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(54) **MAGNESIUM ALLOY AND METHOD FOR PRODUCING SAME**

(57) There is provided a magnesium alloy having high strength and high thermal conductivity, A magnesium alloy according to one aspect of the invention is a magnesium alloy containing a atom% of Zn; b atom% of Y; and a remainder consisting of Mg and unavoidable impurities, where a and b satisfy the following Formulas 1 to 8, and the magnesium alloy contains a $Mg_3Zn_3Y_2$ phase or both a $Mg_3Zn_3Y_2$ phase and a Mg_3Zn_6Y phase, and does not contain a long period stacking ordered structure phase.

(Formula 1) $a = 0.5\ (0.25 \leq b \leq 1.2)$

(Formula 2) $b = 1.2 (0.5 \leq a \leq 1.62)$

(Formula 3) $a = 1.35b\ (1.2 \leq b \leq 3)$

(Formula 4) $b = 3\ (4.05 \leq a \leq 7)$

(Formula 5) $a = 7\ (0.25 \leq b \leq 3)$

(Formula 6) $b = 0.25\ (0.5 \leq a \leq 7)$

(Formula 7) $a = 4.2b + 0.7\ (0.25 \leq b \leq 1.5)$

(Formula 8) $b = 0.25\ (0.5 \leq a \leq 1.75)$

FIG.1A

THERMAL CONDUCTIVITY OF AS-CAST MATERIAL

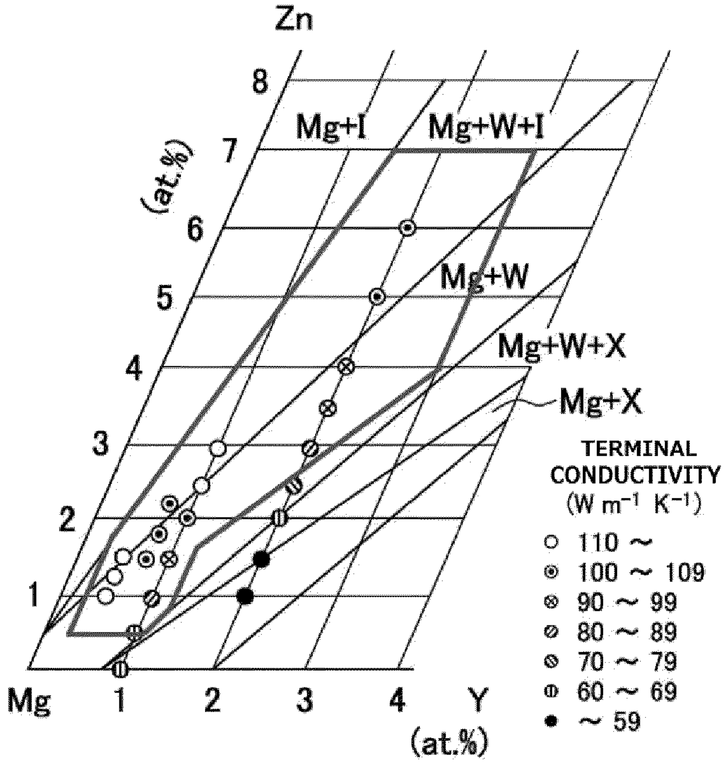
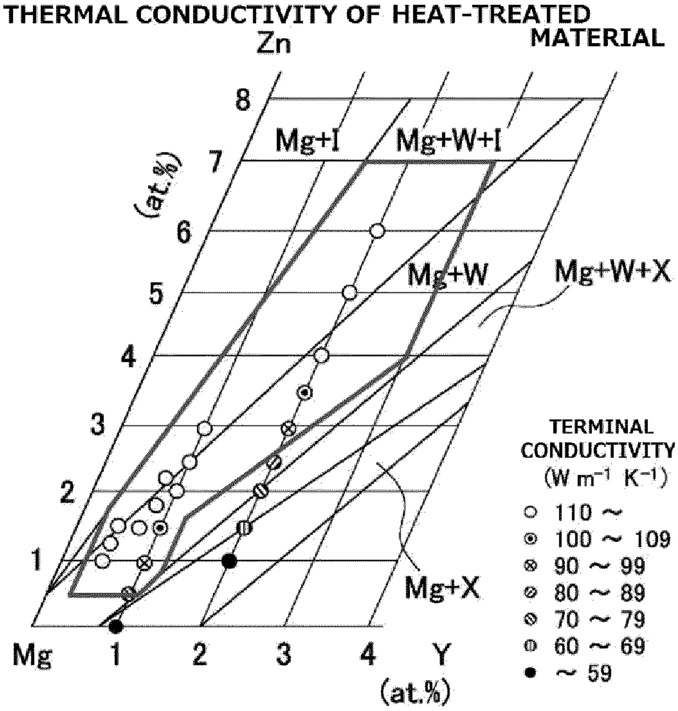


FIG.1B

THERMAL CONDUCTIVITY OF HEAT-TREATED MATERIAL



Description

Technical field

[0001] The present invention relates to a magnesium alloy and a manufacturing method of the same.

Background art

[0002] As more transportation equipment becomes electrified, there is a demand for the development of magnesium alloys that is lightweight and that has high heat dissipation, high strength, and high thermal conductivity.

[0003] However, since the thermal conductivity of AZ91D (ASTM designation) that is a typical magnesium alloy is approximately 60 W/m K, when the AZ91D is used in components that are exposed to a high-temperature usage environment or that generate heat during use, heat dissipation may not be performed well, and thermal deformation may occur in the components (refer to, for example, paragraph [0003] of Patent Document 1). In addition, the strength of the components may be insufficient.

CITATION LIST

PATENT DOCUMENT

[0004] Patent Document 1: JP 2012-197490 A

Disclosure of the invention

PROBLEM TO BE SOLVED BY THE INVENTION

[0005] An object of one aspect of the invention is to provide a magnesium alloy having high thermal conductivity or a manufacturing method of the same.

[0006] In addition, an object of one aspect of the invention is to provide a magnesium alloy having high strength and high thermal conductivity or a manufacturing method of the same.

[0007] In addition, an object of one aspect of the invention is to provide a magnesium alloy having high strength, high thermal conductivity, and non-flammability or a manufacturing method of the same.

Means for solving problem

[0008] Hereinafter, various aspects of the invention will be described.

[1] A magnesium alloy contains a atom% of Zn; b atom% of Y; and a remainder consisting of Mg and unavoidable impurities. A Zn content of a atom% and a Y content of b atom% are set in a range enclosed by straight lines represented by the following (1) to (8) according to coordinates (b, a) where a is taken on a vertical axis and b is taken on a horizontal axis. The magnesium alloy contains a $Mg_3Zn_3Y_2$ phase or both a $Mg_3Zn_3Y_2$ phase and a Mg_3Zn_6Y-phase. The magnesium alloy does not contain a long period stacking ordered structure phase.

