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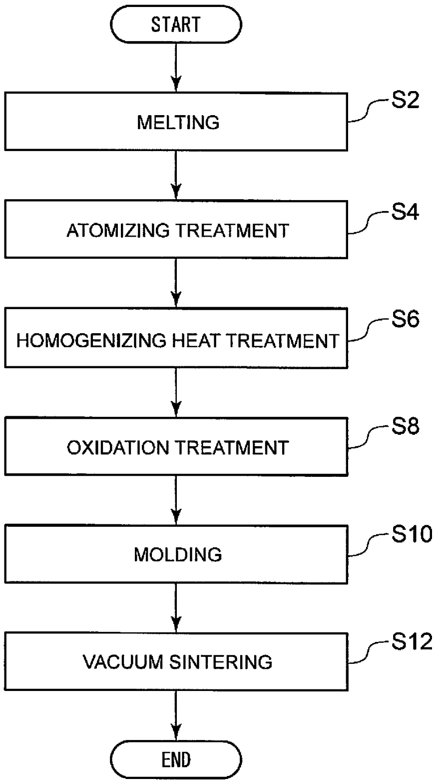
(54) ALUMINUM ALLOY MATERIAL, PRODUCTION METHOD THEREFOR, BASKET FOR CASK, AND CASK

(57) An aluminum alloy material based on aluminum (Al) contains 0.1 wt% or more and 0.3 wt% or less of silicon (Si), 0.1 wt% or more and 0.7 wt% or less of iron (Fe), 1.8 wt% or more and 3.0 wt% or less of manganese (Mn), and 0.8 wt% or more and 1.3 wt% or less of magnesium (Mg).

FIG. 2



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Description

TECHNICAL FIELD

[0001] The present disclosure relates to an aluminum alloy material, a method for producing the same, a basket for a cask, and a cask.

BACKGROUND ART

[0002] An aluminum alloy containing manganese, which is excellent in thermal stability, is often used as the material of a member used in a high-temperature environment for a long period of time.

[0003] For instance, a metal cask for transporting or storing a used fuel stores a spent nuclear fuel for a long period (e.g., 60 years) therein and then transports it to a nuclear reprocessing facility or the like. That is, the metal cask and a structural member thereof are exposed to heat by decay heat of the spent nuclear fuel (heating element) over a long period of storing the used fuel. Non-Patent Document 1 discloses using an aluminum alloy containing manganese as the material of a structural member (e.g., basket) of the metal cask.

[0004] Patent Document 1 discloses producing a material characteristic evaluation sample simulating a heat degradation phenomenon such as coarse precipitation which can occur in an actual product depending on thermal history, in order to evaluate strength characteristics of an aluminum alloy material including an aluminum alloy containing manganese.

Citation List

Patent Literature

[0005] Patent Document 1: JP5960335B

Non-Patent Literature

[0006] Non-Patent Document 1: Japan Society of Mechanical Engineers, "Codes for construction of spent nuclear fuel storage facilities --Rules on transport/storage packagings for spent nuclear fuel-- (2007)", published on February, 2008

SUMMARY

Problems to be Solved

[0007] An aluminum alloy containing manganese (e.g., 3000 series aluminum alloys) is excellent in thermal stability but is inferior in strength characteristics, compared to other aluminum alloys (e.g., 2000 series aluminum alloys containing duralumin). For this reason, the aluminum alloy containing manganese has been hardly used as a strength member, and there has been little need for improvement in strength characteristics of the aluminum alloy containing manganese.

[0008] However, it is desired to improve strength characteristics such as high-temperature strength of the aluminum alloy material containing manganese excellent in thermal stability to improve storage density of the above-described metal cask or to deal with higher burnup fuels.

[0009] In view of the above, an object of at least one embodiment of the present invention is to provide an aluminum alloy material with improved strength characteristics.

Solution to the Problems

[0010]

(1) An aluminum alloy material according to at least one embodiment of the present invention is based on aluminum (Al) and comprises: 0.1 wt% or more and 0.3 wt% or less of silicon (Si); 0.1 wt% or more and 0.7 wt% or less of iron (Fe); 1.8 wt% or more and 3.0 wt% or less of manganese (Mn); and 0.8 wt% or more and 1.3 wt% or less of magnesium (Mg).

[0011] In the aluminum alloy, manganese is a metallic element which contributes to precipitation strengthening. That is, manganese is precipitated as an Al-Mn compound and forms precipitates, thereby improving strength characteristics of the aluminum alloy material. Although the maximum solubility limit of manganese in aluminum is 1.82 wt% at 658.5°C (eutectic temperature), manganese usually does not enter into solid solution in the aluminum alloy containing 1.82 wt% or more of manganese at the eutectic temperature or lower. Thus, such an aluminum alloy does not form a precipitate which contribute to improvement in strength characteristics but forms a eutectic structure of aluminum (Al) and Al_6Mn which does not substantially contribute to improvement in strength characteristics. Accordingly, it is considered that it is difficult to achieve the strength characteristic improvement effect from the aluminum alloy containing more than 1.82% of manganese.

[0012] In this regard, a producing method according to an embodiment described below allows micro particles of Al_6Mn to be precipitated in solid Al using Si and Fe as precipitate nuclei at the eutectic temperature or lower in the aluminum alloy containing more than the maximum solubility limit of manganese as in the above (1). Consequently, more manganese than usual can be precipitated in the aluminum as micro particles of Al_6Mn. Thus, it is possible to obtain the aluminum alloy material with improved strength characteristics.

(2) In some embodiments, in the aluminum alloy material described in the above (1), at least a part of the manganese is contained as a non-equilibrium precipitate of Al_6Mn.

[0013] When the melt of the aluminum alloy with the composition described in the above (1), (i.e., the aluminum alloy containing more than the maximum solubility limit of manganese) is relatively slowly cooled so that the equilibrium state is maintained, a eutectic structure of aluminum (Al) and Al_6Mn is formed. If such a eutectic structure is formed, it is difficult to achieve the strength characteristic improvement effect in the aluminum alloy material.

