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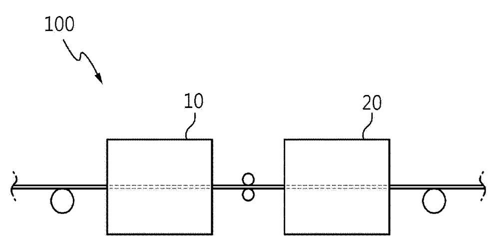
(54) APPARATUS FOR MANUFACTURING CARBON FIBER BY USING MICROWAVES

(57) The present invention relates to an apparatus for manufacturing carbon fiber by using microwaves, and more particularly, to an apparatus for manufacturing carbon fiber by using microwaves, which directly or indirectly heats and carbonizes a carbon fiber precursor by using microwaves, so that energy efficiency is improved because an entire carbonization furnace is not heated, and a property of the precursor is adjusted by a simpler method by the microwaves.

[FIG. 1]



EP 3 556 916 A1

Description

[Technical Field]

[0001] This application claims priority to and the benefit of Korean Patent Application No. 10-2016-0173883 filed in the Korean Intellectual Property Office on December 19, 2016, the entire contents of which are incorporated herein by reference.

[0002] The present invention relates to an apparatus for manufacturing carbon fiber by using microwaves, and more particularly, to an apparatus for manufacturing carbon fiber by using microwaves, which directly or indirectly heats and carbonizes a carbon fiber precursor by using microwaves, so that energy efficiency is improved because an entirety of a carbonization furnace is not heated, and a property of the precursor is adjusted by a simpler method by the microwaves.

[Background Art]

[0003] Carbon fiber means fiber obtained by pyrolyzing an organic precursor material in the form of fiber manufactured from polyacrylonitrile (PAN), pitch that is a petroleum-based/coal-based hydrocarbon residue, or rayon that is a carbon material of a fiber sheet in which a mass content of carbon elements is 90% or more in an inert atmosphere.

[0004] The carbon fiber is lighter than steel and has excellent strength, so that the carbon fiber is widely applied to various fields, such as a vehicle field, an aerospace field, a wind power generation field, and a sport field. For example, recently, environmental regulations related to exhaust gas of a vehicle are tightened due to an environment problem, so that a light vehicle having high efficiency has been increasingly demanded, and as a method of decreasing weight of a vehicle without sacrificing structural and mechanical strength, a technology using a carbon fiber reinforced composite has attracted attention.

[0005] However, since the carbon fiber is expensive, there is a limit in the application and the commercialization of the carbon fiber, and thus, there is an urgent demand for a development of a technology for mass producing carbon fiber having high performance at low cost.

[0006] A process of carbonizing carbon fiber in the related art is performed by heat treatment at a high temperature of 1,000°C to 1,500°C by using an electric carbonization furnace. The electric carbonization furnace is generally divided into two or more heat zones including a heat zone for a low temperature and a heat zone for a high temperature. The carbonization process using the electric carbonization furnace has a scheme in which heat is transmitted to carbon fiber by an internal temperature of the carbonization furnace or heat moves in a direction from an outer side to an inner side of the fiber, so that there is a problem in that energy efficiency is not high.

[0007] Further, the carbonization process in the related art is the scheme in which the entirety of the carbonization furnace is heated in order to increase an internal temperature of the carbonization furnace, and a temperature of a heating furnace needs to be maintained higher than a carbonization temperature of a precursor, so that there is a problem in that heat resistance is required.

[0008] In relation to this, there needs a process of carbonizing carbon fiber having high energy efficiency.

[Detailed Description of the Invention]

[Technical Problem]

[0009] The present invention is conceived to solve the foregoing problems, and an object of the present invention is to provide an apparatus for manufacturing carbonized fiber using microwaves, which includes a carbonization furnace that directly heats a precursor by using a micro wave, in order to improve energy efficiency.

[0010] Another object of the present invention is to provide an apparatus for manufacturing carbonized fiber using microwaves, which includes a heating body heated by microwaves inside a main body of a carbonization furnace in order to carbonize stabilized fiber having low reactivity to microwaves and increase energy efficiency for heating compared to a carbonization process of heating an entirety of a carbonization furnace in the related art.

