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(54) PLASTIC FORMING AND TOUGHENING PROCESS METHOD AND APPARATUS BASED ON ULTRASONIC VIBRATION

(57) The present invention belongs to the field of amorphous alloy thermoplastic forming, and discloses a plastic forming and gradient toughening method and a device based on ultrasonic vibration. The method includes: (a) dividing one or more portions to be toughened on an amorphous alloy part to be formed, the portion being used for generating a nanocrystalline toughening phase; (b) designing a toughening device for forming, wherein the toughening device comprises one or more inserts connected to an ultrasonic vibration amplitude transformer and one or more heating rods, the insert is disposed corresponding to the portion to be toughened and used for applying ultrasonic vibration to the portion to be toughened, and the heating rod is used for heating raw material blank to be processed to a forming temperature, and (c) placing the raw material blank in the device, heating it by the heating rod, and performing mold closing of the device to form a required amorphous alloy part, ultrasonic vibration being started in the mold closing process and stopped when mold opening is performed. Meanwhile, the invention further discloses the utilized device. With the method of the present invention, toughening and thermoplastic forming can be performed at the same time, so that integration of forming and toughening is achieved, which simplifies production processes, shortens the processing time and improves the dimensional accuracy.

ACCOMPANYING FIGURES

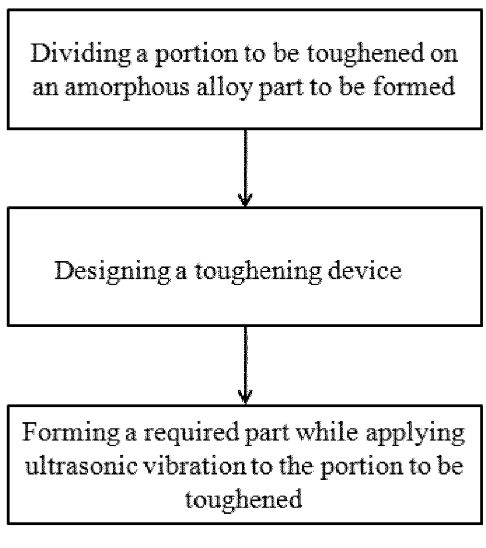

FIG. 1

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Description

BACKGROUND OF THE INVENTION

Technical Field

The present invention

[0001] The invention belongs to the field of amorphous alloy thermoplastic forming, and more particularly relates to a plastic forming and gradient toughening method and a device based on ultrasonic vibration.

Description of the Related Art

[0002] Amorphous alloy is a novel material with excellent properties such as high strength, corrosion resistance and wear resistance. Amorphous alloy exhibits good superplasticity in the hot state and can achieve near net shape formation of parts. However, due to the significant room temperature brittleness of the amorphous alloy, the amorphous alloy parts may directly undergo brittle fracture and completely fail once they are overloaded during service, making it difficult to directly apply the amorphous alloy parts in occasions where impact loads are present. Therefore, it is necessary to further improve the toughness of the amorphous alloy without impairing its excellent properties so as to improve the impact resistance of the amorphous alloy parts.

[0003] The amorphous alloy is in a thermodynamically metastable state, and spontaneously transformed to its thermodynamically stable state after obtaining sufficient energy, that is, crystallization occurs. After the amorphous alloy is crystallized, its properties are also changed. By forming nanocrystallines inside the amorphous alloy, the strength and toughness of the amorphous alloy can be remarkably improved. Therefore, according to the requirements of actual service conditions for the performance of amorphous alloy parts, nanocrystallines can be induced locally in the amorphous matrix by some means to form a nanocrystalline toughened amorphous matrix composite with a mechanical property gradient.

