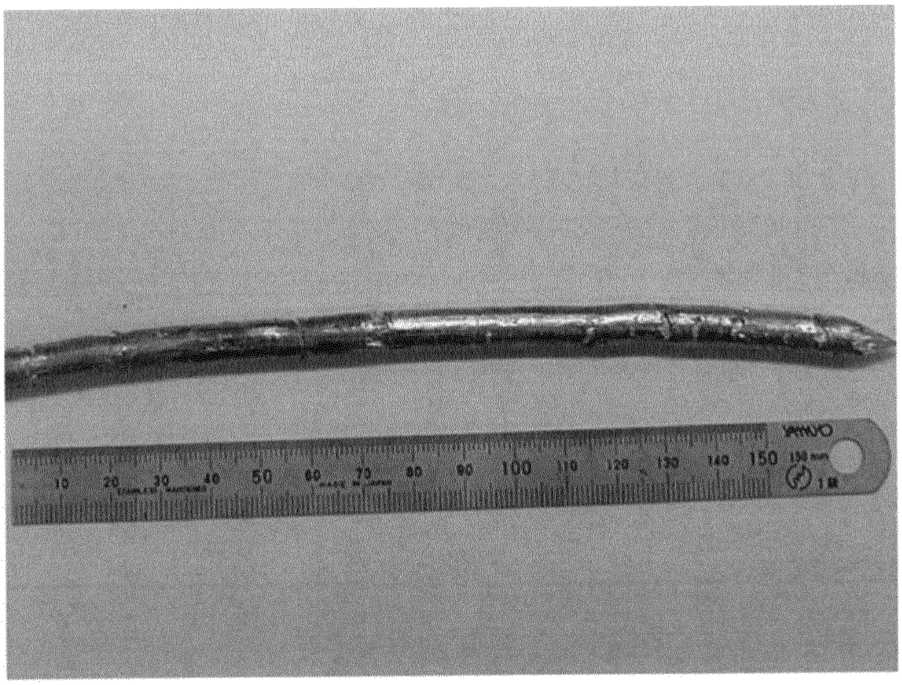


FIG. 10



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2013/064755

A. CLASSIFICATION OF SUBJECT MATTER

C22C23/06(2006.01)i, *B21J5/00*(2006.01)i, *C22F1/06*(2006.01)i, *C22F1/00* (2006.01)n

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)
C22C23/06, B21J5/00, C22F1/06, C22F1/00

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	1996-2013
Kokai Jitsuyo Shinan Koho	1971-2013	Toroku Jitsuyo Shinan Koho	1994-2013

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.
X	JP 2008-214668 A (National Institute of Advanced Industrial Science and Technology), 18 September 2008 (18.09.2008), entire text; particularly, claims 1, 5, 13; paragraphs [0007], [0016], [0026], [0027], [0033]; tables 2, 3 (Family: none)	1-9
X	JP 44-31694 B1 (Director General of National Research Institute for Science and Technology Agency), 18 December 1969 (18.12.1969), entire text; particularly, claims; fig. 1, 2 (Family: none)	1-9

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

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- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
09 July, 2013 (09.07.13)	23 July, 2013 (23.07.13)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2013/064755

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 47-7973 B1 (Director General of National Research Institute for Science and Technology Agency), 07 March 1972 (07.03.1972), entire text; particularly, claims; page 1, right column, line 34 to page 2, left column, line 8; fig. 1, 2 (Family: none)	1-9
X	Yasumasa CHINO, Motohisa KADO, Katsuya KIMURA, Masataka HAKAMADA, Mamoru MABUCHI, "Mg-Ce-kei Magnesium Gokin Atsuenzai no Seikeisei to Soshiki no Kankei", Abstracts of the Japan Institute of Metals, 27 March 2007 (27.03.2007), 2007 Nen Shunki (Dai 140 Kai) Taikai, page 452	1-9
X	Yasumasa CHINO, Motohisa KADO, Katsuya KIMURA, Mamoru MABUCHI, "Mg-0.2mass%Ce Gokin no Joon· Koon Asshuku Henkei Tokusei", Abstracts of the Japan Institute of Metals, 19 September 2007 (19.09.2007), 2007 Nen Shuki (Dai 141 Kai) Taikai, page 149	1-9
X	Yasumasa Chino, Motohisa Kado, Mamoru Mabuchi, Compressive deformation behavior at room temperature-773 K in Mg-0.2 mass% (0.035at.%)Ce alloy, Acta Materialia, February 2008, Vol.56, No.3, p.387-394, entire text, Fig.1-13	1-9
E,X	JP 2013-129914 A (National Institute of Advanced Industrial Science and Technology), 04 July 2013 (04.07.2013), entire text; particularly, claims 1 to 19; paragraph [0055] (Family: none)	1-9

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- JP 2010013725 A **[0009]**
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- JP 2003226929 A **[0009]**
- JP 9041066 A **[0009]**
- JP 2010222645 A **[0009]**
- JP 4840751 B **[0009]**