[0014] In this regard, in the above configuration (2), the aluminum alloy material contains at least a part of the manganese as a non-equilibrium precipitate of Al_6Mn, which contribute to improvement in strength characteristics. Thus, the aluminum alloy material described in the above (2) has improved strength characteristics, compared with an aluminum alloy material in which the eutectic structure is formed.

> (3) In some embodiments, in the above configuration (2), the non-equilibrium precipitate of Al_6Mn is a granular precipitate.

[0015] In the above configuration (3), since the non-equilibrium precipitate of Al_6Mn contained in the aluminum alloy material is a granular precipitate, strength characteristics of the aluminum alloy material are improved compared with a case where a laminated eutectic structure is formed.

> (4) A basket for a cask according to at least one embodiment of the present invention is formed of the aluminum alloy material described in any one of the above (1) to (3).

[0016] In the above configuration (4), the basket for a cask is formed of the above aluminum alloy material (1), which has improved strength characteristics since more manganese than usual is precipitated in the aluminum as micro particles of Al_6Mn. Thus, it is possible to obtain the basket for a cask with improved strength characteristics.

> (5) A cask according at least one embodiment of the present invention comprises: the basket described in the above (4); a main body accommodating the basket; and a lid portion for closing an end opening of the main body.

[0017] In the above configuration (5), the basket for a cask is formed of the above aluminum alloy material (1), which has improved strength characteristics since more manganese than usual is precipitated in the aluminum as micro particles of Al_6Mn. Thus, it is possible to obtain the basket for a cask with improved strength characteristics.

> (6) A method for producing an aluminum alloy material according to at least one embodiment of the present invention comprises: a cooling step of cooling a melt of an aluminum alloy based on aluminum (Al) and containing 1.8 wt% or more and 3.0 wt% or less of manganese (Mn) so that the manganese enters into solid solution in an aluminum parent phase in a supersaturated manner to obtain a supersaturated solid solution; and a heat treatment step of subjecting the supersaturated solid solution to a heat treatment to precipitate at least a part of the manganese as Al_6Mn, whereby an aluminum alloy material is obtained.

[0018] In the above producing method (6), the melt of the aluminum alloy containing more than the maximum solubility limit (1.82 wt%) of manganese is appropriately cooled so that the manganese enters into solid solution in the aluminum in a supersaturated manner without forming a eutectic structure of aluminum (Al) and Al_6Mn. Then, the supersaturated solid solution thus obtained is subjected to a heat treatment to precipitate at least a part of the manganese dissolved in the aluminum in the supersaturated solid solution as Al_6Mn.

[0019] Accordingly, the above producing method (6) allows micro particles of Al_6Mn to be precipitated in solid Al in the aluminum alloy containing more than the maximum solubility limit of manganese. Consequently, more manganese than usual can be precipitated as micro particles in the aluminum. Thus, it is possible to obtain the aluminum alloy material with improved strength characteristics.

> (7) In some embodiments, in the above producing method (6), the cooling step includes jetting a gas to the melt to atomize the melt.

[0020] In the above producing method (7), since the melt of the aluminum alloy containing manganese is atomized and rapidly cooled by jetting a gas to the melt, it is possible to form the supersaturated solid solution in which the manganese enters into solid solution in the aluminum in a supersaturated manner. Then, the supersaturated solid solution thus obtained is subjected to a heat treatment to precipitate at least a part of the manganese dissolved in the aluminum in the supersaturated solid solution as Al_6Mn. Thereby, it is possible to obtain the aluminum alloy material with improved strength characteristics.

> (8) In some embodiments, in the above producing method (7), powder of the supersaturated solid solution obtained by the cooling step has an average particle size of 5 μm or more and 80 μm or less.

[0021] When the powder obtained by jetting a gas to the melt of the aluminum alloy has an average particle size of 5 μm or more as in the above producing method (8), the powder can be easily formed by jetting the gas to the melt. When the powder has an average particle size of 80 μm or less as in the above producing method

(8), the specific surface area is relatively large, and the melt can be easily rapidly cooled when atomized. Thus, the supersaturated solid solution can be easily formed.

> (9) In some embodiments, the above producing method (7) or (8) further comprises a step of subjecting the supersaturated solid solution in a powder state to an oxidation treatment, before the heat treatment step.

[0022] In the above producing method (9), the powdered supersaturated solid solution obtained by atomizing the melt is subjected to the oxidation treatment, so that an aluminum oxide layer is formed on the surface of the powder. If aluminum oxide thus formed is incorporated in an aluminum parent phase for instance in a downstream process such as molding, strength characteristics of the aluminum alloy are improved through dispersed-particle strengthening. Thus, with the above producing method (9), it is possible to improve strength characteristics of the aluminum alloy material even more.

> (10) In some embodiments, in the above producing method (6), the cooling step includes forming a molding of the supersaturated solid solution by a DC casting method (Direct Chill Casting).

[0023] In the above producing method (10), since the molding is obtained while the melt of the aluminum alloy is directly cooled with a coolant through the DC casting method, the melt can be rapidly cooled. Thus, it is possible to obtain the molding of the supersaturated solid solution in which the manganese enters into solid solution in the aluminum in a supersaturated manner.

> (11) In some embodiments, in any of the above producing methods (6) to (10), the heat treatment step includes heating and keeping the supersaturated solid solution within a temperature range of 400°C or higher and 620°C or lower.

[0024] As in the above producing method (11), when the supersaturated solid solution is heated and kept at 400°C or higher, fine Al_6Mn particles are easily precipitated. Further, as in the above producing method (11), when the supersaturated solid solution is heated and kept at 620°C or lower, homogeneous Al_6Mn particles are easily precipitated.

[0025] Thus, the above producing method (11) makes it possible to effectively precipitate Al_6Mn particles, which contribute to improvement in strength characteristics of the aluminum alloy.