[0004] Chinese Patent Publication No. 101736213 proposed a method for strengthening and toughening an amorphous alloy by ultrasonic treatment, in which the amorphous alloy is strengthened and toughened by placing the amorphous alloy in a cooling water tank with a temperature lower than the crystallization temperature of the amorphous alloy and then applying an oscillation frequency with a power less than 3×10^4 W/mm^2 per unit area at the bottom of the water tank. The amorphous alloy treated by the method has a great improvement in plastic deformation capability at room temperature and an increase in thermal discharge in relaxation, with the precondition that the fracture strength is not changed. However, this method can only perform strengthening and toughening treatment on the entire amorphous alloy sample, and cannot retain some amorphous regions according to actual use requirements to form an amorphous matrix composite with a mechanical property gradient; Chinese Patent Publication No. 102002659 proposed a method for continuously performing nanocrystallization on an amorphous alloy strip, in which at a temperature below the glass transition temperature of the amorphous alloy, the amorphous alloy strip is pressed on the top end of an amplitude transformer of a power ultrasonic device, and the amplitude transformer of the ultrasonic device exerts an ultrasonic effect on the amorphous alloy strip as the amorphous alloy strip moves, thereby achieving continuous nanocrystallization of the amorphous alloy strip. However, this method can only process the entire amorphous alloy strip, and can neither process actual parts with complex shapes nor achieve nanocrystal gradient toughening; Chinese Patent Publication No. 105420522 proposed a method for preparing an amorphous matrix composite, in which the flaky amorphous alloy and the second phase toughening material are alternately laminated and placed in a jig, and under a condition of constant pressure or increasing load, the laminated amorphous alloy and porous plate are heated while ultrasonic vibration is applied thereto, so that the amorphous alloy is rapidly softened and pressed into the pores of the second phase toughening plate to obtain an amorphous matrix composite. However, this method needs to introduce a second phase to perform overall toughening treatment on the amorphous alloy, is only suitable for the processing of sheet products, and cannot enable the processing of actual parts with complex shapes as well as local nanocrystalline gradient toughening of the parts according to actual use requirements. The above three strengthening and toughening methods are all not combined with the thermoplastic forming process of the amorphous alloy, and thus the parts need to be specially processed after being formed, resulting in complicated process and long production cycle.

SUMMARY OF THE INVENTION

[0005] In view of the above-described defects or improvement requirements in the art, the present invention provides a plastic forming and gradient toughening method and a device based on ultrasonic vibration, which aims to achieve nanocrystallization of a local region to be toughened on the amorphous alloy part by applying ultrasonic vibration to the local region to be toughened with an insert connected to an ultrasonic vibration amplitude transformer, thereby solving the technical problem of local toughening during thermoplastic forming.

[0006] In order to achieve the above objective, according to an aspect of the present invention, there is provided a plastic forming and gradient toughening method based on ultrasonic vibration, characterized in that the toughening method comprising:

(a) according to actual use requirements of an amorphous alloy part to be formed, dividing one or more portions to be toughened on the amorphous alloy part to be formed, the portion being used for generating a nanocrystalline toughening phase and an amorphous state of other portions being retained;

(b) designing a toughening device for forming the amorphous alloy part to be formed, wherein the toughening device is connected to an external drive mechanism and comprises one or more inserts connected to an ultrasonic vibration amplitude transformer and one or more heating rods, the insert is disposed corresponding to the portion to be toughened and used for applying ultrasonic vibration to the portion to be toughened, the heating rod is used for heating raw material blank to be processed to a forming temperature, and parameters of the ultrasonic vibration generated by the ultrasonic vibration amplitude transformer are obtained by analyzing an energy propagation process of the ultrasonic vibration by finite element numerical simulation, in which energy of the ultrasonic vibration is adjusted by adjusting an amplitude, a frequency and a power of the ultrasonic vibration, and when the energy of the ultrasonic vibration exceeds an energy threshold value required for nanocrystallization, the corresponding amplitude, frequency and power of the ultrasonic vibration are required parameters of the ultrasonic vibration; and

(c) placing raw material blank in the toughening device, heating the raw material blank by the heating rod to a forming temperature, and performing mold closing of the toughening device to form a required amorphous alloy part, ultrasonic vibration being started in the mold closing process and stopped when mold opening is performed.

[0007] Preferably, the forming temperature is between a glass transition temperature and a crystallization temperature of the raw material blank.

[0008] Further preferably, in the step (b), the heating rod is preferably a resistance heating rod.

[0009] Further preferably, in the step (b), the toughening device is preferably a mold for thermoplastic forming.

