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(54) Title: ALLOY COMPOSITION

(57) Abstract: An alloy composition includes from about 4 wt% to about 11 wt% of silicon based on a total wt% of the alloy composition; from about 0.1 wt% to about 0.5 wt% of chromium based on the total wt% of the alloy composition; from about 0.1 wt% to about 0.5 wt% of magnesium based on the total wt% of the alloy composition; from about 0.01 wt% to about 0.05 wt% of titanium based on the total wt% of the alloy composition; equal to or less than 0.5 wt% of iron based on the total wt% of the alloy composition; equal to or less than 0.5 wt% of manganese based on the total wt% of the alloy composition; and a balance of aluminum.

ALLOY COMPOSITION

BACKGROUND

[1] Die casting processes are commonly used to form high volume automobile components. In particular, aluminum alloys are often used to form the structural components in the die casting process because aluminum alloys have many favorable properties, such as light weight and high dimensional stability, which allows the formation of more complex and thin wall components compared to other alloys. Traditionally, aluminum die castings have a limitation on ductility due to air entrapment and Fe-intermetallic phases. Many technologies developed for reducing these issues, such as semisolid die casting and super-vacuum die casting, form porosity-free castings.

SUMMARY

[2] In an example of an alloy disclosed herein, the alloy composition includes from about 4 wt% to about 11 wt% of silicon based on a total wt% of the alloy composition; from about 0.1 wt% to about 0.5 wt% of chromium based on the total wt% of the alloy composition; from about 0.1 wt% to about 0.5 wt% of magnesium based on the total wt% of the alloy composition; from about 0.01 wt% to about 0.05 wt% of titanium based on the total wt% of the alloy composition; equal to or less than 0.5 wt% of iron based on the total wt% of the alloy composition; equal to or less than 0.5 wt% of manganese based on the total wt% of the alloy composition; and a balance of aluminum.

DETAILED DESCRIPTION

[3] Aluminum alloys often include aluminum, alloying elements (e.g., silicon and iron), and impurities. Some aluminum alloys have been developed with low iron content. These alloys have been used for body structural components, which have superior ductility after solution- followed-by-precipitation hardening treatment. However, it has been found that with low-iron aluminum alloys, die sticking or die soldering occurs during the die casting process. Die sticking can destroy the casting during ejection, or even dramatically reduce die life.

[4] The examples disclosed herein can reduce the die sticking or die soldering of aluminum alloy die castings through a micro-alloying method. This micro-alloying method can also improve the strength of die castings. In particular, it has been found that the combination of particular alloying elements in particular amounts can reduce the solubility of iron in molten aluminum. Reducing the iron solubility, and thus the amount of dissolved iron in the molten aluminum, also reduces the amount of iron-intermetallics that form as a result of the molten aluminum reacting with the dissolved iron. These iron-intermetallics can stick to the die used in casting, which results in die soldering. When die soldering occurs, the surface finish of the resulting part (i.e., casting, structural body) may be destroyed when ejected from the die, and the die life may be reduced as well. In the examples of the alloy composition disclosed herein, the iron solubility is reduced, and, in turn, the die soldering is reduced.

[5] In an aluminum-silicon alloy system (e.g., Al-10Si), the solubility of iron is about 1.5%. Some elements, such as manganese, have been added in an attempt to reduce the solubility of iron in molten aluminum, and thus to reduce the number of iron-intermetallics that are formed. A minimum of 0.6 wt% of manganese has been found to reduce the iron solubility in Al-10Si to about 0.6%, which is about 2/3 less than the 1.5% solubility of the iron in the alloy without the manganese. However, it has been found that even this relatively small percentage of manganese can form large intermetallics. Large intermetallics can deleteriously affect (e.g., reduce) the ductility of a structural casting formed from this alloy (i.e., Al-10Si-0.6Mn).

[6] The structural casting formed from Al-10Si or Al-10Si-0.6Mn may be exposed to a heat treatment in order to improve the ductility. However, the additional heat treatment adds an increased risk of deformation of the structural casting. In addition, the heat treatment increases the cost of production of the structural casting.