[Technical Solution]

[0011] An apparatus for manufacturing carbonized fiber by using microwaves according to the present invention includes: a heat treatment furnace which stabilizes a precursor; and a carbonization furnace which is positioned at one side of the heat treatment furnace and carbonizes the stabilized precursor, in which the carbonization furnace carbonizes the precursor by using microwaves as a heat source.

[0012] The carbonization furnace may include: a main body; a micro emitting unit which is positioned inside or outside the main body, and emits microwaves to the stabilized precursor; and a heating body which is positioned inside the main body and is heated by the microwaves.

[0013] The heating body may occupy 0.1% to 5% of a volume of the main body.

[0014] One or more carbonization furnaces may be positioned at one side of the heat treatment furnace.

[0015] A continuous process may be performed by rollers positioned at one side and the other side of each of the heat treatment furnace and the carbonization furnace.

[0016] The carbonization furnace may have a carbonization temperature of 400°C to 1,500°C.

[Advantageous Effects]

[0017] According to the present invention, the carbonization furnace includes the emitting unit that emits microwaves inside or outside thereof and directly/indirectly heats the fiber passing the stabilization fiber to increase a carbonization speed of carbon fiber, so that the carbon fiber is obtained within a short time, thereby achieving an effect in that energy efficiency is increased.

[0018] Further, the carbonization furnace includes the heating body inside thereof, so that there is no limit in the kind of precursor used for manufacturing the carbonized fiber, and the precursor is indirectly heated and the entirety of the carbonization furnace is not heated, thereby achieving an effect in that energy efficiency for heating is improved compared to the carbonization process in the related art.

[Brief Description of Drawings]

[0019]

FIG. 1 is a cross-sectional view of a carbon fiber manufacturing apparatus using microwaves according to an exemplary embodiment of the present invention.

FIG. 2 is a cross-sectional view of a carbonization furnace according to the exemplary embodiment of the present invention.

FIG. 3 is a perspective view of a heating body according to the exemplary embodiment of the present invention.

[Best Mode]

[0020] The present invention will be described in detail with reference to the accompanying drawings. Herein, repeated description, and detailed description of a publicly known function and configuration which may unnecessarily make the main point of the present invention be unclear will be omitted. The exemplary embodiments of the present invention are provided for more completely explaining the present invention to those skilled in the art. Accordingly, shapes, sizes, and the like of the elements in the drawings may be exaggerated for clear description.

[0021] In the entire specification, unless explicitly described to the contrary, when it is said that a part "comprises/includes" a constituent element, this means that another constituent element may be further "included/comprised", not that another constituent element is excluded.

[0022] Hereinafter, an exemplary embodiment is presented for helping understanding of the present invention. However, the exemplary embodiment below is simply provided for more easy understanding of the present invention, and the contents of the present invention are not limited by the exemplary embodiment.

<Carbon fiber manufacturing apparatus using microwave>

[0023] FIG. 1 is a cross-sectional view of a carbon fiber manufacturing apparatus 100 using microwaves according to an exemplary embodiment of the present invention. The carbon fiber manufacturing apparatus 100 using the microwaves may include a heat treatment furnace 10 and a carbonization furnace 20, and a process may be continuously performed by rollers positioned at one side and the other side of each of the heat treatment furnace 10 and the carbonization furnace 20.

[0024] The heat treatment furnace 10 is a configuration of stabilizing a precursor, and may serve to make the precursor be in contact with air and oxidize the precursor. The process of stabilizing the precursor is a process of insolubilizing the precursor so as to have flame resistance when the precursor is carbonized. The stabilization of the precursor may provide an inner side of the heat treatment furnace 10 with an air atmosphere, and heat treat the precursor at a temperature of 200°C to 300°C for one to two hours to stabilize a fiber structure of the precursor. In this case, when a stabilization reaction of the precursor progresses, the stabilization may sharply progress, so that it is noted that the temperature is increased to 200°C to 300°C by stages. When the stabilization condition of the precursor is 200°C or lower and less than one hour, there may be a problem in that oxidization and stabilization are inadequate, and when the stabilization condition of the precursor is higher than 300°C and longer than two hours, a property of the carbonized fiber may be negatively influenced, so that there may be a problem in energy loss.