[0010] Further preferably, the amorphous alloy is a Pd, Pt, Au, Zr, Ti, Fe, Cu, Ni, Al, Mg or Ce based amorphous alloy with a thermoplastic forming ability.

[0011] According to another aspect of the present invention, there is provided a device for use in the above toughening method, characterized in that the device comprises an upper mold, a lower mold and a female mold,

[0012] the upper mold and the lower mold are oppositely disposed and form a mold cavity with the female mold, the upper mold and the lower mold are respectively provided with a punch and one or more inserts, the punches are connected to a driving servo press and used to form raw material blank into a desired three-dimensional structure, the inserts are connected to an ultrasonic vibration amplitude transformer and used to apply ultrasonic vibration to one or more portions to be toughened, the female mold is provided with one or more heating rod for heating the raw material blank.

[0013] In general, by comparing the above technical solution of the present inventive concept with the prior art, the present invention has the following beneficial effects:

1. in the present invention, an insert which is partially connected with an ultrasonic vibration amplitude transformer is disposed corresponding to a portion to be toughened to apply ultrasonic vibration to the portion, thereby achieving nanocrystallization process. The nanocrystallization process and the thermoplastic forming process are simultaneously carried out without additional processing after the parts are formed, which simplifies production processes and shortens the forming time;

2. in the present invention, ultrasonic vibration is adopted to improve the toughness of the material, since the ultrasonic vibration can significantly improve the forming ability of the material, and the propagation of the ultrasonic vibration wave has strong directionality so that the vibration energy distribution of the ultrasonic vibration wave can be precisely controlled. Therefore, nanocrystallization can be facilitated by using the ultrasonic vibration to achieve amorphous alloy toughening;

3. in the present invention, one or more resistance heating rods are used, so that the forming temperature in the thermoplastic forming process is ensured on the one hand, and the uniformity of the temperature field inside the mold can be ensured by adjusting the distribution of the resistance heating rods on the other hand; and

4. in the method based ultrasonic vibration according to the present invention, nanocrystallization toughening and thermoplastic forming of an amorphous alloy part are combined to achieve integration of forming and toughening, which simplifies production processes, shortens the processing time and improves the dimensional accuracy. Meanwhile, according to the actual service conditions of the amorphous alloy part, the microstructure of an amorphous alloy-based composite with a mechanical property gradient is formed inside the part, which can significantly improve the overall performance of the part.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014]

FIG. 1 is a flow chart of a toughening method according to a preferred embodiment of the present invention; and

FIG. 2 is a schematic structural diagram of an amorphous alloy gear member forming device according to the preferred embodiment of the present invention.

[0015] In all figures, the same elements or structures are denoted by the same reference numerals, in which:

1-upper ultrasonic vibration ring, 2-upper punch, 3-heating rod, 4-female mold, 5-raw material blank, 6-lower ultrasonic vibration ring, and 7-lower punch.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0016] For clear understanding of the objectives, features and advantages of the present invention, detailed description of the present invention will be given below in conjunction with accompanying drawings and specific embodiments. It should be noted that the embodiments described herein are only meant to explain the present invention, and not to limit the scope of the present invention. Furthermore, the technical features related to the embodiments of the invention described below can be mutually combined if they are not found to be mutually exclusive.

[0017] FIG. 1 is a flow chart of a toughening method according to a preferred embodiment of the present invention, and as shown in FIG. 1, a plastic forming and gradient toughening method based on ultrasonic vibration is illustrated, the method comprising:

(1) According to actual use requirements of the amorphous alloy part, the amorphous state is retained in a portion requiring high strength, strong corrosion resistance and wear resistance, and the nanocrystalline toughening phase is formed in a portion requiring high toughness. Therefore, in the design of the thermoplastic forming process, ultrasonic vibration is applied to the portion where the nanocrystalline toughening phase needs to be formed, and the ultrasonic vibration is not applied to the portion where the amorphous state needs to be retained.