[7] The examples of the alloy composition disclosed herein reduce the iron solubility and are capable of forming structural bodies that exhibit suitable ductility. The alloy composition disclosed herein includes aluminum, silicon, chromium, magnesium, titanium, iron, and manganese in specific amounts. For chromium, the specific amount ranges from about 0.1 wt% to about 0.5 wt%, and for manganese, the specific amount is equal to or less than 0.5 wt%. The combination of these elements in these amounts has unexpectedly been

found to further reduce the iron solubility (when compared to the Al-10Si-0.6Mn), to a point where most of the iron is insoluble. For example, with the alloy composition(s) disclosed herein, the iron solubility may be as low as 0.12%, e.g., when the chromium amount ranges from about 0.1 wt% to about 0.2 wt%. This reduction in, or elimination of the iron solubility reduces or eliminates the formation of iron intermetallics, and thus also reduces the occurrence of die soldering.

[8] In addition, the combination of these elements in these amounts has unexpectedly been found to form a structural casting with uncompromised ductility, even without a subsequent heat treatment. It has been found that the ductility may be further improved by controlling both manganese and iron, so that each is present in the alloy composition in an amount ranging from about 0.1 wt% to about 0.2 wt%.

[9] The use of chromium in the alloy compositions disclosed herein is particularly unexpected in foundry practice, in part because chromium typically leads to sludge formation. However, it has been found that specifically regulating the amount of chromium, in particular with respect to the amounts of manganese and iron, can prevent sludge formation. For example, it has been found that sludge may not form when the total amount of the chromium plus the manganese plus the iron is less than 0.6 wt%. In addition, tuning the amount of the chromium plus the manganese plus the iron can advantageously reduce die sticking or die soldering.

[10] The chromium that is added to the alloy compositions disclosed herein also forms smaller intermetallics (e.g., compared to iron intermetallics) having a round-shaped morphology. These chromium-containing intermetallics are less detrimental to ductility, and thus may contribute to the elimination of a post-formation heat treatment (described below).

[11] With reduced iron solubility, reduced iron intermetallic formation, improved ductility, and elimination of sludge formation, the example alloy compositions disclosed herein may be used to form as-cast structural bodies with suitable ductility and yield strength. It is to be understood that an as-cast structural casting, as defined herein, is the part, component, etc. that is formed from die casting the alloy composition, but is not exposed to an additional heat treatment. Since the as-cast example structural bodies disclosed herein maintain a high ductility, high yield strength, or high elongation, no additional heat treatment is required. The

elimination of a post-formation heat treatment reduces the cost associated with manufacturing the structural castings and also reduces the risk of deformation in the final structural casting (which can result from heat treatment).

[12] As mentioned above, examples of the alloy composition disclosed herein may include silicon, chromium, magnesium, titanium, iron, manganese, and a balance of aluminum. In some examples, the alloy composition may include these metals, without any other metals. Further, in some examples, the alloy composition may exclude copper, zinc, zirconium, vanadium, or combinations thereof, or any other non-listed elements. Still further, in another example, the alloy composition may consist essentially of silicon, chromium, magnesium, titanium, iron, manganese, and a balance of aluminum. In these instances, other inevitable impurities may be present in the alloy composition. Examples of the metals added to the alloy composition disclosed herein are discussed in greater detail below.

[13] The alloy composition includes silicon. Silicon may be added to the alloy composition to reduce the melting temperature of aluminum and improve the fluidity of the molten aluminum. In an example, the silicon may be present in the alloy composition in an amount ranging from about 4 wt% to about 11 wt% based on the total wt% of the alloy composition. In another example, the silicon may be present in an amount ranging from about 4 wt% to about 7 wt%. In still a further example, the silicon may be present in an amount ranging from about 7 wt% to about 9 wt%.

[14] The alloy composition further includes chromium. As previously stated above, the specific amount of chromium contributes to the reduction in the solubility of iron in molten aluminum and also does not deleteriously affect the ductility and/or yield strength in the final structural casting formed from the alloy composition(s). As such, the addition of the specific amount of chromium may contribute to the lack of a need for an additional heat treatment of the structural casting after the die casting process. Chromium may also improve toughness of the structural casting formed from the die casting process. In an example, chromium may be present in the alloy composition in an amount ranging from about 0.1 wt% to about 0.5 wt% based on the total wt% of the alloy composition. In another example, the chromium may be present in an amount ranging from about 0.15 wt% to about 0.2 wt%. In still another example, the chromium may be present in an amount of about 0.17 wt%.