(1) When b is in a range defined by the following Formula 1a, a straight line represented by the following Formula 1b is obtained.

$$\text{(Formula 1a)}\ 0.25 \le b \le 1.09$$

$$\text{(Formula 1b)}\ a = 0.5$$

(2) When b is in a range defined by the following Formula 2a, a straight line represented by the following Formula 2b is obtained.

$$\text{(Formula 2a)}\ 1.09 \le b \le 1.2$$

$$\text{(Formula 2b)}\ a = 2.91b - 2.67$$

(3) When a is in a range defined by the following Formula 3a, a straight line represented by the following Formula 3b is obtained.

$$\text{(Formula 3a)}\ 0.82 \le a \le 1.62$$

$$\text{(Formula 3b)}\ b = 1.2$$

(4) When b is in a range defined by the following Formula 4a, a straight line represented by the following Formula 4b is obtained.

$$\text{(Formula 4a)}\ 1.2 \le b \le 3$$

$$\text{(Formula 4b)}\ a = 1.35b$$

(5) When a is in a range defined by the following Formula 5a, a straight line represented by the following Formula 5b is obtained.

$$\text{(Formula 5a)}\ 4.05 \le a \le 7$$

$$\text{(Formula 5b)}\ b = 3$$

(6) When b is in a range defined by the following Formula 6a, a straight line represented by the following Formula 6b is obtained.

$$\text{(Formula 6a)}\ 1.5 \le b \le 3$$

$$\text{(Formula 6b) } a = 7$$

(7) When b is in a range defined by the following Formula 7a, a straight line represented by the following Formula 7b is obtained.

$$\text{(Formula 7a) } 0.25 \leq b \leq 1.5$$

$$\text{(Formula 7b) } a = 4.2b + 0.7$$

(8) When a is in a range defined by the following Formula 8a, a straight line represented by the following Formula 8b is obtained.

$$\text{(Formula 8a) } 0.5 \leq a \leq 1.75$$

$$\text{(Formula 8b) } b = 0.25$$

[2] In the magnesium alloy according to the above [1], the magnesium alloy has a thermal conductivity of 90 W/m·K or more (preferably 100 W/m·K or more, more preferably 110 W/m·K or more, and still more preferably 130 W/m·K or more).

[3] In the magnesium alloy according to the above [1] or [2], the magnesium alloy contains any one element selected from the group consisting of Yb in an amount of 0.05 atom% or more and 0.6 atom% or less, Be in an amount of 0.03 atom% or more and 0.3 atom% or less, Ca in an amount of 1.0 atom% or more and 2.0 atom% or less, and Sr in an amount of 0.1 atom% or more and 2.0 atom% or less.

[4] In the magnesium alloy according to the above [1] or [2], Zn/Y, which is a composition ratio of Zn to Y in the magnesium alloy, is in a range of 2 or more and 5 or less.

[5] In the magnesium alloy according to the above [1] or [2], the magnesium alloy has a structure in which the $Mg_3Zn_3Y_2$ phase is not formed in a network shape at grain boundaries (a structure in which a network is formed in a collapsed state) or a structure in which both the $Mg_3Zn_3Y_2$ phase and the Mg_3Zn_6Y phase are not formed in a network shape at grain boundaries (a structure in which a network is formed in a collapsed state).

[6] In the magnesium alloy according to the above [1] or [2], the magnesium alloy has a yield strength of 300 MPa or more and an elongation of 5% or more.

[7] A method for manufacturing a magnesium alloy containing a atom% of Zn, b atom% of Y, and a remainder consisting of Mg and unavoidable impurities, the method including a step (a) of forming a cast material by casting the magnesium alloy at a solidification rate of less than 1000 K/sec. A Zn content of a atom% and a Y content of b atom% are set in a range enclosed by straight lines represented by the following (1) to (8) according to coordinates (b, a) where a is taken on a vertical axis and b is taken on a horizontal axis. The cast material contains a $Mg_3Zn_3Y_2$ phase or both a $Mg_3Zn_3Y_2$ phase and a Mg_3Zn_6Y phase. The cast material does not contain a long period stacking ordered structure phase.

(1) When b is in a range defined by the following Formula 1a, a straight line represented by the following Formula 1b is obtained.

$$\text{(Formula 1a) } 0.25 \leq b \leq 1.09$$

$$\text{(Formula 1b) } a = 0.5$$

(2) When b is in a range defined by the following Formula 2a, a straight line represented by the following Formula 2b is obtained.

$$\text{(Formula 2a) } 1.09 \leq b \leq 1.2$$

$$\text{(Formula 2b) } a = 2.91b - 2.67$$

(3) When a is in a range defined by the following Formula 3a, a straight line represented by the following Formula 3b is obtained.

$$\text{(Formula 3a) } 0.82 \leq a \leq 1.62$$

$$\text{(Formula 3b) } b = 1.2$$

(4) When b is in a range defined by the following Formula 4a, a straight line represented by the following Formula 4b is obtained.

$$\text{(Formula 4a) } 1.2 \leq b \leq 3$$

$$\text{(Formula 4b) } a = 1.35b$$

(5) When a is in a range defined by the following Formula 5a, a straight line represented by the following Formula 5b is obtained.

$$\text{(Formula 5a) } 4.05 \leq a \leq 7$$

$$\text{(Formula 5b) } b = 3$$

(6) When b is in a range defined by the following Formula 6a, a straight line represented by the following Formula 6b is obtained.

$$\text{(Formula 6a) } 1.5 \leq b \leq 3$$

$$\text{(Formula 6b) } a = 7$$

(7) When b is in a range defined by the following Formula 7a, a straight line represented by the following Formula 7b is obtained.

$$\text{(Formula 7a) } 0.25 \leq b \leq 1.5$$

$$\text{(Formula 7b) } a = 4.2b + 0.7$$

(8) When a is in a range defined by the following Formula 8a, a straight line represented by the following Formula 8b is obtained.

$$\text{(Formula 8a) } 0.5 \leq a \leq 1.75$$

$$\text{(Formula 8b) } b = 0.25$$

[8] The method for manufacturing a magnesium alloy according to the above [7] further includes a step (b) of forming a heat-treated material by performing heat treatment on the cast material after the step (a). The heat-treated material has a thermal conductivity of 90 W/m·K or more (preferably 100 W/m·K or more, more preferably 110 W/m·K or more, and still more preferably 130 W/m·K or more). The heat-treated material contains the $Mg_3Zn_3Y_2$ phase or both the $Mg_3Zn_3Y_2$ phase and the Mg_3Zn_6Y phase. The heat-treated material does not contain the long period stacking ordered structure phase.

[9] In the method for manufacturing a magnesium alloy according to the above [8], conditions for performing the heat treatment are set to at a temperature of 200°C or more and 500°C or less (preferably 300°C or more and 450°C or less) and a heat treatment time of 48 hours or less.

[10] In the method for manufacturing a magnesium alloy according to any one of the above [7] to [9], the magnesium alloy contains any one element selected from the group consisting of Yb in an amount of 0.05 atom% or more and 0.6 atom% or less, Be in an amount of 0.03 atom% or more and 0.3 atom% or less, Ca in an amount of 1.0 atom% or more and 2.0 atom% or less, and Sr in an amount of 0.1 atom% or more and 2.0 atom% or less.

[11] In the method for manufacturing a magnesium alloy according to any one of the above [7] to [9], Zn/Y, which is a composition ratio of Zn to Y in the cast material, is in a range of 2 or more and 5 or less.

[12] The method for manufacturing a magnesium alloy according to any one of the above [7] to [9] further includes a step (c) of forming a plastically processed material by performing plastic processing on the heat-treated material after the step (a) or the step (b). The plastically processed material has a structure in which the $Mg_3Zn_3Y_2$ phase is not formed in a network shape at grain boundaries (a structure in which a network is formed in a collapsed state) or a structure in which both the $Mg_3Zn_3Y_2$ phase and the Mg_3Zn_6Y phase are not formed in a network shape at grain boundaries (a structure in which a network is formed in a collapsed state).

[13] In the method for manufacturing a magnesium alloy according to the above [12], the plastically processed material has a yield strength of 300 MPa or more and an elongation of 5% or more.

[0009] According to one aspect of the invention, it is possible to provide the magnesium alloy having high thermal conductivity or the manufacturing method of the same.

[0010] In addition, according to one aspect of the invention, it is possible to provide the magnesium alloy having high strength and high thermal conductivity or the manufacturing method of the same.

[0011] In addition, according to one aspect of the invention, it is possible to provide the magnesium alloy having high strength, high thermal conductivity, and non-flammability or the manufacturing method of the same.