Advantageous Effects

[0026] According to at least one embodiment of the present invention, there is provided an aluminum alloy material with improved strength characteristics.

BRIEF DESCRIPTION OF DRAWINGS

[0027]

> FIG. 1 is a diagram showing a part of the aluminum side of an Al-Mn binary phase diagram.
> FIG. 2 is a flowchart of a method for producing an aluminum alloy material according to an embodiment.
> FIG. 3 is a diagram showing an example of temperature change of an aluminum alloy when heat treatment step is performed.
> FIG. 4 is a configuration diagram of a cask according to an embodiment.

DETAILED DESCRIPTION

[0028] Embodiments of the present invention will now be described in detail with reference to the accompanying drawings. It is intended, however, that unless particularly identified, dimensions, materials, shapes, relative positions and the like of components described in the embodiments shall be interpreted as illustrative only and not intended to limit the scope of the present invention.

[0029] First, a configuration of an aluminum alloy material according to some embodiments will be described.

[0030] The aluminum alloy material according to some embodiments is mainly composed of aluminum (Al) and further contains 0.1 wt% or more and 0.3 wt% or less of silicon (Si), 0.1 wt% or more and 0.7 wt% or less of iron (Fe), 1.8 wt% or more and 3.0 wt% or less of manganese (Mn), and 0.8 wt% or more and 1.3 wt% or less of magnesium (Mg).

[0031] In the aluminum alloy, manganese is a metallic element which contributes to precipitation strengthening. That is, manganese is precipitated as an Al-Mn compound and forms precipitates, thereby improving strength characteristics of the aluminum alloy material.

[0032] The aluminum alloy with the above configuration contains 1.8 wt% or more and 3.0 wt% or less of manganese (Mn). That is, the aluminum alloy contains the maximum solubility limit (1.82 wt% at 658.5°C (eutectic temperature)) or more of manganese.

[0033] The aluminum alloy containing manganese in an amount of more than 1.82 wt%, the maximum solubility limit, forms a eutectic structure of aluminum (Al) and Al_6Mn at the eutectic temperature or lower. This eutectic structure has a laminated structure and does not substantially contribute to improvement in strength characteristics. Accordingly, it is generally considered that it is difficult to achieve the strength characteristic improvement effect from the aluminum alloy containing more than the maximum solubility limit of manganese.

[0034] In this regard, a producing method according to an embodiment described below allows micro particles of Al_6Mn to be precipitated in solid Al using Si and Fe as precipitate nuclei at the eutectic temperature or lower in the aluminum alloy containing more than the maximum solubility limit of manganese. Consequently, more manganese than usual can be precipitated as micro particles of Al_6Mn in the aluminum. Thus, it is possible to obtain the aluminum alloy material containing the maximum solubility limit or more of manganese with improved strength characteristics.

[0035] As described above, when the content of Si is 0.1 wt% or more, it is possible to sufficiently precipitate the manganese as an Al-Mn compound using Si as precipitate nuclei in the aluminum alloy. Further, when the content of Si is 0.3 wt% or less, it is possible to suppress embrittlement of the aluminum alloy material.

[0036] Additionally, as described above, when the content of Fe is 0.1 wt% or more, it is possible to sufficiently precipitate the manganese as an Al-Mn compound using Fe as precipitate nuclei in the aluminum alloy. Further, when the content of Fe is 0.7 wt% or less, it is possible to suppress embrittlement of the aluminum alloy material.

[0037] In some embodiments, in the aluminum alloy material, at least a part of Mn is contained as a non-equilibrium precipitate of Al_6Mn.

[0038] The non-equilibrium precipitate of Al_6Mn contributes to improvement in strength characteristics in the aluminum alloy material. Thus, strength characteristics of the aluminum alloy material are improved by containing at least a part of Mn as the non-equilibrium precipitate of Al_6Mn.

[0039] In some embodiments, the non-equilibrium precipitate of Al_6Mn is granular precipitates.

[0040] When the non-equilibrium precipitate of Al_6Mn contained in the aluminum alloy material is granular precipitates, strength characteristics of the aluminum alloy material are improved compared with a case where a laminated eutectic structure is formed.

[0041] Next, a method for producing the aluminum alloy material according to some embodiments will be described.

[0042] The method for producing the aluminum alloy material according to some embodiments starts with melting an aluminum alloy based on aluminum (Al) and containing 1.8 wt% or more and 3.0 wt% or less of manganese (Mn) to obtain a melt of the aluminum alloy. The melt is then cooled so that the manganese enters into solid solution in an aluminum parent phase in a supersaturated manner to obtain a supersaturated solid solution. The resulting supersaturated solid solution is subjected to a heat treatment to precipitate at least a part of the manganese as Al_6Mn. Consequently, the aluminum alloy material is obtained.

(Melting step)

[0043] In the step of obtaining the melt of the aluminum alloy, the aluminum alloy based on aluminum (Al) and containing 1.8 wt% or more and 3.0 wt% or less of manganese (Mn) is melted. In this step, various additives may be added to the melt of the aluminum alloy so that a final aluminum alloy material has a desired composition.

[0044] For instance, the melt of the aluminum alloy may contain 0.1 wt% or more and 0.3 wt% or less of silicon (Si) and 0.1 wt% or more and 0.7 wt% or less of iron (Fe). When the content of Si or Fe is the above-described lower limit or more, it is possible to sufficiently precipitate the manganese as an Al-Mn compound using Si or Fe as precipitate nuclei in the aluminum alloy. When the content of Si or Fe is the above-described upper limit or less, it is possible to suppress embrittlement of the aluminum alloy material.

(Cooling step)

[0045] In the step of cooling the melt of the aluminum alloy, the melt of the aluminum alloy is appropriately cooled so that the manganese enters into solid solution in the aluminum in a supersaturated manner to obtain a supersaturated solid solution without forming a eutectic structure of aluminum (Al) and Al_6Mn.

[0046] For instance, the melt of the aluminum alloy is relatively rapidly cooled to obtain a supersaturated solid solution in which the manganese enters into solid solution in the aluminum in a supersaturated manner.