[15] The alloy composition further includes magnesium. Magnesium improves the yield strength by solid solution strengthening. Magnesium may be present in an amount ranging from about 0.1 wt% to about 0.5 wt% based on the total wt% of the alloy composition. In another example, the magnesium may be present in an amount ranging from about 0.2 wt% to about 0.5 wt%. Still further, in another example, the magnesium may be present in an amount of about 0.3 wt%.

[16] The alloy composition also includes titanium. Titanium may be added as a grain refiner to improve the control of the grain growth of the molten aluminum during the die casting process. In an example, the titanium may be present in an amount ranging from about 0.01 wt% to about 0.05 wt% based on the total wt% of the alloy composition. In another example, the titanium may be present in an amount ranging from about 0.01 wt% to about 0.02 wt%. In still another example, the titanium is present in an amount of about 0.015 wt%.

[17] Additionally, the alloy composition also includes manganese. The manganese may be added to reduce the die sticking or soldering. As mentioned herein, controlling the amount of chromium, iron, and manganese can reduce die sticking or soldering. In an example, the manganese may be present in an amount equal to or less than 0.5 wt% based on the total wt% of the alloy composition. In another example, the manganese may be present in an amount of equal to or less than 0.2 wt% of the alloy composition. In yet another example, the manganese may be present in an amount of equal to or less than 0.15 wt% of the alloy composition. It is to be understood that the wt% of manganese is greater than 0 wt%, and thus at least some manganese is present in the alloy composition.

[18] The alloy composition also includes iron. Some iron may be added to improve yield strength of the structural casting formed from the die casting process. Iron is also included for ductility. In an example, the iron may be present in an amount equal to or less than 0.5 wt% based on the total wt% of the alloy composition. In another example, the iron may be present in an amount of equal to or less than 0.2 wt% of the alloy composition. It is to be understood that the wt% of iron is greater than 0 wt%, and thus at least some iron is present in the alloy composition.

[19] The remainder of the alloy composition includes a balance of aluminum. In an example, the aluminum starting material used to form the aluminum in the alloy composition

may be 99.9% pure aluminum with less than 0.1 wt% of impurities. The impurities present in the aluminum starting material may include iron, manganese, chromium, vanadium, silicon, or the like.

[20] In one example of the alloy composition, the alloy composition includes the silicon present in an amount ranging from about 6 wt% to about 9 wt%, the chromium present in an amount ranging from about 0.15 wt% to about 0.2 wt%, the magnesium present in an amount ranging from about 0.2 wt% to about 0.5 wt%, the titanium present in an amount ranging from about 0.01 wt% to about 0.02 wt%, the iron in an amount equal to or less than 0.1 wt%, the manganese in an amount equal to or less than 0.1 wt%, and a balance of aluminum. The structural casting formed from this example alloy has a higher ductility or elongation (without a heat treatment) when compared to other structural castings formed from different alloy compositions using the same die casting process. This example alloy may attain from about 8% to about 10% elongation in the as-cast state, compared to a traditional Al-Si10-Mn(0.6)Mg alloy, which attains from about 4% to about 6% elongation in the as-cast state.

[21] In another example of the alloy composition, the alloy composition includes the silicon present in an amount ranging from about 4 wt% to about 7 wt%, the chromium present in an amount ranging from about 0.15 wt% to about 0.2 wt%, the magnesium present in an amount ranging from about 0.2 wt% to about 0.5 wt%, the titanium present in an amount ranging from about 0.01 wt% to about 0.02 wt%, the iron present in an amount equal to or less than 0.1 wt%, the manganese present in an amount equal to or less than 0.15 wt%, and a balance of aluminum. The structural casting formed from this example alloy has a higher average elongation when compared to other structural castings formed from other alloys using the same die casting process. In an example, the average elongation of the structural casting formed from this alloy composition may be about 7% in the as-cast state, compared to a the traditional Al-Si10-Mn(0.6)Mg alloy, which attains from about 4% to about 6% elongation in the as-cast state.