(2) In the mold design, one or more inserts connected to the ultrasonic vibration amplitude transformer are disposed in one or more portions where ultrasonic vibration is required; the amplitude, frequency and power of the ultrasonic vibration are determined by analyzing the energy propagation process of the ultrasonic vibration by finite element numerical simulation and adjusting the amplitude, frequency and power of the ultrasonic vibration such that the vibration energy in the toughening target region exceeds the energy threshold value for nanocrystallization; and one or more resistance heating rods are embedded in the mold to heat the blank to a set forming temperature, and the mold is integrally mounted on a servo press.

(3) Integration of forming and toughening

[0018] The amorphous alloy blank is placed in the mold cavity and heated by the one or more resistance heating rods to a temperature between a glass transition temperature and a crystallization temperature. The lower mold and the female mold are kept stationary, and ultrasonic vibration is started after the upper mold is moved down and comes into contact with the blank. The upper mold continues to be moved down until the upper mold, the lower mold and the female mold are completely closed to obtain a desired amorphous alloy part. The ultrasonic vibration is stopped, and the upper mold is moved up to be separated from the part. The lower mold is moved up until the part is pushed out of the female mold.

[0019] The present invention will be further described in detail below with reference to the embodiment and the accompanying drawings.

[0020] FIG. 2 is a schematic structural diagram of an amorphous alloy gear member forming device according to the preferred embodiment of the present invention, and as shown in FIG. 2, ultrasonic vibration assisted hot closed-die forging forming of the amorphous alloy gear member is illustrated.

[0021] Since gear failure mainly occurs in the tooth portion, it is necessary to perform nanocrystallization toughening of the tooth portion while retaining the amorphous state of the spoke portion, so as to improve the impact resistance of the amorphous alloy gear member. According to this demand, a forming device as shown in FIG. 2 was designed.

[0022] The forming device is composed of three parts of an upper mold, a lower mold and a female mold 4. In the forming device, the upper mold is composed of an upper ultrasonic vibration ring 1 and an upper punch 2, the upper punch 2 is embedded in the upper ultrasonic vibration ring 2, and the upper punch 2 is provided with a shoulder for limiting the movement of the upper ultrasonic vibration ring 1. The lower mold is composed of a lower ultrasonic vibration ring 6 and a lower punch 7, the lower punch 7 is embedded in the lower ultrasonic vibration ring 6, and the lower punch 7 is provided with a shoulder for limiting the movement of the lower ultrasonic vibration ring 6. The upper punch 2 is connected to an upper slider of a servo press. The lower punch 7 is connected to a lower slider of the servo press. The upper ultrasonic vibration ring 1 and the lower ultrasonic vibration ring 6 are respectively connected to an ultrasonic generator. An inner wall of the female mold 4 is machined in a tooth shape, and one or more resistance heating rods 3 are embedded in the female mold 4.

[0023] At the time of forming, a cylindrical blank 5 is first placed inside the female mold 4. The resistance heating rods 3 are started to heat the blank 5 to a set temperature. The lower molds (6 and 7) and the female mold 4 are kept stationary. The upper punch 2 drives the upper ultrasonic vibration ring 1 to move down until they come into contact with the upper surface of the blank 5. The upper ultrasonic vibration ring 1 and the lower ultrasonic vibration ring 6 are started to vibrate at a set frequency and amplitude. The upper punch 2 continues to drive the upper ultrasonic vibration ring 1 to move down at a set loading rate until the female mold 4 is completely filled by the blank 5. In this process, the ultrasonic vibration concentrates on the edge portion of the blank 5, that is, the tooth portion of the gear member. On the one hand, filling of the material into the mold cavity can be significantly facilitated, and the dimensional accuracy of the part can be improved; on the other hand, nanocrystallization is induced in the tooth portion to achieve toughening, while the amorphous state of the spoke portion is retained. The ultrasonic vibration of the upper ultrasonic vibration ring 1 and the lower ultrasonic vibration ring 6 and the resistance heating rod 3 are closed. The upper ultrasonic vibration ring 1, the upper punch 2, the lower ultrasonic vibration ring 6 and the lower punch 7 are moved up together at the same speed until the formed part 5 is pushed out of the inner cavity of the female mold 5. At this time, the forming process is finished.

[0024] It should be readily understood to those skilled in the art that the above description is only preferred embodiments of the present invention, and does not limit the scope of the present invention. Any change, equivalent substitution and modification made without departing from the spirit and scope of the present invention should be included within the scope of the protection of the present invention.