Brief description of drawings

[0012]

Fig. 1A is a diagram showing the compositions of a plurality of samples according to an example of the invention, the thermal conductivity of cast materials of magnesium alloys having the compositions, and the constituent phases of these cast materials, and Fig. 1B is a diagram showing the thermal conductivity of heat-treated materials obtained by performing heat treatment on the cast materials of the plurality of samples shown in Fig. 1A, and the constituent phases of these heat-treated materials;

Fig. 2 is a diagram showing stress-strain curves of a heat-treated cast material;

Fig. 3 is a diagram showing stress-strain curves of an extrusion material;

Fig. 4 is a diagram showing that the Mg-1.88Zn-0.75Y-xYb alloy and the Mg-1.88Zn-0.75Y-xCa alloy are non-flammable;

Fig. 5 is a diagram showing the XRD (X-ray diffraction method) measurement results of the Mg-1.88Zn-0.75Y alloy; and

Fig. 6 is a diagram showing the properties of an Mg-1.88Zn-0.75Y-0.1Yb alloy extrusion material of an example.

Best modes for carrying out the invention

[0013] Hereinafter, embodiments of the invention will be described in detail with reference to the drawings. However, the invention is not limited to the following description, and it will be easily understood by those skilled in the art that the modes and details of the invention can be modified in various forms without departing from the concept and scope of the invention. Therefore, the invention should not be interpreted as being limited to the contents of the embodiments shown below.

(First embodiment)

<Composition of magnesium alloy>

[0014] Fig. 1A is a diagram showing the thermal conductivity of cast materials of magnesium alloys according to one aspect of the invention and the constituent phases of these cast materials, and the composition range enclosed by straight lines in Fig. 1A is the composition range of Zn and Y contents in which the as-cast materials of the magnesium alloys according to one aspect of the invention has a thermal conductivity of 90 W/m K or more. Fig. 1B is a diagram showing the thermal conductivity of heat-treated materials after casting of the magnesium alloys according to one aspect of the invention and the constituent phases of these heat-treated materials, and the composition range enclosed by straight lines in Fig. 1B is the composition range of the Zn and Y contents in which the heat-treated cast materials of the magnesium alloys according to one aspect of the invention has a thermal conductivity of 90 W/m K or more. Incidentally, the composition range shown in Fig. 1A and Fig. 1B can also be used as the composition range of plastically processed cast materials (for example, extrusion materials and extrusion materials after heat treatment) of the magnesium alloys according to one aspect of the invention. In addition, the details of each of the thermal conductivity of the as-cast materials shown in Fig. 1A and the thermal conductivity of the heat-treated materials shown in Fig. 1B will be described in examples to be described later. In addition, the details of each of the cast materials, the heat-treated cast materials, and the plastically processed cast materials will be described in a second embodiment.

[0015] In addition, it is preferable that the magnesium alloys according to one aspect of the invention have a thermal conductivity of 90 W/m·K or more (preferably 100 W/m·K or more, more preferably 110 W/m·K or more, and still more preferably 130 W/m·K or more).

[0016] In addition, in this specification, the "cast materials" refer to cast materials that are cast at a solidification rate of less than 1000 K/s, and includes cast materials produced by casting methods such as metal mold casting, sand casting, and semi-continuous casting, as well as die casting, injection molding, and twin-roll casting.

[0017] In addition, in this specification, the "heat-treated cast materials" refer to heat-treated materials obtained by heat-treating the above-described cast materials.

[0018] In addition, in this specification, the "plastically processed cast materials" include both plastically processed materials produced by subjecting the above-described heat-treated materials to plastic processing such as extrusion, rolling, forging, wire drawing, and the solidification and molding of chipping material, and plastically processed materials produced by subjecting the above-described cast materials to plastic processing such as extrusion, rolling, forging, wire drawing, and the solidification and molding of chipping material without performing heat treatment on the above-described cast materials.

[0019] The magnesium alloys according to the present embodiment have the following composition range. The magnesium alloys contain a atom% of Zn, b atom% of Y, and a remainder consisting of Mg and unavoidable impurities.

[0020] As shown in Fig. 1, it is preferable that the Zn content of a atom% and the Y content of b atom% are set in a range enclosed by straight lines represented by the following (1) to (8), according to coordinates (b, a) where a representing the Zn content (atom%) is taken on the vertical axis and b representing the Y content (atom%) is taken on the horizontal axis.

(1) When b is in a range defined by the following Formula 1a, a straight line represented by the following Formula 1b is obtained.

$$\text{(Formula 1a) } 0.25 \leq b \leq 1.09$$

$$\text{(Formula 1b) } a = 0.5$$

(2) When b is in a range defined by the following Formula 2a, a straight line represented by the following Formula 2b is obtained.

$$\text{(Formula 2a) } 1.09 \leq b \leq 1.2$$

$$\text{(Formula 2b) } a = 2.91b - 2.67$$

(3) When a is in a range defined by the following Formula 3a, a straight line represented by the following Formula 3b is obtained.

$$\text{(Formula 3a) } 0.82 \leq a \leq 1.62$$

$$\text{(Formula 3b) } b = 1.2$$

(4) When b is in a range defined by the following Formula 4a, a straight line represented by the following-

ing Formula 4b is obtained.

$$\text{(Formula 4a) } 1.2 \leq b \leq 3$$

$$\text{(Formula 4b) } a = 1.35b$$

(5) When a is in a range defined by the following Formula 5a, a straight line represented by the following Formula 5b is obtained.

$$\text{(Formula 5a) } 4.05 \leq a \leq 7$$

$$\text{(Formula 5b) } b = 3$$

(6) When b is in a range defined by the following Formula 6a, a straight line represented by the following Formula 6b is obtained.

$$\text{(Formula 6a) } 1.5 \leq b \leq 3$$

$$\text{(Formula 6b) } a = 7$$

(7) When b is in a range defined by the following Formula 7a, a straight line represented by the following Formula 7b is obtained.

$$\text{(Formula 7a) } 0.25 \leq b \leq 1.5$$

$$\text{(Formula 7b) } a = 4.2b + 0.7$$

(8) When a is in a range defined by the following Formula 8a, a straight line represented by the following Formula 8b is obtained.

$$\text{(Formula 8a) } 0.5 \leq a \leq 1.75$$

$$\text{(Formula 8b) } b = 0.25$$

<Constituent phases of magnesium alloy>

[0021] As shown in Fig. 1A and Fig. 1B, it can be seen that magnesium alloys exhibiting high thermal conductivity necessarily contain a W phase ($Mg_3Zn_3Y_2$ phase) or both a W phase ($Mg_3Zn_3Y_2$ phase) and an I phase (Mg_3Zn_6Y phase), and do not contain an X phase (long period stacking order (LPSO) phase: $Mg_{12}ZnY$). From these findings, it can be seen that the solute element concentration of Mg can be reduced by forming the W phase or the W phase and the I phase instead of the LPSO phase, thereby realizing high thermal conductivity properties.

[0022] As shown in Fig. 1A and Fig. 1B, in order to obtain magnesium alloys having high thermal conductivity, it is preferable that Zn/Y, which is the composition ratio of Zn to Y in the magnesium alloys, is in a range of 2 or more and 5 or less.

[0023] By subjecting each of the cast materials and the heat-treated cast materials of the magnesium alloys shown in Fig. 1A and Fig. 1B to plastic processing such as extrusion, it is possible to obtain magnesium alloys having a structure in which the W phase ($Mg_3Zn_3Y_2$ phase) is not formed in a network shape at grain boundaries (namely, a structure in which a network is formed in a collapsed state) or a structure in which both the W phase ($Mg_3Zn_3Y_2$ phase) and the I phase (Mg_3Zn_6Y phase) are not formed in a network shape at grain boundaries (namely, a structure in which a network is formed in a collapsed state). Accordingly, it is considered that the thermal conductivity can be increased.

[0024] By performing plastic processing such as extrusion on the Mg-Zn-Y alloy having high thermal conductivity shown in Fig. 1A and Fig. 1B, excellent yield stress and ductility can be realized in a state where high thermal conductivity properties are maintained. For example, a yield strength of 300 MPa or more and an elongation of 5% or more can be realized.