[0047] FIG. 1 is a diagram showing a part of the aluminum side of an Al-Mn binary phase diagram.

[0048] When the melt of the aluminum alloy containing more than the maximum solubility limit of manganese is relatively slowly cooled so that the equilibrium state is maintained, a eutectic structure of aluminum (Al) and Al_6Mn is formed, as described below.

[0049] That is, as shown in FIG. 1, in a region where the Mn content is more than the maximum solubility limit, i.e., 1.82 wt%, the aluminum alloy at a temperature higher than the eutectic temperature, i.e., 658.5°C, is in a state where liquid and an Al-Mn compound coexist (region indicated by "L+$MnAl_6$" in FIG. 1). Accordingly, when the molten aluminum alloy containing more than 1.82 wt% (the maximum solubility limit) of manganese is relatively slowly cooled, in the course of cooling, a eutectic structure of Al and Al_6Mn is formed rather than Al_6Mn is precipitated as small precipitates, through the region where liquid and an Al-Mn compound coexist (region indicated by "L+$MnAl_6$") on the phase diagram because the diffusion rate of manganese is relatively high in a liquid phase.

[0050] If the eutectic structure is formed in the aluminum alloy, it is difficult to achieve the strength characteristic improvement effect in the aluminum alloy material.

[0051] By contrast, in the cooling step according to the above embodiment, for instance, the melt of the aluminum alloy is relatively rapidly cooled. This enables formation of a supersaturated solid solution in which the maximum solubility limit or more of manganese enters into solid solution in an aluminum parent phase. Thus, in a subsequent heat treatment step, the manganese in the supersaturated solid solution can be precipitated as micro particles of $MnAl_6$ in solid Al. Consequently, more manganese than usual can be precipitated as micro particles in the aluminum. Thus, it is possible to obtain the aluminum alloy material with improved strength characteristics.

[0052] In an embodiment, the cooling step includes jetting a gas to the melt of the aluminum alloy containing manganese to atomize the melt. That is, in an embodiment, the melt of the aluminum alloy containing manganese is made into powder by an atomization method.

[0053] In this case, since the melt of the aluminum alloy containing manganese is atomized and rapidly cooled by jetting a gas to the melt, it is possible to form the supersaturated solid solution in which the manganese enters into solid solution in the aluminum in a supersaturated manner.

[0054] In an embodiment, the cooling step includes forming a molding of the supersaturated solid solution by a DC casting method (Direct Chill Casting).

[0055] In the DC casting method, a molding is obtained while a molten metal is directly cooled with a coolant. That is, when the DC casting method is adopted in the cooling step, since the molding is obtained while the melt of the aluminum alloy is directly cooled with a coolant (e.g., water), the melt can be rapidly cooled. Thus, it is possible to obtain the molding of the supersaturated solid solution in which the manganese enters into solid solution in the aluminum in a supersaturated manner.

(Heat treatment step)

[0056] In the heat treatment step, the supersaturated solid solution obtained in the cooling step is subjected to a heat treatment to precipitate at least a part of the manganese dissolved in the aluminum in the supersaturated solid solution as Al_6Mn. In some embodiments, the heat treatment step includes heating and keeping the supersaturated solid solution within a temperature range of 400°C or higher and 620°C or lower.

[0057] As described above, when the supersaturated solid solution is heated and kept at 400°C or higher, fine Al_6Mn particles are easily precipitated. Further, as described above, when the supersaturated solid solution is heated and kept at 620°C or lower, homogeneous Al_6Mn particles are easily precipitated.

[0058] Thus, when supersaturated solid solution is heated and kept within the above temperature range, it is possible to effectively precipitate Al_6Mn particles, which contribute to improvement in strength characteristics of the aluminum alloy.

[0059] In a case of manufacturing a metallic material for use in a basket for a cask described later, before the heat treatment step, powder of a neutron absorbing material (e.g., B_4C) may be mixed to the powdered supersaturated solid solution, for instance. In this case, it is possible to impart the neutron absorbing function to the resulting metallic material.

[0060] The entire method for producing the aluminum alloy material in a case where the atomization method is adopted in the cooling step will now be described with a flowchart.

[0061] FIG. 2 is a flowchart of the method for producing the aluminum alloy material according to an embodiment.

[0062] Each step described below can also be applied in a case where a method other than the atomization method is adopted in the cooling step. For instance, the heat treatment step described below can be applied in a case where the cooling step is performed with the DC casting method.

[0063] As shown in FIG. 2, the method for producing the aluminum alloy material according to an embodiment starts with melting an aluminum alloy containing 1.8 wt% or more and 3.0 wt% or less of manganese (Mn) to obtain a melt of the aluminum alloy (S2; the above-described "melting step").

[0064] Then, in an embodiment, in the cooling step, a gas is jetted to the melt of the aluminum alloy containing manganese to atomize the melt (S4; the above-described "cooling step"). In this way, the melt of the aluminum alloy is atomized and relatively rapidly cooled by the atomization method to obtain a supersaturated solid solution in which the manganese enters into solid solution in the aluminum in a supersaturated manner.

[0065] The powder of the supersaturated solid solution obtained by atomizing the melt of the aluminum alloy by the atomization method may have an average particle size of 5 μm or more and 80 μm or less.

[0066] When the powder obtained by jetting a gas to the melt of the aluminum alloy has an average particle size of 5 μm or more, the powder can be easily formed by jetting the gas to the melt. When the powder has an average particle size of 80 μm or less, the specific surface area is relatively large, and the melt can be easily rapidly cooled when atomized. Thus, the supersaturated solid solution can be easily formed.

[0067] Then, the powdered supersaturated solid solution obtained by the atomizing treatment in step S4 is subjected to a homogenizing heat treatment (S6). The homogenizing heat treatment is performed to obtain homogeneous fine precipitates by subjecting the manganese dissolved in the supersaturated solid solution in the aluminum alloy to a heat treatment.