Claims

1. A plastic forming and gradient toughening method based on ultrasonic vibration, **characterized in that** the toughening method comprising:

    (a) according to actual use requirements of an amorphous alloy part to be formed, dividing one or more portions to be toughened on the amorphous alloy part to be formed, the portion being used for generating a nanocrystalline toughening phase and an amorphous state of other portions being retained;
    (b) designing a toughening device for forming the amorphous alloy part to be formed, wherein the toughening device is connected to an external drive mechanism and comprises one or more inserts connected to an ultrasonic vibration amplitude transformer and one or more heating rods, the insert is disposed corresponding to the portion to be toughened and used for applying ultrasonic vibration to the portion to be toughened, the heating rod is used for heating raw material blank to be processed to a forming temperature, and parameters of the ultrasonic vibration generated by the ultrasonic vibration amplitude transformer are obtained by analyzing an energy propagation process of the ultrasonic vibration by finite element numerical simulation, in which energy of the ultrasonic vibration is adjusted by adjusting an amplitude, a frequency and a power of the ultrasonic vibration, and when the energy of the ultrasonic vibration exceeds an energy threshold value required for nanocrystallization, the corresponding amplitude, frequency and power of the ultrasonic vibration are required parameters of the ultrasonic vibration; and
    (c) placing raw material blank in the toughening device, heating the raw material blank by the heating rod to a forming temperature, and performing mold closing of the toughening device to form a required amorphous alloy part, ultrasonic vibration being started in the mold closing process and stopped when mold opening is performed.

2. The plastic forming and gradient toughening method based on ultrasonic vibration according to claim 1, **characterized in that** the forming temperature is between a glass transition temperature and a crystallization temperature of the raw material blank.

3. The plastic forming and gradient toughening method based on ultrasonic vibration according to claim 1 or 2, **characterized in that** in the step (b), the heating rod is preferably a resistance heating rod.

4. The plastic forming and gradient toughening method based on ultrasonic vibration according to any one of claims 1-3, **characterized in that** in the step (b), the toughening device is preferably a mold for thermoplastic forming.

5. The plastic forming and gradient toughening method based on ultrasonic vibration according to any one of claims 1-4, **characterized in that** the amorphous alloy is a Pd, Pt, Au, Zr, Ti, Fe, Cu, Ni, Al, Mg or Ce based amorphous alloy with a thermoplastic forming ability.

6. A device for use in the toughening method according to any one of claims 1-5, **characterized in that** the device comprises an upper mold, a lower mold and a female mold,
    the upper mold and the lower mold are oppositely disposed and form a mold cavity with the female mold, the upper mold and the lower mold are respectively provided with a punch and one or more inserts, the punches are connected to a driving servo press

and used to form raw material blank into a desired three-dimensional structure, the inserts are connected to an ultrasonic vibration amplitude transformer and used to apply ultrasonic vibration to one or more portions to be toughened, the female mold is provided with one or more heating rod for heating the raw material blank.