[0025] According to the present embodiment, by setting the composition range of Zn and Y, which have a large negative mixing enthalpy, to the range shown in Fig. 1A and Fig. 1B, the $Mg_3Zn_3Y_2$ phase or both the $Mg_3Zn_3Y_2$ phase and the Mg_3Zn_6Y phase can precipitate in the α-Mg matrix of the magnesium alloys, thereby highly purifying the α-Mg matrix. Accordingly, the thermal conductivity of the magnesium alloys can be improved.

[0026] Fig. 4 is a diagram showing that the the Mg-1.88Zn-0.75Y-xYb alloy and the Mg-1.88Zn-0.75Y-xCa alloy are non-flammable. In Fig. 4, the vertical axis represents the ignition temperature (T/K), and the horizontal axis represents the Yb or Ca content denoted by x (atom%).

[0027] According to Fig. 4, it was confirmed that the Mg-1.88Zn-0.75Y alloy could be made non-flammable by adding Yb in an amount of 0.1 atom% or more or Ca in an amount of 1.0 atom% or more to the alloy. Therefore, it can be expected that the magnesium alloys having the composition range enclosed by the lines shown in Fig. 1A and Fig. 1B can be made non-flammable by adding Yb in an amount of 0.05 atom% or more and 0.6 atom% or less or Ca in an amount of 1.0 atom% or more and 2.0 atom% or less. The reason that the lower limit of Yb to be added is set to 0.05 atom% is that a Yb2O3 film is formed on an outermost layer when the amount of Yb added is equal to or greater than this amount, and the reason that the upper limit of Yb is set to 0.6 atom% is to suppress adverse effects on mechanical properties.

[0028] In addition, the reason that the lower limit of Ca to be added is set to 1.0 atom% is that a CaO film starts to form on the outermost layer when the amount of Ca added is equal to or greater than this amount, and the reason that the upper limit of Ca is set to 2.0 atom% is to suppress adverse effects on mechanical properties.

[0029] In addition, in addition to Yb and Ca, it can be expected that the above-described magnesium alloys can also be made non-flammable by adding Be in an amount of 0.03 atom% or more and 0.3 atom% or less or Sr in an amount of 0.1 atom% or more and 2.0 atom% or less to the magnesium alloys.

[0030] The reason that non-flammability can also be achieved by adding Be is that it has been reported that the ignition temperature of an alloy containing Y is improved. The reason that the lower limit of Be is set to 0.03 atom% is that this concentration improves the oxygen barrier performance of the Y2O3 film, and the reason that the upper limit of Be is set to 0.3 atom% is that the ignition temperature is not improved at this concentration or higher.

[0031] The reason that non-flammability can also be achieved by adding Sr is that it has been reported that the ignition temperature of an alloy containing Y is improved. The reason that the lower limit of Sr is set to 0.1 atom% is that this concentration improves the oxygen barrier performance of the Y2O3 film, and the reason that the upper limit of Sr is set to 2.0 atom% is to prevent an increase in the volume fraction of intermetallic compounds.

[0032] Fig. 5 is a diagram showing the XRD (X-ray diffraction method) measurement results of the Mg-1.88Zn-0.75Y alloy.

[0033] As shown in Fig. 5, it was confirmed that both the as-cast material and the heat-treated material had the W phase ($Mg_3Zn_3Y_2$ phase) and the I phase (Mg_3Zn_6Y phase).

(Second embodiment)

<Method for manufacturing magnesium alloy>

[0034] A magnesium alloy having the composition range according to the first embodiment is melted at a predetermined temperature in a non-flammable gas atmosphere (for example, in an Ar atmosphere), and then is cast at a solidification rate of less than 1000 K/s.

[0035] The magnesium alloy ingot after casting is cut into a predetermined shape. Accordingly, a cast material is produced. The cast material contains the $Mg_3Zn_3Y_2$ phase or both the $Mg_3Zn_3Y_2$ phase and the Mg_3Zn_6Y phase, and does not contain the long period stacking ordered structure phase.

[0036] Next, a heat-treated cast material is formed by performing heat treatment on the cast material at a temperature of 200°C or more and 450°C or less (preferably 300°C or more and 450°C or less) for 0 hour or more and 48 hours or less. The heat-treated cast material has a thermal conductivity of 90 W/m·K or more (preferably 100 W/m·K or more, more preferably 110 W/m·K or more, and still more preferably 130 W/m·K or more). In addition, the heat-treated cast material contains the $Mg_3Zn_3Y_2$ phase or both the $Mg_3Zn_3Y_2$ phase and the Mg_3Zn_6Y phase, and does not contain the long period stacking ordered structure phase. Incidentally, the above-described heat treatment may be performed in an air atmosphere.

[0037] Next, plastic processing is performed on the heat-treated cast material. The plastic processing includes extrusion, rolling, forging, wire drawing, severe plastic deformation, and the like. The severe plastic deformation includes equal-channel-angular-extrusion (ECAE) processing.

[0038] The plastically processed material on which the above-described plastic processing has been performed has a structure in which the $Mg_3Zn_3Y_2$ phase is not formed in a network shape at grain boundaries (a structure in which a network is formed in a collapsed state) or a structure in which both the $Mg_3Zn_3Y_2$ phase and the Mg_3Zn_6Y phase are not formed in a network shape at grain boundaries (a structure in which a network is formed in a collapsed state). In addition, the plastically processed material has a yield strength of 300 MPa or more and an elongation of 5% or more.

[0039] Incidentally, in the present embodiment, plastic processing is performed on the heat-treated cast material; however, plastic processing may be performed on the above-described cast material.

[0040] In addition, it is preferable that the plastically processed materials obtained by performing plastic processing on each of the cast material and the heat-treated cast material described above contain the $Mg_3Zn_3Y_2$ phase or both the $Mg_3Zn_3Y_2$ phase and the Mg_3Zn_6Y phase, and do not contain the long period stacking ordered structure phase.

[0041] In addition, each of the cast material and the plastically processed materials described above also has high thermal conductivity.

<Casting chip solidification>

[0042] A cast material is produced using the same method as the above-described casting method. Next, for example, a chip material chipped into a size of 1 to 2 mm is formed by cutting the cast material using a machine. Next, a solidified molded material is formed by solidifying and molding the chip material at room temperature through pressure molding.

[0043] In addition, before the chip material is formed, the same heat treatment as that of the above-described casting method may be performed on the cast material. In addition, before the solidified molded material is formed, the same heat treatment as that of the above-described casting method may be performed on the chip material. In addition, the same heat treatment as that of the above-described casting method may be formed on the solidified molded material. The solidified molded material after the heat treatments has a thermal conductivity of 90 W/K·m or more (preferably 100 W/m·K or more, more preferably 110 W/m·K or more, and still more preferably 130 W/m·K or more).

[0044] In addition, each of the chip material, the heat-treated chip material on which heat treatment has been performed, the heat-treated material obtained by performing heat treatment on the chip material, and the solidified molded material described above contains the $Mg_3Zn_3Y_2$ phase or both the $Mg_3Zn_3Y_2$ phase and the Mg_3Zn_6Y phase, and does not contain the long period stacking ordered structure phase.

[0045] Incidentally, plastic processing may be performed on the solidified molded material. Accordingly, a plastically processed material having a yield strength of 300 MPa or more and an elongation of 5% or more.

<Injection molding method>

[0046] An injection-molded material is produced by heating and melting a magnesium alloy having the composition range according to the first embodiment at a predetermined temperature in a non-flammable gas atmosphere (for example, in an Ar atmosphere), and injecting the molten magnesium alloy melt into a mold and cooling and solidifying the molten magnesium alloy melt. It is preferable that the cooling rate is 1000 K/sec or less.

[0047] Next, a heat-treated injection-molded material is formed by performing the same heat treatment as that of the above-described casting method on the above-described injection-molded material. It is preferable that the heat-treated injection-molded material has a thermal conductivity of 90 W/m·K or more (preferably 100 W/m·K or more, more preferably 110 W/m·K or more, and still more preferably 130 W/m·K or more).