[22] Additionally, the structural casting formed from this other example alloy may have increased yield strength. In an example, the yield strength of the structural casting formed from this other example alloy may be about 300 MPa.

[23] In yet another example, the alloy composition includes the silicon present in an amount ranging from about 9 wt% to about 11 wt%, the chromium present in an amount ranging from about 0.15 wt% to about 0.2 wt%, the magnesium present in an amount ranging from about 0.1 wt% to about 0.2 wt%, the titanium present in an amount ranging from about 0.01 wt% to about 0.02 wt%, the iron present in an amount equal to or less than 0.15 wt%, the manganese present in an amount equal to less than 0.2 wt%, and a balance of aluminum. This example alloy forms a structural casting (body) with superior castability that does not stick to the die when ejected from the die mold. In addition, the yield strength may range from about 150 MPa to about 200 MPa.

[24] In any of the example alloy compositions disclosed herein, the total wt% of the chromium plus the manganese plus the iron may be less than 0.6 wt% based on the total wt% of the alloy composition. The total weight percent of these particular alloyed elements advantageously reduces die sticking or soldering.

[25] In an example of the method, an example of the molten alloy composition disclosed herein is die cast to form a structural casting. The examples of the molten alloy composition disclosed herein reduce the die soldering that may take place during the die casting process. In particular, the amount of chromium, alone or in combination with the amount of manganese, may be selected so that the iron solubility is reduced, which reduces iron-intermetallic formation and also reduces die soldering during the die casting process. As discussed above, to reduce die soldering, the alloy composition may be formed with from about 0.1 wt% to about 0.5 wt% of chromium.

[26] Once the wt% of the chromium is selected, the alloy composition may be formed. The alloy composition may be formed by adding the alloying elements into a pure aluminum melt. The method may also involve known techniques for controlling the impurity levels.

[27] The die casting process used to make a casting from the alloy composition may be a high-pressure die casting (HPDC) process, or a low-pressure die casting process, or a squeeze casting (or liquid forging) process. A dosing furnace with a degassing system may be used to hold and transfer the aluminum-based melt (i.e., molten alloy composition) to the die casting machine. The die casting process parameters may be varied, depending upon the die casting machine that is used, the size and/or shape of the casting, etc.

[28] After the alloy composition solidifies to form the structural casting, the structural casting may be removed from the die. In an example, the casting is ejected from the die. In some examples, the casting is removed using ejector pins. Since soldering is reduced during die casting, little or no scrap casting remains in the die. However, if scrap casting remains, it may be removed from the die. Even though the alloying elements and impurities are controlled, the scrap casting may not be suitable for recycling.

[29] In an example, after the structural casting is removed from the die, the structural casting is not exposed to a subsequent heat treatment and yet exhibits desirable mechanical properties (e.g., ductility, elongation, strength, etc.). The final structural casting may be an automobile part, a computer part, a communication part, or a consumer electronic part. For examples of the automobile parts, the structural casting may be an aluminum-based part for the body of a vehicle, or an aluminum-based wheel. The final structural casting may also be a part utilized in an elevator application.

[30] Reference throughout the specification to "one example", "another example", "an example", and so forth, means that a particular element (e.g., feature, structure, and/or characteristic) described in connection with the example is included in at least one example described herein, and may or may not be present in other examples. In addition, it is to be understood that the described elements for any example may be combined in any suitable manner in the various examples unless the context clearly dictates otherwise.

[31] It is to be understood that the ranges provided herein include the stated range and any value or sub-range within the stated range. For example, a range from about 7 wt% to about 9 wt% should be interpreted to include not only the explicitly recited limits of from about 7 wt% to about 9 wt%, but also to include individual values, such as 7.25 wt%, 8.25 wt%, 8.9 wt%, etc., and sub-ranges, such as from about 7.25 wt% to about 8.50 wt%, etc. Furthermore, when "about" is utilized to describe a value, this is meant to encompass minor variations (up to +/- 5%) from the stated value.