ACCOMPANYING FIGURES

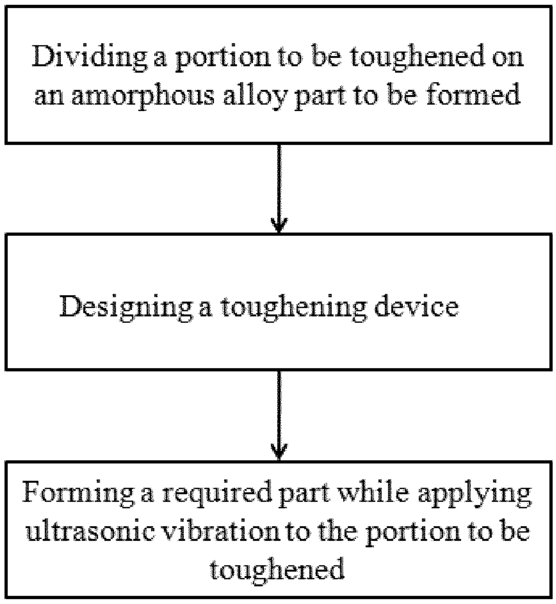

FIG. 1

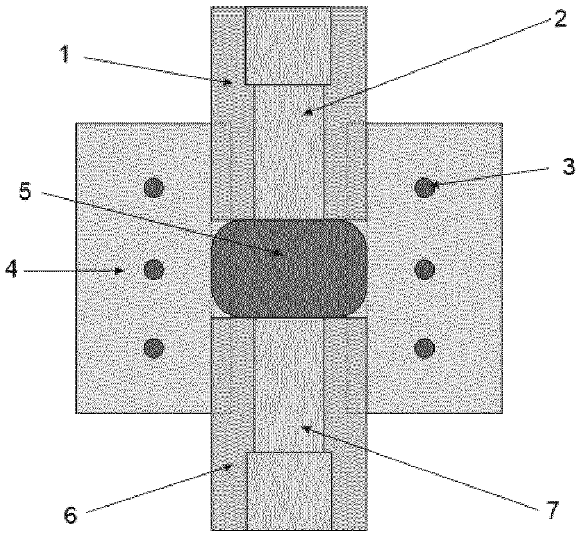

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2017/117069

A. CLASSIFICATION OF SUBJECT MATTER

C22F 3/00(2006.01)i； C21D 10/00(2006.01)i； B21D 37/10(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)

C22F； ; C21D； ; B21D； ; B29C； ; B21C； ; B21J

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, CNKI, CNABS, SIPOABS, CNTXT, 王新云, 张茂, 邓磊, 金俊松, 龚攀, 华中科技, 纳米晶, 晶化, 超声, 振动, 震动, 韧性, 局部, 部位, 区域, 金属玻璃, 非晶合金; nanocrystal+, crystal+, ultrasonic, vibration, toughen+, location, area+, district+, region+, section+, regional+, zone?, rang+, segment?, metallic, glass+, amorphous, alloy+

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	CN 105215246 A (SHANGHAI INSTITUTE OF SATELLITE EQUIPMENT) 06 January 2016 (2016-01-06) description, paragraphs [0024]-[0038], and figure 1	1-6
Y	CN 105396888 A (GUANGXI UNIVERSITY) 16 March 2016 (2016-03-16) description, paragraph [0004] to last paragraph, and figure 1	1-6
Y	CN 101623918 A (SHENZHEN UNIVERSITY) 13 January 2010 (2010-01-13) description, embodiment 3, and figure 3	1-6
A	CN 102601936 A (DALIAN UNIVERSITY OF TECHNOLOGY) 25 July 2012 (2012-07-25) entire document	1-6
A	CN 106975670 A (HARBIN UNIVERSITY OF SCIENCE AND TECHNOLOGY) 25 July 2017 (2017-07-25) entire document	1-6
A	JP 2000-140999 A (TOYOTA MOTOR CORP.) 23 May 2000 (2000-05-23) entire document	1-6

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

* Special categories of cited documents:

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"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

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Date of the actual completion of the international search	Date of mailing of the international search report
08 August 2018	**30 August 2018**

Name and mailing address of the ISA/CN	Authorized officer
State Intellectual Property Office of the P. R. China No. 6, Xitucheng Road, Jimenqiao Haidian District, Beijing 100088 China	
Facsimile No. **(86-10)62019451**	Telephone No.

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

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2017/117069

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2014/0219861 A1 (PURDUE RESEARCH FOUNDATION) 07 August 2014 (2014-08-07) entire document	1-6

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2017/117069

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
CN	105215246	A	06 January 2016	CN	105215246	B	22 December 2017
CN	105396888	A	16 March 2016	CN	105396888	B	20 October 2017
CN	101623918	A	13 January 2010	None			
CN	102601936	A	25 July 2012	None			
CN	106975670	A	25 July 2017	None			
JP	特开2000-140999	A	23 May 2000	None			
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				CA	2757805	C	10 February 2015
				US	2012115708	A1	10 May 2012
				US	9222158	B2	29 December 2015

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

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- CN 101736213 **[0004]**
- CN 102002659 **[0004]**
- CN 105420522 **[0004]**