[0048] In addition, each of the injection-molded material and the heat-treated injection-molded material described above contains the $Mg_3Zn_3Y_2$ phase or both the $Mg_3Zn_3Y_2$ phase and the Mg_3Zn_6Y phase, and does not contain the long period stacking ordered structure phase.

<Die casting method>

[0049] A die-cast material is produced by heating and melting a magnesium alloy having the composition range according to the first embodiment at a predetermined temperature in a non-flammable gas atmosphere (for example, in an Ar atmosphere), and pressure-feeding the molten magnesium alloy melt into a mold. It is preferable that the cooling rate at this time is less than 1000 K/sec. Incidentally, the die casting method is a casting method for mass-producing castings with high dimensional accuracy in a short period of time.

[0050] Next, a heat-treated die-cast material is formed by performing the same heat treatment as that of the above-described casting method on the above-described die-cast material. It is preferable that the heat-treated die-cast material has a thermal conductivity of 90 W/m·K or more (preferably 100 W/m·K or more, more preferably 110 W/m·K or more, and still more preferably 130 W/m·K or more).

[0051] In addition, each of the die-cast material and the heat-treated die-cast material described above contains the $Mg_3Zn_3Y_2$ phase or both the $Mg_3Zn_3Y_2$ phase and the Mg_3Zn_6Y phase, and does not contain the long period stacking ordered structure phase.

Example

[0052] Fig. 1A is a diagram showing the compositions of a plurality of samples according to an example of the invention, the thermal conductivity of cast materials of magnesium alloys having the compositions, and the constituent phases of these cast materials. Fig. 1B is a diagram showing the thermal conductivity of heat-treated materials obtained by performing heat treatment on the cast materials of the plurality of samples shown in Fig. 1A, and the constituent phases of these heat-treated materials.

[0053] The W phase shown in Fig. 1A and Fig. 1B indicates the $Mg_3Zn_3Y_2$ phase, the I phase indicates the Mg_3Zn_6Y phase, and the X phase indicates the long period stacking ordered structure phase (LPSO phase).

[0054] According to Fig. 1A and Fig. 1B, the solute element concentration of the Mg phase can be reduced by forming the W phase or both the W phase and the I phase instead of the LPSO phase, thereby realizing high thermal conductivity properties.

[0055] Cast ingots were produced by weighing raw materials for the samples having the compositions shown in Fig. 1A, melting the weighed raw materials in an Ar atmosphere using a high-frequency melting furnace, and pouring the molten metals into a mold. The cast ingots were cut into $\phi 32 \times 70$ mm pieces to produce cast materials. The results of measuring the thermal conductivity of these cast materials are shown in Fig. 1A. Incidentally, the method for measuring the thermal conductivity is as follows.

[0056] The samples are processed into $\phi 5$ mm $\times$ 1-3 mm or $5 \times 5 \times$ 1-3 mm^3. After the dimensions and weights of the samples are measured, blackening treatment is performed on the surfaces of the samples using a dry carbon spray. After the blackening treatment, weight measurement is performed again, and then the thermal diffusivity of the samples is measured using the laser flash method. The product of the obtained thermal diffusivity, the specific gravity, and the specific heat capacity of the samples is the thermal conductivity.

[0057] Next, heat-treated cast materials were formed by performing heat treatment on the above-described cast materials of the samples at a temperature of 360°C for 15 hours. The results of measuring the thermal conductivity of these heat-treated cast materials are shown in Fig. 1B. The method for measuring the thermal conductivity of the heat-treated cast materials is the same as the above-described method.

[0058] Next, extrusion materials were formed by performing extrusion on the heat-treated cast materials. The extrusion conditions at this time were set to an extrusion ratio of 15, an extrusion temperature of 250°C, and an extrusion rate of 1.0 mm/s.

[0059] The extrusion materials can realize excellent yield stress and ductility while maintaining high thermal conductivity.

[0060] Fig. 2 is a diagram showing stress-strain curves of a heat-treated cast material. The composition of the heat-treated cast material was Mg-1.88Zn-0.75Y, and the heat treatment conditions were set to a temperature of 360°C and a heat treatment time of 15 hours. The thermal conductivity of the heat-treated cast material was 141 W/m·K. The results of performing a tensile test on the heat-treated cast material twice were that the 0.2% yield strength $\sigma_{0.2}$ was 119 MPa and the elongation ε was 4.4%, and the 0.2% yield strength $\sigma_{0.2}$ was 121 MPa and the elongation ε was 3.9%. The average value of the 0.2% yield strength $\sigma_{0.2}$ was 120 MPa and the average value of the elongation ε was 4.2%.

[0061] Fig. 3 is a diagram showing stress-strain curves of an extrusion material. The composition of the extrusion material is Mg-1.88Zn-0.75Y. The extrusion material was obtained by extruding the heat-treated cast material under the above-described extrusion conditions, and the heat treatment conditions for the heat-treated cast material were set to a temperature of 360°C and a heat treatment time of 15 hours. The thermal conductivity of the extrusion material was 131 W/m·K. The results of performing a tensile test on the extrusion material three times were that the 0.2% yield strength $\sigma_{0.2}$ was 361 MPa and the elongation ε was 10.7%, the 0.2% yield strength $\sigma_{0.2}$ was 365 MPa and the elongation ε was 9.6%, and the 0.2% yield strength $\sigma_{0.2}$ was 358 MPa and the elongation ε was 8.8%. The average value of the 0.2% yield strength $\sigma_{0.2}$ was 361 MPa and the average value of the elongation ε was 9.7%.

[0062] Fig. 4 is a diagram showing that the Mg-1.88Zn-0.75Y-xYb alloy and the Mg-1.88Zn-0.75Y-xCa alloy are non-flammable. By adding Yb in an amount of 0.1 atom% or more or Ca in an amount of 1 atom% or more to the Mg-1.88Zn-0.75Y alloys, these alloys could be made non-flammable.

[0063] Fig. 6 is a diagram showing the properties of an Mg-1.88Zn-0.75Y-0.1Yb alloy extrusion material of an example.

[0064] According to Fig. 6, the Mg-1.88Zn-0.75Y-0.1Yb alloy extrusion material could achieve a high yield strength $\sigma_{0.2}$ of 383 MPa, a high thermal conductivity properties λ of 137 $Wm^{-1}K^{-1}$, and a non-flammability T_{ig} of 1324 K. Therefore, it could be confirmed that even when Yb was added, the thermal conductivity properties did not decrease.

Claims

1. A magnesium alloy comprising:

a atom% of Zn;
b atom% of Y; and
a remainder consisting of Mg and unavoidable impurities,
wherein a Zn content of a atom% and a Y content of b atom% are set in a range enclosed by straight lines represented by the following (1) to (8) according to coordinates (b, a) where a is taken on a vertical axis and b is taken on a horizontal axis,
the magnesium alloy contains a $Mg_3Zn_3Y_2$ phase or both a $Mg_3Zn_3Y_2$ phase and a Mg_3Zn_6Y phase, and
the magnesium alloy does not contain a long period stacking ordered structure phase.