[32] In describing and claiming the examples disclosed herein, the singular forms "a", "an", and "the" include plural referents unless the context clearly dictates otherwise.

[33] While several examples have been described in detail, it is to be understood that the disclosed examples may be modified. Therefore, the foregoing description is to be considered non-limiting.

What is claimed is:

1. An alloy composition, comprising:

from about 4 wt% to about 11 wt% of silicon based on a total wt% of the alloy composition;

from about 0.1 wt% to about 0.5 wt% of chromium based on the total wt% of the alloy composition;

from about 0.1 wt% to about 0.5 wt% of magnesium based on the total wt% of the alloy composition;

from about 0.01 wt% to about 0.05 wt% of titanium based on the total wt% of the alloy composition;

equal to or less than 0.5 wt% of iron based on the total wt% of the alloy composition;

equal to or less than 0.5 wt% of manganese based on the total wt% of the alloy composition; and

a balance of aluminum.

2. The alloy composition as defined in claim 1 wherein the alloy composition excludes copper, zinc, zirconium, vanadium, or combinations thereof.

3. The alloy composition as defined in claim 1 wherein:

from about 6 wt% to about 9 wt% of the silicon is present in the alloy composition;

from about 0.15 wt% to about 0.2 wt% of the chromium is present in the alloy composition;

from about 0.2 wt% to about 0.5 wt% of the magnesium is present in the alloy composition;

from about 0.01 wt% to about 0.02 wt% of the titanium is present in the alloy composition;

equal to or less than 0.10 wt% of the iron is present in the alloy composition; and

equal to or less than 0.10 wt% of the manganese is present in the alloy composition.

4. The alloy composition as defined in claim 3 wherein an as-cast structure of the alloy composition has a ductility ranging from about 10% to about 12%.

5. The alloy composition as defined in claim 1 wherein:

from about 4 wt% to about 7 wt% of the silicon is present in the alloy composition;

from about 0.15 wt% to about 0.2 wt% of the chromium is present in the alloy composition;

from about 0.2 wt% to about 0.5 wt% of the magnesium is present in the alloy composition;

from about 0.01 wt% to about 0.02 wt% of the titanium is present in the alloy composition;

equal to or less than 0.10 wt% of the iron is present in the alloy composition; and

equal to or less than 0.15 wt% of the manganese is present in the alloy composition.

6. The alloy composition as defined in claim 5 wherein an as-cast structure of the alloy composition has an average elongation index (EI) of about 7% and a yield strength of about 300 MPa.

7. The alloy composition as defined in claim 1 wherein:

from about 9 wt% to about 11 wt% of the silicon is present in the alloy composition;

from about 0.15 wt% to about 0.2 wt% of the chromium is present in the alloy composition;

from about 0.1 wt% to about 0.2 wt% of the magnesium is present in the alloy composition;

from about 0.01 wt% to about 0.02 wt% of the titanium is present in the alloy composition;

equal to or less than 0.15 wt% of the iron is present in the alloy composition; and

equal to or less than 0.2 wt% of the manganese is present in the alloy composition.

8. The alloy composition as defined in claim 1 wherein a total wt% of the chromium plus the manganese plus the iron is less than 0.6 wt% based on the total wt% of the alloy composition.

9. The alloy composition as defined in claim 1 wherein the aluminum is 99.9% pure before alloying elements of silicon, chromium, magnesium, titanium, iron, and manganese are added thereto.

10. An alloy composition, consisting essentially of:

from about 4 wt% to about 11 wt% of silicon based on a total wt% of the alloy composition;

from about 0.1 wt% to about 0.5 wt% of chromium based on the total wt% of the alloy composition;

from about 0.1 wt% to about 0.5 wt% of magnesium based on the total wt% of the alloy composition;

from about 0.01 wt% to about 0.05 wt% of titanium based on the total wt% of the alloy composition;

equal to or less than 0.5 wt% of iron based on the total wt% of the alloy composition;

equal to or less than 0.5 wt% of manganese based on the total wt% of the alloy composition; and

a balance of aluminum.