[0068] The homogenizing heat treatment may be performed by keeping the supersaturated solid solution within a temperature range of 400°C or higher and 620°C or lower, for 0.5 hour or more.

[0069] Further, the powdered supersaturated solid solution obtained by the atomizing treatment in step S4 is subjected to an oxidation treatment (S8).

[0070] When the powdered supersaturated solid solution obtained by atomizing the melt is subjected to the oxidation treatment, an aluminum oxide layer is formed on the surface of the powder. If aluminum oxide thus formed is incorporated in an aluminum parent phase for instance in a downstream process such as molding, strength characteristics of the aluminum alloy are improved through dispersed-particle strengthening. Thus, it is possible to improve strength characteristics of the aluminum alloy material even more.

[0071] Then, the powdered supersaturated solid solution is molded by, for instance, pressure molding under a hydrostatic pressure (S10), and the molded sample is sintered under vacuum to precipitate a least a part of the manganese dissolved in the aluminum in the supersaturated solid solution as Al_6Mn (S12; the above-described "heat treatment step").

[0072] Step S12 may be performed by keeping the supersaturated solid solution within a temperature range of 400°C or higher and 620°C or lower, for 0.5 hour or more.

[0073] FIG. 3 is a diagram showing an example of temperature change of the aluminum alloy when the vacuum sintering (heat treatment step S12) is performed.

[0074] In an embodiment, as shown in FIG. 3, before the vacuum sintering (S126), moisture contained in the supersaturated solid solution of the aluminum alloy is removed (S122 and S124). Steps S122 to S126 are performed under a reduced pressure (e.g., 20 Pa or less).

[0075] First, the supersaturated solid solution of the aluminum alloy is heated to T_1 and kept for 0.5 hour or more in a vacuum sintering furnace to remove adsorbed water contained in the supersaturated solid solution (S122). The temperature T_1 may be within a range of 100°C or higher and 180°C or lower.

[0076] Once the moisture is sufficiently removed in step S122, the temperature is further raised to T_2 and kept for 0.5 hour or more to remove adsorbed water, such as hydrated water, chemically or physically adsorbed to the supersaturated solid solution (S124). The temperature T_2 may be within a range of 350°C or higher and 480°C or lower.

[0077] Once the moisture is sufficiently removed in step S124, the temperature is further raised to T_3 and kept for 0.5 hour or more to sinter the supersaturated solid solution under vacuum (S126). The temperature T_3 may be within a range of 400°C or higher and 620°C or lower.

[0078] In S122 and S124, whether the moisture is sufficiently removed or not may be judged by the pressure in the vacuum sintering furnace. During removal of moisture, although the pressure increases with evaporation of moisture, the pressure decreases back with a decrease in moisture contained in the supersaturated solid solution by the evaporation. Accordingly, after starting to keep the temperature at T_1 or T_2, when the pressure increases and then decreases back (for instance, to 20 Pa or less), it may be judged that the moisture is sufficiently removed.

[0079] In each step of S122 to S126, for increasing the temperature, the temperature may be raised at a temperature increase rate of 100°C/hour or less.

[0080] Steps S2 to S8 described above allow micro particles of Al_6Mn to be precipitated in solid Al in the aluminum alloy containing more than the maximum solubility limit of manganese. Consequently, more manganese than usual can be precipitated in the aluminum as micro particles. Thus, it is possible to obtain the aluminum alloy material with improved strength characteristics.

[0081] The homogenizing heat treatment step S6 may be performed simultaneously with the vacuum sintering step (heat treatment step) S12. The homogenizing heat treatment step S6 and the oxidation treatment S8 are optional steps which are not necessarily performed and may be performed as needed.

[0082] Next, a cask and a basket for a cask according to an embodiment will be described.

[0083] FIG. 4 is a configuration diagram of a cask according to an embodiment. The cask shown in FIG. 4 is a metal cask for transporting or storing a used fuel.

[0084] As shown in FIG. 4, the cask 1 according to an embodiment includes a basket 16, a main body 2 accommodating the basket 16, and a lid portion 10 for closing an end opening of the main body 2. The basket 16 is formed of the aluminum alloy material according to the above-described embodiments.

[0085] The cask 1 includes a resin 4, for shielding neutrons, disposed around an outer periphery of the main body 2, an external cylinder 6 therearound, and a bottom portion 8. The main body 2 and the bottom portion 8 may be forging products made of carbon steel, which shields γ rays. The lid portion 10 may include a primary lid 11 and a secondary lid 12. The primary lid 11 and the secondary lid 12 may be made of stainless steel. The main body 2 and the bottom portion 8 may be joined by butt welding. Although not illustrated, the structure may include a tertiary lid.

[0086] Trunnions 24 for suspending the cask 1 may be disposed on both sides of a cask body 22. In FIG. 4, one of the trunnions 24 is not shown for clarity.

[0087] Further, shock absorbers 26, 28 in which a shock-absorbing member such as wood is encapsulated are attached on both ends of the cask body 22.

[0088] A plurality of internal fins 14 for thermal conduction is disposed between the main body 2 and the external cylinder 6. The resin 4 is injected in a fluid state into a space formed by the internal fins 14 and then solidified by thermal curing or the like.

[0089] The basket 16 includes an assembly of rectangular pipes 18 which are bundled and is inserted into a cavity 20 of the main body 2. The rectangular pipes 18 may be formed of the aluminum alloy material according to the above-described embodiments. The aluminum alloy constituting the rectangular pipes 18 may contain a neutron absorbing member (boron: B) for absorbing neutrons from the spent nuclear fuel. An individual storage space (cell) formed by each of the rectangular pipes 18 may store a single used fuel assembly.

[0090] The basket 16 or the rectangular pipes 18 may be formed in the shape of a product by extrusion or other processing on the aluminum alloy material according to the above-described embodiments. The rectangular pipes 18 may be formed in a grid structure like box of cakes.