(1) When b is in a range defined by the following Formula 1a, a straight line represented by the following Formula 1b is obtained.

$$\text{(Formula 1a) } 0.25 \leq b \leq 1.09$$

$$\text{(Formula 1b) } a = 0.5$$

(2) When b is in a range defined by the following Formula 2a, a straight line represented by the following Formula 2b is obtained.

$$\text{(Formula 2a) } 1.09 \leq b \leq 1.2$$

$$\text{(Formula 2b) } a = 2.91b - 2.67$$

(3) When a is in a range defined by the following Formula 3a, a straight line represented by the following Formula 3b is obtained.

$$\text{(Formula 3a) } 0.82 \leq a \leq 1.62$$

$$\text{(Formula 3b) } b = 1.2$$

(4) When b is in a range defined by the following Formula 4a, a straight line represented by the following Formula 4b is obtained.

$$\text{(Formula 4a) } 1.2 \leq b \leq 3$$

$$\text{(Formula 4b) } a = 1.35b$$

(5) When a is in a range defined by the following Formula 5a, a straight line represented by the following Formula 5b is obtained.

$$\text{(Formula 5a) } 4.05 \leq a \leq 7$$

$$\text{(Formula 5b) } b = 3$$

(6) When b is in a range defined by the following Formula 6a, a straight line represented by the following Formula 6b is obtained.

$$\text{(Formula 6a) } 1.5 \leq b \leq 3$$

$$\text{(Formula 6b) } a = 7$$

(7) When b is in a range defined by the following Formula 7a, a straight line represented by the following Formula 7b is obtained.

$$\text{(Formula 7a) } 0.25 \leq b \leq 1.5$$

$$\text{(Formula 7b) } a = 4.2b + 0.7$$

(8) When a is in a range defined by the following Formula 8a, a straight line represented by the following Formula 8b is obtained.

$$\text{(Formula 8a) } 0.5 \leq a \leq 1.75$$

$$\text{(Formula 8b) } b = 0.25$$

2. The magnesium alloy according to claim 1, wherein the magnesium alloy has a thermal conductivity of 90 W/m·K or more.

3. The magnesium alloy according to claim 1 or 2, wherein the magnesium alloy contains any one element selected from the group consisting of Yb in an amount of 0.05 atom% or more and 0.6 atom% or less, Be in an amount of 0.03 atom% or more and 0.3 atom% or less, Ca in an amount of 1.0 atom% or more and 2.0 atom% or less, and Sr in an amount of 0.1 atom% or more and 2.0 atom% or less.

4. The magnesium alloy according to claim 1 or 2, wherein Zn/Y, which is a composition ratio of Zn to Y in the magnesium alloy, is in a range of 2 or more and 5 or less.

5. The magnesium alloy according to claim 1 or 2, wherein the magnesium alloy has a structure in which the $Mg_3Zn_3Y_2$ phase is not formed in a network shape at grain boundaries or a structure in which both the $Mg_3Zn_3Y_2$ phase and the Mg_3Zn_6Y phase are not formed in a network shape at grain boundaries.

6. The magnesium alloy according to claim 1 or 2, wherein the magnesium alloy has a yield strength of 300 MPa or more and an elongation of 5% or more.

7. A method for manufacturing a magnesium alloy containing a atom% of Zn, b atom% of Y, and a remainder consisting of Mg and unavoidable impurities, the method comprising:

a step (a) of forming a cast material by casting the magnesium alloy at a solidification rate of less than 1000 K/sec,
wherein a Zn content of a atom% and a Y content of b atom% are set in a range enclosed by straight lines represented by the following (1) to (8) according to coordinates (b, a) where a is taken on a vertical axis and b is taken on a horizontal axis,
the cast material contains a $Mg_3Zn_3Y_2$ phase or both a $Mg_3Zn_3Y_2$ phase and a Mg_3Zn_6Y phase, and
the cast material does not contain a long period stacking ordered structure phase.
(1) When b is in a range defined by the following Formula 1a, a straight line represented by the following Formula 1b is obtained.

$$\text{(Formula 1a) } 0.25 \leq b \leq 1.09$$

$$\text{(Formula 1b) } a = 0.5$$

(2) When b is in a range defined by the following Formula 2a, a straight line represented by the following Formula 2b is obtained.

$$\text{(Formula 2a) } 1.09 \leq b \leq 1.2$$

$$\text{(Formula 2b) } a = 2.91b - 2.67$$

(3) When a is in a range defined by the following Formula 3a, a straight line represented by the following Formula 3b is obtained.

$$\text{(Formula 3a) } 0.82 \leq a \leq 1.62$$

$$\text{(Formula 3b) } b = 1.2$$

(4) When b is in a range defined by the following Formula 4a, a straight line represented by the following Formula 4b is obtained.

$$\text{(Formula 4a) } 1.2 \leq b \leq 3$$

$$\text{(Formula 4b) } a = 1.35b$$

(5) When a is in a range defined by the following Formula 5a, a straight line represented by the

following Formula 5b is obtained.

$$\text{(Formula 5a) } 4.05 \leq a \leq 7$$

$$\text{(Formula 5b) } b = 3$$

(6) When b is in a range defined by the following Formula 6a, a straight line represented by the following Formula 6b is obtained.

$$\text{(Formula 6a) } 1.5 \leq b \leq 3$$

$$\text{(Formula 6b) } a = 7$$

(7) When b is in a range defined by the following Formula 7a, a straight line represented by the following Formula 7b is obtained.

$$\text{(Formula 7a) } 0.25 \leq b \leq 1.5$$

$$\text{(Formula 7b) } a = 4.2b + 0.7$$

(8) When a is in a range defined by the following Formula 8a, a straight line represented by the following Formula 8b is obtained.

$$\text{(Formula 8a) } 0.5 \leq a \leq 1.75$$

$$\text{(Formula 8b) } b = 0.25$$

8. The method for manufacturing a magnesium alloy according to claim 7, further comprising:

a step (b) of forming a heat-treated material by performing heat treatment on the cast material after the step (a),
wherein the heat-treated material has a thermal conductivity of 90 W/m K or more,
the heat-treated material contains the $Mg_3Zn_3Y_2$ phase or both the $Mg_3Zn_3Y_2$ phase and the Mg_3Zn_6Y phase, and
the heat-treated material does not contain the long period stacking ordered structure phase.

9. The method for manufacturing a magnesium alloy according to claim 8,
wherein conditions for performing the heat treatment are set to at a temperature of 200°C or more and 500°C or less and a heat treatment time of 48 hours or less.

10. The magnesium alloy according to any one of claims 7 to 9,
wherein the magnesium alloy contains any one element selected from the group consisting of Yb in an amount of 0.05 atom% or more and 0.6 atom% or less, Be in an amount of 0.03 atom% or more and 0.3 atom% or less, Ca in an amount of 1.0 atom% or more and 2.0 atom% or less, and Sr in an amount of 0.1 atom% or more and 2.0 atom% or less.

11. The method for manufacturing a magnesium alloy according to any one of claims 7 to 9,
wherein Zn/Y, which is a composition ratio of Zn to Y in the cast material, is in a range of 2 or more and 5 or less.

12. The method for manufacturing a magnesium alloy according to any one of claims 7 to 9, further comprising:

a step (c) of forming a plastically processed material by performing plastic processing on the heat-treated material after the step (a) or the step (b),
wherein the plastically processed material has a structure in which the $Mg_3Zn_3Y_2$ phase is not formed in a network shape at grain boundaries or a structure in which both the $Mg_3Zn_3Y_2$ phase and the Mg_3Zn_6Y phase are not formed in a network shape at grain boundaries.

13. The method for manufacturing a magnesium alloy according to claim 12,
wherein the plastically processed material has a yield strength of 300 MPa or more and an elongation of 5% or more.