11. A method, comprising:

reducing die soldering during a die casting process by die casting a molten alloy composition, including:

from about 4 wt% to about 11 wt% of silicon based on a total wt% of the alloy composition;

from about 0.1 wt% to about 0.5 wt% of chromium based on the total wt% of the alloy composition;

from about 0.1 wt% to about 0.5 wt% of magnesium based on the total wt% of the alloy composition;

from about 0.01 wt% to about 0.05 wt% of titanium based on the total wt% of the alloy composition;

equal to or less than 0.5 wt% of iron based on the total wt% of the alloy composition;

equal to or less than 0.5 wt% of manganese based on the total wt% of the alloy composition; and

a balance of aluminum.

12. The method as defined in claim 11 wherein a total wt% of the chromium plus the manganese plus the iron is less than 0.6 wt% based on the total wt% of the molten alloy composition.

13. The method as defined in claim 11, further comprising selecting a wt% of the chromium to reduce a solubility of the iron in the molten alloy composition from about 1.5% to about 0.12%.

14. The method as defined in claim 11, further comprising:

die casting the molten alloy composition to form a structural body;

removing the structural body from a steel die used during the die casting process; and

wherein the structural body is not exposed to a subsequent heat-treatment process.

15. The method as defined in claim 14 wherein one of:

i) from about 6 wt% to about 9 wt% of the silicon is present in the alloy composition;

from about 0.15 wt% to about 0.2 wt% of the chromium is present in the alloy composition;

from about 0.2 wt% to about 0.5 wt% of the magnesium is present in the alloy composition;

from about 0.01 wt% to about 0.02 wt% of the titanium is present in the alloy composition;

equal to or less than 0.10 wt% of the iron is present in the alloy composition; and

equal to or less than 0.10 wt% of the manganese is present in the alloy composition;

and wherein the structural body has a ductility that ranges from about 10% to about 12%; or

ii) from about 4 wt% to about 7 wt% of the silicon is present in the alloy composition;

from about 0.15 wt% to about 0.2 wt% of the chromium is present in the alloy composition;

from about 0.2 wt% to about 0.5 wt% of the magnesium is present in the alloy composition;

from about 0.01 wt% to about 0.02 wt% of the titanium is present in the alloy composition;

equal to or less than 0.10 wt% of the iron is present in the alloy composition; and

equal to or less than 0.15 wt% of the manganese is present in the alloy composition

and wherein the structural body has an average elongation index (EI) of about 7% in an as-cast condition and a yield strength of about 300 MPa.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2015/074554

A. CLASSIFICATION OF SUBJECT MATTER

C22C 21/02(2006.01)i; C22C 21/00(2006.01)i; B22D 17/00(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)

C22C 21; B22D 17

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

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

DWPI, SIPOABS, VEN, CN-PAT, CNKI: Si, Sillicon, Silicium, Silicone, Ti, Titanium, Titanic, Cr, chromium, Chrome, Chrom, Mg, Magnesium, die cast+, diecast+,

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012168041 A1 (NIPPON LIGHT METAL CO) 05 July 2012 (2012-07-05) claim1, description, paragraphs 32 and 39	1-15
X	JP 2001200326 A (SUMITOMO ELECTRIC INDUSTRIES ET AL.) 24 July 2001 (2001-07-24) claim 1	1-10
X	CN 102301021 A (DAIKI ALUMINIUM IND CO LTD) 28 December 2011 (2011-12-28) claims 1 and 4	1, 2, 10-14
X	US 5837070 A (PECHINEY RHENALU) 17 November 1998 (1998-11-17) claim 1	1, 2, 10-14
X	EP 1130125 A2 (DAIKI ALUMINIUM IND) 05 September 2001 (2001-09-05) claims 1 and 2	1, 2, 10-12
A	US 2004011437 A1 (ALCOA INC ET AL.) 22 January 2004 (2004-01-22) the whole document	1-15

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

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Date of the actual completion of the international search	Date of mailing of the international search report
27 November 2015	**23 December 2015**
Name and mailing address of the ISA/CN **STATE INTELLECTUAL PROPERTY OFFICE OF THE P.R.CHINA** **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088, China** Facsimile No. **(86-10)62019451**	Authorized officer **NIE,Xiaoxue** Telephone No. **(86-10)62085018**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2015/074554

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