[0091] In the cask described above, the basket for the cask is formed by the aluminum alloy material according to the above-described embodiments; this aluminum alloy material has improved strength characteristics since more manganese than usual is precipitated in the aluminum as micro particles of Al_6Mn. Thus, it is possible to form the basket with improved strength characteristics.

[0092] Embodiments of the present invention were described in detail above, but the present invention is not limited thereto, and various amendments and modifications may be implemented.

[0093] Further, in the present specification, an expression of relative or absolute arrangement such as "in a direction", "along a direction", "parallel", "orthogonal", "centered", "concentric" and "coaxial" shall not be construed as indicating only the arrangement in a strict literal sense, but also includes a state where the arrangement is relatively displaced by a tolerance, or by an angle or a distance whereby it is possible to achieve the same function.

[0094] For instance, an expression of an equal state such as "same" "equal" and "uniform" shall not be construed as indicating only the state in which the feature is strictly equal, but also includes a state in which there is a tolerance or a difference that can still achieve the same function.

[0095] Further, for instance, an expression of a shape such as a rectangular shape or a cylindrical shape shall not be construed as only the geometrically strict shape, but also includes a shape with unevenness or chamfered corners within the range in which the same effect can be achieved.

[0096] On the other hand, an expression such as "comprise", "include", "have", "contain" and "constitute" are not intended to be exclusive of other components.

Reference Signs List

[0097]

1	Cask
2	Main body
4	Resin
6	External cylinder
8	Bottom portion
10	Lid portion
11	Primary lid
12	Secondary lid
14	Internal fin
16	Basket
18	Rectangular pipe
20	Cavity
22	Cask body
24	Trunnion
26	Shock absorber
28	Shock absorber

Claims

1. An aluminum alloy material based on aluminum (Al), comprising:

0.1 wt% or more and 0.3 wt% or less of silicon (Si);
0.1 wt% or more and 0.7 wt% or less of iron (Fe);
1.8 wt% or more and 3.0 wt% or less of manganese (Mn); and
0.8 wt% or more and 1.3 wt% or less of magnesium (Mg).

2. The aluminum alloy material according to claim 1, wherein at least a part of the manganese is contained as a non-equilibrium precipitate of Al_6Mn.

3. The aluminum alloy material according to claim 2, wherein the non-equilibrium precipitate of Al_6Mn is a granular precipitate.

4. A basket for a cask, formed of the aluminum alloy material according to any one of claims 1 to 3.

5. A cask comprising:

the basket according to claim 4;
a main body accommodating the basket; and
a lid portion for closing an end opening of the main body.

6. A method for producing an aluminum alloy material, comprising:

a cooling step of cooling a melt of an aluminum alloy based on aluminum (Al) and containing 1.8 wt% or more and 3.0 wt% or less of manganese (Mn) so that the manganese enters into solid solution in an aluminum parent phase in a supersaturated manner to obtain a supersaturated solid solution; and
a heat treatment step of subjecting the supersaturated solid solution to a heat treatment to precipitate at least a part of the manganese as Al_6Mn, whereby an aluminum alloy material is obtained.

7. The method for producing an aluminum alloy material according to claim 6,
wherein the cooling step includes jetting a gas to the melt to atomize the melt.

8. The method for producing an aluminum alloy material according to claim 7,
wherein powder of the supersaturated solid solution obtained by the cooling step has an average particle size of 5 μm or more and 80 μm or less.

9. The method for producing an aluminum alloy material according to claim 7 or 8, further comprising a step of subjecting the supersaturated solid solution in a powder state to an oxidation treatment, before the heat treatment step.

10. The method for producing an aluminum alloy material according to claim 6,
wherein the cooling step includes forming a molding of the supersaturated solid solution by a DC casting method.

11. The method for producing an aluminum alloy material according to any one of claims 6 to 10,
wherein the heat treatment step includes heating and keeping the supersaturated solid solution within a temperature range of 400°C or higher and 620°C or lower.

FIG. 1

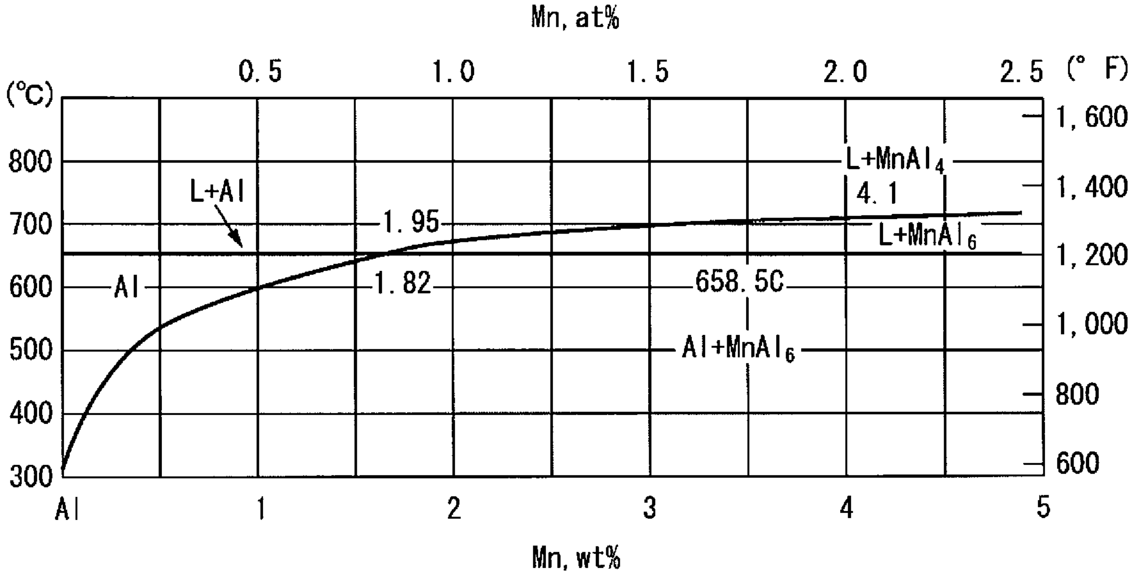

Mn, at%
0. 5
1. 0
1. 5
2. 0
2. 5
(° F)
(℃)
800
700
600
500
400
300
1, 600
1, 400
1, 200
1, 000
800
600
L+Al
L+MnAl$_4$
4. 1
1. 95
L+MnAl$_6$
Al
1. 82
658. 5C
Al+MnAl$_6$
Al
1
2
3
4
5
Mn, wt%