FIG.1A

THERMAL CONDUCTIVITY OF AS-CAST MATERIAL

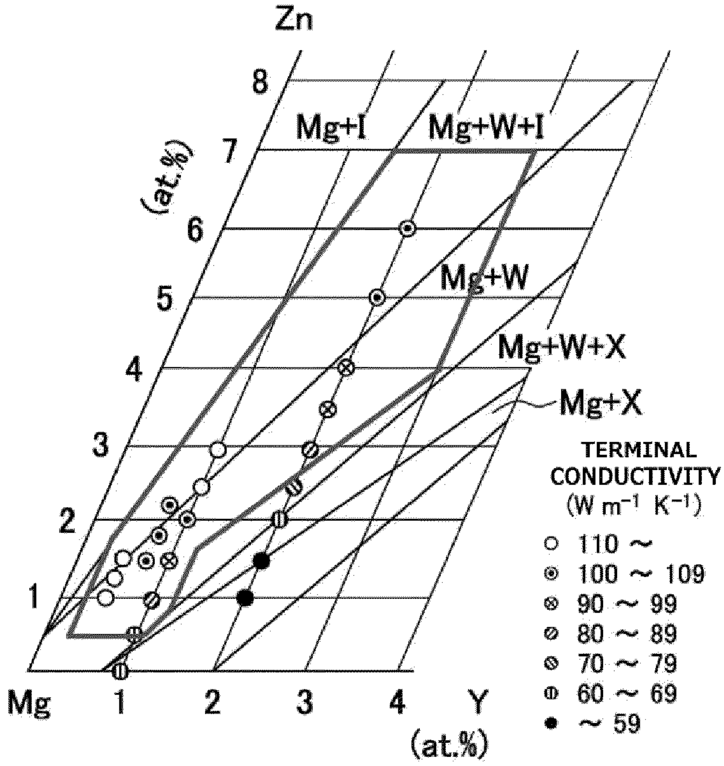


FIG.1B

THERMAL CONDUCTIVITY OF HEAT-TREATED MATERIAL

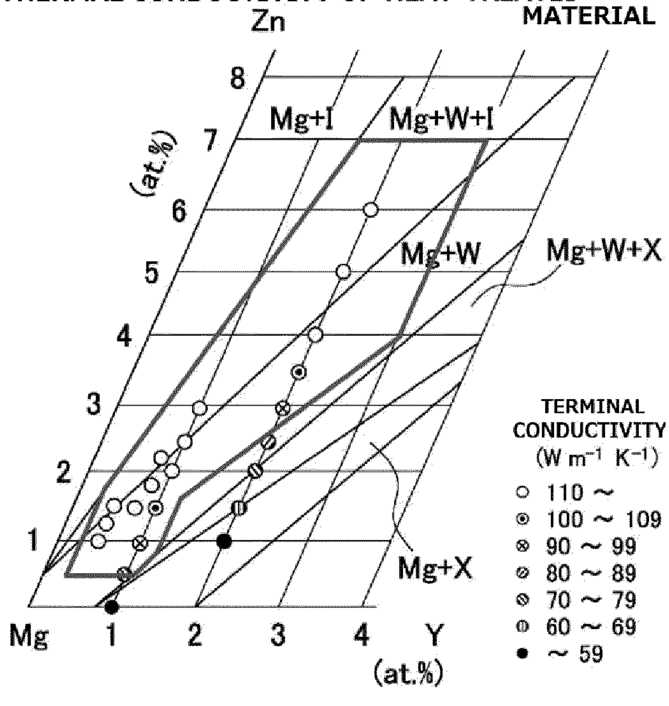


FIG.2

STRESS-STRAIN CURVE OF HEAT-TREATED MATERIAL

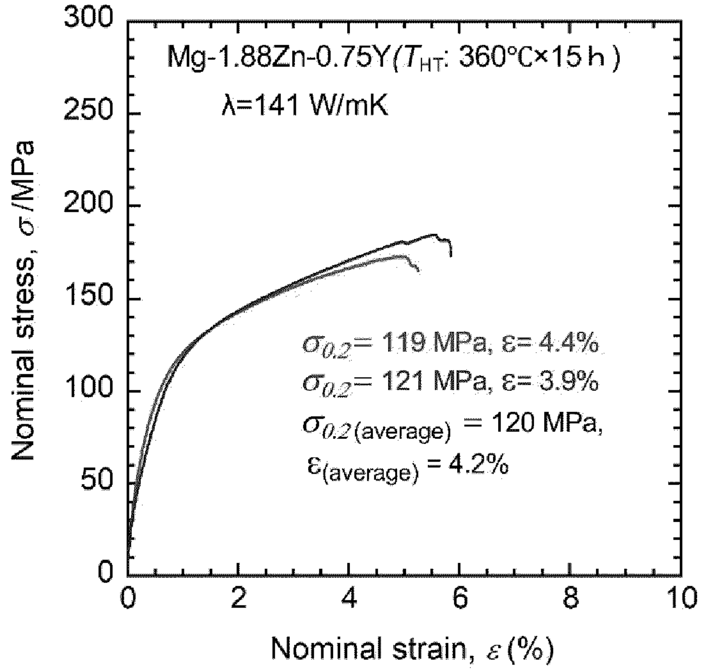


FIG.3

STRESS-STRAIN CURVE OF EXTRUSION MATERIAL

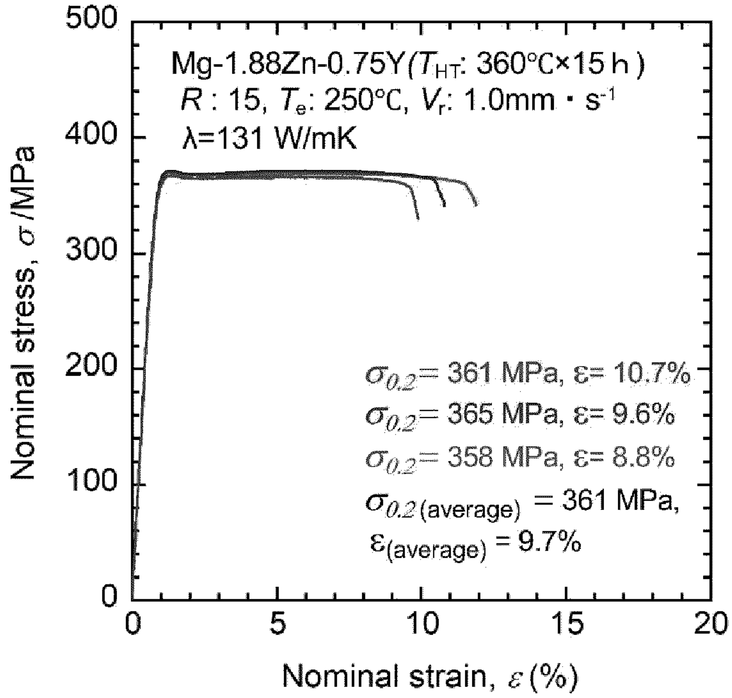


FIG.4

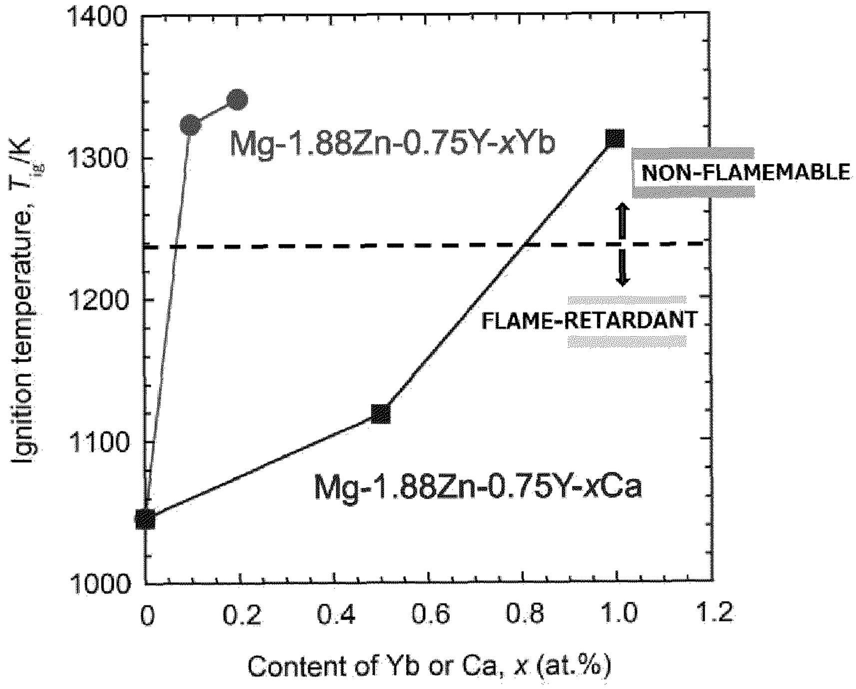

1400
1300
1200
1100
1000
Ignition temperature, T_{ig}/K
Mg-1.88Zn-0.75Y-xYb
NON-FLAMEMABLE
FLAME-RETARDANT
Mg-1.88Zn-0.75Y-xCa
0
0.2
0.4
0.6
0.8
1.0
1.2
Content of Yb or Ca, x (at.%)

FIG.5

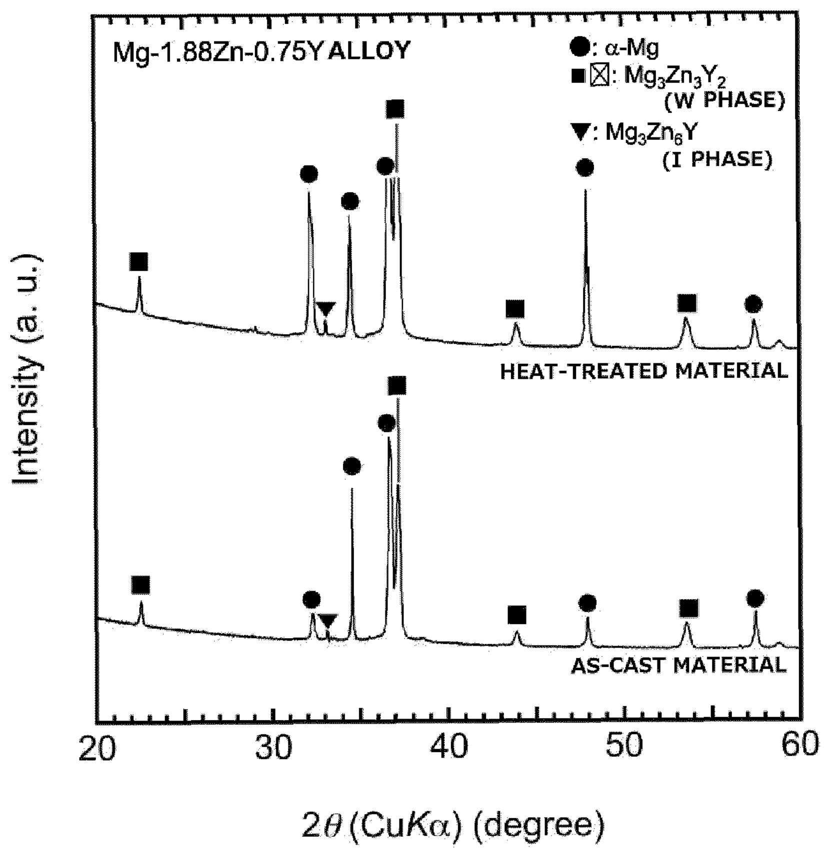
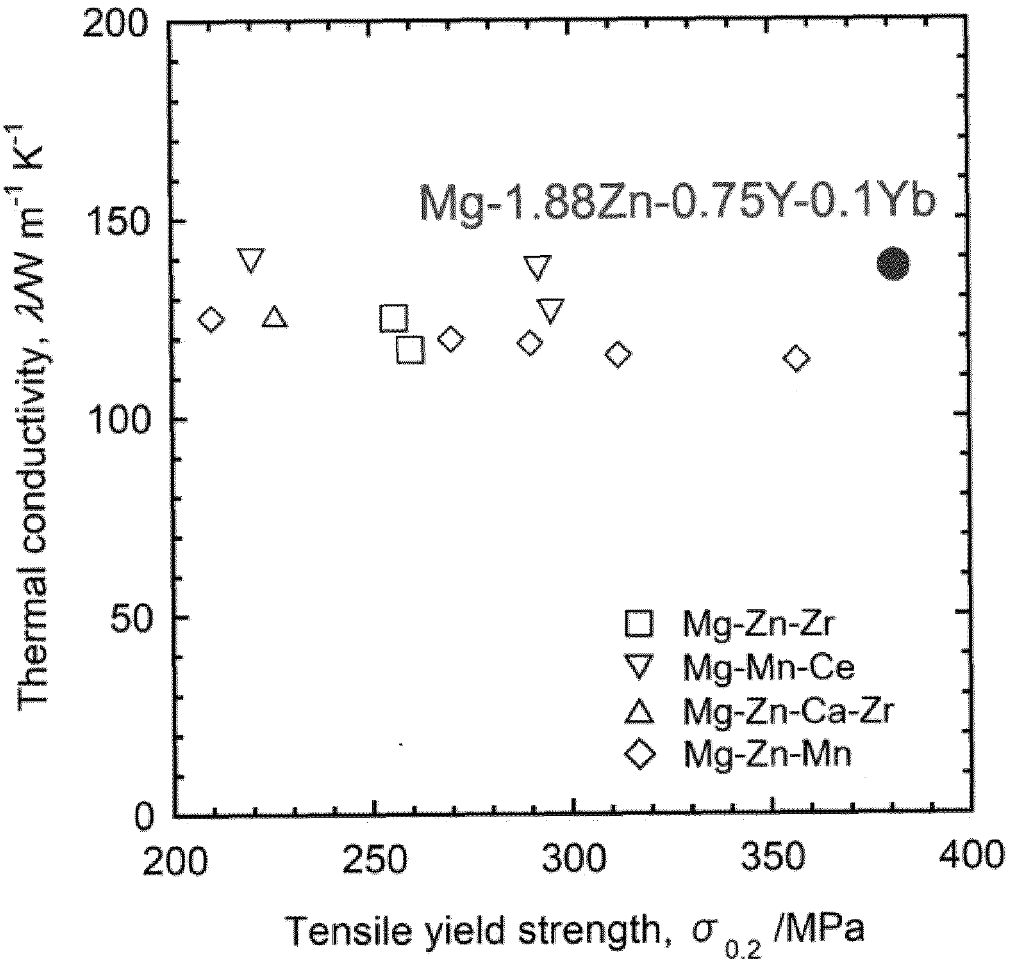

Mg-1.88Zn-0.75Y ALLOY
●: α-Mg
■☒: $Mg_3Zn_3Y_2$
(W PHASE)
▼: Mg_3Zn_6Y
(I PHASE)
HEAT-TREATED MATERIAL
AS-CAST MATERIAL
Intensity (a. u.)
20
30
40
50
60
2θ (CuKα) (degree)

FIG.6


Mg-1.88Zn-0.75Y-0.1Yb
Thermal conductivity, λ/W m-1 K-1
Tensile yield strength, σ0.2 /MPa
200
150
100
50
0
200
250
300
350
400
Mg-Zn-Zr
Mg-Mn-Ce
Mg-Zn-Ca-Zr
Mg-Zn-Mn

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/037309

A. CLASSIFICATION OF SUBJECT MATTER

C22C 23/04(2006.01)i; ***C22C 23/06***(2006.01)i; *C22F 1/00*(2006.01)n; ***C22F 1/06***(2006.01)i
FI: C22C23/04; C22C23/06; C22F1/06; C22F1/00 611; C22F1/00 612; C22F1/00 630A; C22F1/00 630K; C22F1/00 650F; C22F1/00 681; C22F1/00 682; C22F1/00 683; C22F1/00 685Z; C22F1/00 691B; C22F1/00 691C; C22F1/00 694A; C22F1/00 694B; C22F1/00 694Z

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)

C22C23/04; C22C23/06; C22F1/00; C22F1/06

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2006-097037 A (KUMAMOTO UNIV.) 13 April 2006 (2006-04-13)	1-13
A	WO 2005/052203 A1 (KAWAMURA, Yoshihito) 09 June 2005 (2005-06-09)	1-13
A	JP 2002-309332 A (YONSEI UNIV.) 23 October 2002 (2002-10-23)	1-13

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 December 2023	**19 December 2023**

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office (ISA/JP) **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/037309

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		EP 1640466 A1	
WO 2005/052203 A1	09 June 2005	US 2015/0020931 A1	
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		WO 2002/083964 A1	
		KR 10-2002-0078936 A	

Form PCT/ISA/210 (patent family annex) (January 2015)

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- JP 2012197490 A **[0004]**