FIG. 2

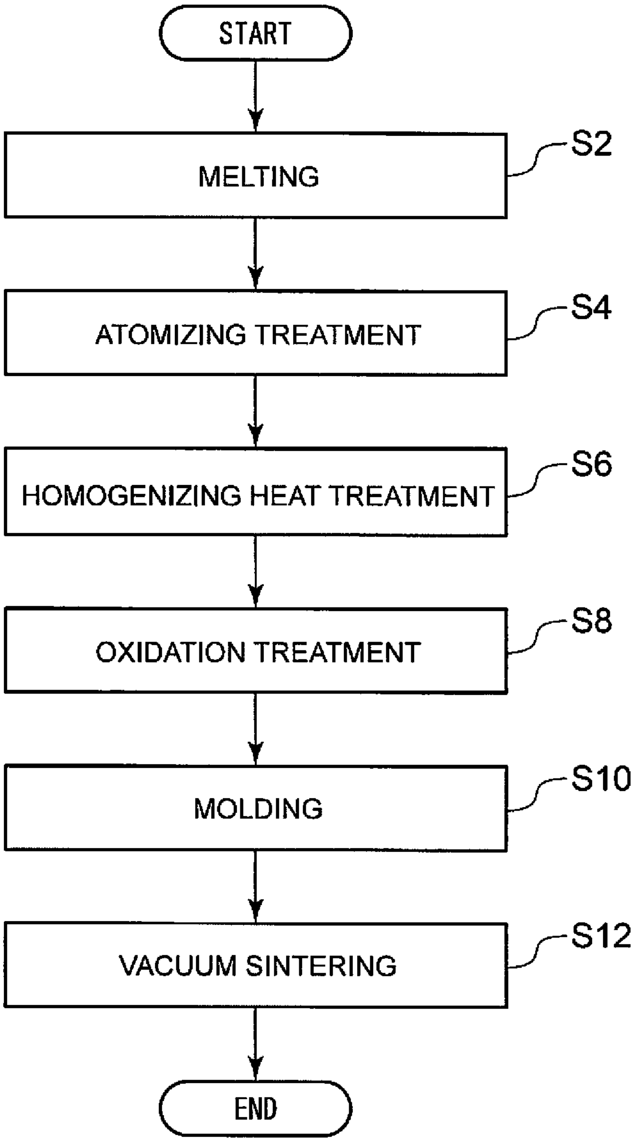

START
MELTING
S2
ATOMIZING TREATMENT
S4
HOMOGENIZING HEAT TREATMENT
S6
OXIDATION TREATMENT
S8
MOLDING
S10
VACUUM SINTERING
S12
END

FIG. 3

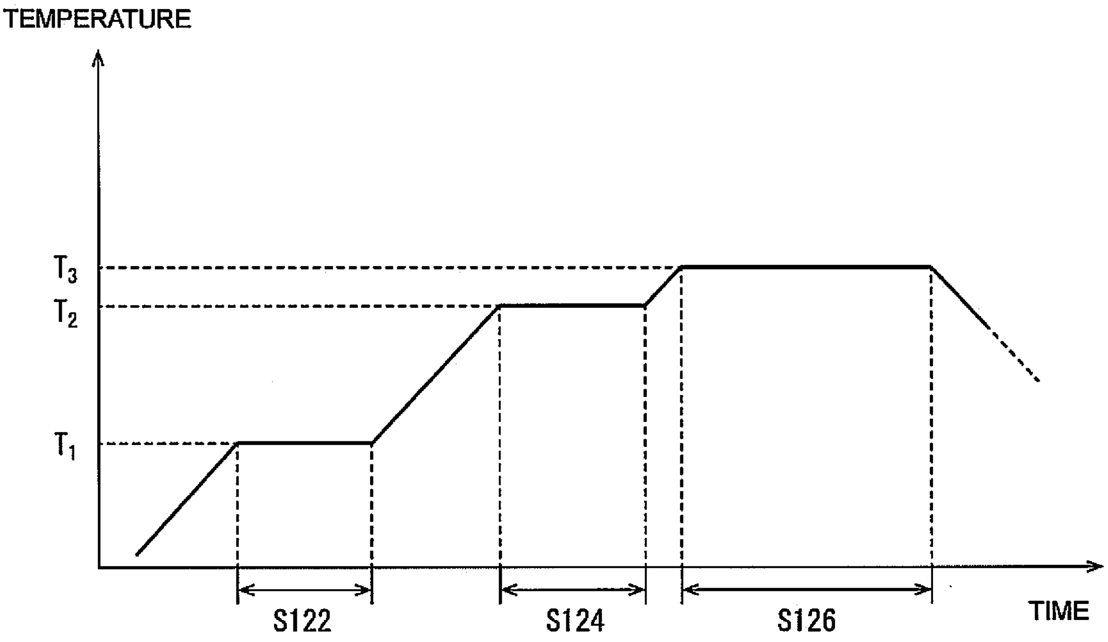
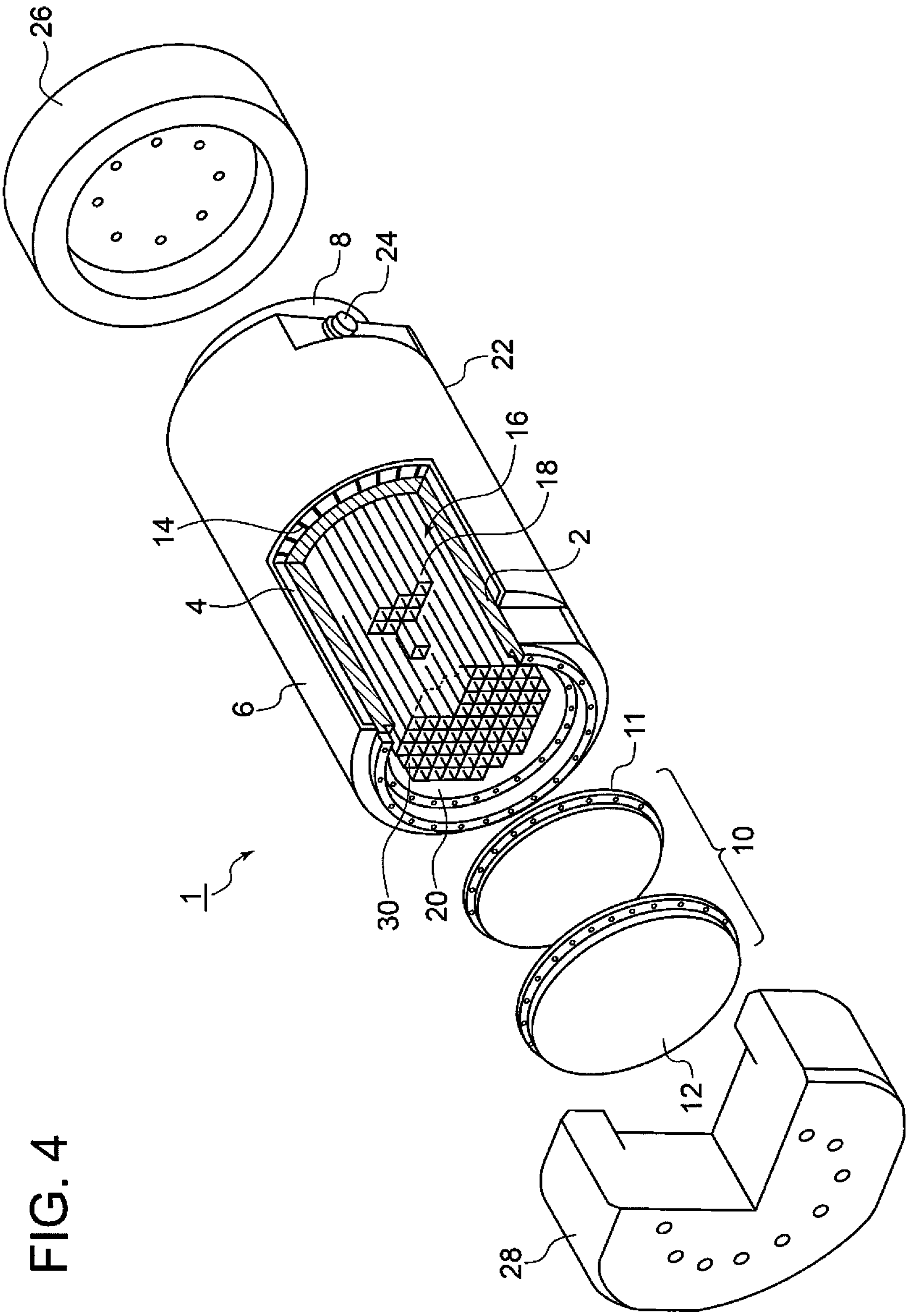


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2016/085035

A. CLASSIFICATION OF SUBJECT MATTER
C22C21/00(2006.01)i, *C22F1/04*(2006.01)i, *G21C19/32*(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C21/00-21/18, C22F1/00-1/18, G21C19/32

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	1996-2017
Kokai Jitsuyo Shinan Koho	1971-2017	Toroku Jitsuyo Shinan Koho	1994-2017

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 Y	JP 7-180005 A (Mitsubishi Aluminum Co., Ltd.), 18 July 1995 (18.07.1995), table 1 (Family: none)	1 4-5
X Y	JP 11-61490 A (Fujikura Ltd.), 05 March 1999 (05.03.1999), claim 3; paragraphs [0021], [0024]; examples (Family: none)	2-3 4-5
Y	JP 2001-42090 A (Mitsubishi Heavy Industries, Ltd.), 16 February 2001 (16.02.2001), paragraph [0017] (Family: none)	4-5

☒ 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 11 January 2017 (11.01.17)	Date of mailing of the international search report 24 January 2017 (24.01.17)
Name and mailing address of the ISA/ Japan Patent Office 3-4-3,Kasumigaseki,Chiyoda-ku, Tokyo 100-8915,Japan	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2016/085035

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 2007-40914 A (Nippon Light Metal Co., Ltd.), 15 February 2007 (15.02.2007), paragraph [0013]; example 1; table 1 (Family: none)	6-8,11 9
Y	JP 2010-95433 A (Sumitomo Chemical Co., Ltd.), 30 April 2010 (30.04.2010), paragraph [0090] (Family: none)	9
X Y	JP 49-113709 A (Swiss Aluminum Ltd.), 30 October 1974 (30.10.1974), example 1 & US 3891433 A example 1 & GB 1439563 A & DE 2406446 A & FR 2218221 A & CH 572268 A5	6,11 10
Y	JP 6-128678 A (Sky Aluminium Co., Ltd.), 10 May 1994 (10.05.1994), paragraph [0033] (Family: none)	10
A	JP 2006-316321 A (Nippon Light Metal Co., Ltd.), 24 November 2006 (24.11.2006), claim 1 (Family: none)	1-11
A	EP 1956107 A1 (Nippon Light Metal Co., Ltd.), 13 August 2008 (13.08.2008), examples (Family: none)	1-11

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REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 5960335 B **[0005]**

Non-patent literature cited in the description

- Codes for construction of spent nuclear fuel storage facilities --Rules on transport/storage packagings for spent nuclear fuel-- (2007). *Japan Society of Mechanical Engineers,* February 2008 **[0006]**