[0025] Herein, the precursor may be formed of a composition of any one of a rayon-series material, a pitch-series material, a polyacrylonitrile-series material, and a cellulose-series material.

[0026] The carbonization furnace 20 is a configuration of carbonizing the stabilized precursor, and may carbonize the precursor by using microwaves as a heat source. During the carbonization process, the carbonization furnace may carbonize the precursor at a temperature of 400°C to 1,500°C, and in this case, the carbonization process may be divided into low-temperature carbonization and high-temperature carbonization. The low-temperature carbonization may carbonize the precursor at a temperature of 400°C to 900°C, and the high-temperature carbonization process may carbonize the precursor at a temperature of 900°C to 1,500°C.

[0027] Further, the carbonization furnace 20 may be positioned at one side of the heat treatment furnace 10, and may include a main body 21 and a micro emitting unit 22 for carbonizing the stabilized precursor.

[0028] The main body 21 may mean a space of which a temperature is increased by the micro emitting unit 22 which is to be described below.

[0029] The micro emitting unit 22 may be installed outside or inside an outer circumference surface of the main body 21 and serve to emit microwaves to the stabilized precursor. By adjusting an energy size (output), an energy emission time, and the like of the microwaves according to the present invention, the carbon fiber having a required property may be irradiated with a high yield within a shorter reaction time.

[0030] Further, the carbonization furnace 20 according to the present invention may carbonize the precursor by directly heating the stabilized precursor by the microwaves to manufacture the carbon fiber. In the carbonization furnace 20 according to the present invention, the microwaves directly heat the precursor without heating the main body unlike the carbonization technology in the related art, thereby achieving an advantage in that energy efficiency is improved compared to the carbonization process in the related art.

[0031] FIG. 2 is a cross-sectional view of the carbonization furnace 20 according to the exemplary embodiment of the present invention, and FIG. 3 is a perspective view of a heating body 23 according to the exemplary embodiment of the present invention. The carbonization furnace 20 according to the present invention may further include the heating body 23. The heating body 23 may be positioned inside the main body 21, and is directly heated by the microwaves emitted from the micro emitting unit 22 to serve to indirectly carbonize the precursor. Further, the heating body may be formed of a composition of any one of silicon carbide, silicon, a metal silicide, carbon, and a carbon fiber composite material.

[0032] In this case, the main body 21 is the configuration including any one or more of the micro emitting unit 22 and the heating body 23, and it is noted that the configurations, such as a manipulating unit and an operating unit, additionally configurable in the carbonization process are not included inside the main body 21. According to some exemplary embodiments, the main body 21 may be formed at a position with a size in which only the heating body 23 may be included.

[0033] The heating body 23 is formed with an inlet through which the precursor enters and an outlet through which the carbon fiber formed by carbonizing the precursor is discharged. The inner side of the heating body 23 may be provided with an atmosphere of gas, such as nitrogen, argon, and helium or mixed gas thereof, and preferably, the carbonization process may be formed in a nitrogen atmosphere. For example, the precursor stabilized in the heat treatment furnace 10 may be inserted into the heating body 23 in the nitrogen atmosphere, the heating body 23 is heated to a temperature of 400°C to 1,500°C by the microwaves emitted by the micro emitting unit 22, and then, the precursor may be indirectly heated by radiant heat of the heating body 23.

[0034] Herein, the carbonization furnace 20 according to the present invention carbonizes the precursor by using the indirect heating, thereby achieving an advantage in that even the stabilized fiber having low reactivity to the microwaves may be carbonized, and achieving an effect in that it is possible to improve a property and energy efficiency of the manufactured carbon fiber according to a structure and a volume of the heating body 23.

[0035] It is noted that as long as the heating body 23 has a volume of 0.1% to 5% of a volume of the main body 21, the form of the heating body 23 is not limited. When the volume of the heating body 23 exceeds 5%, a large amount of microwaves needs to be emitted for heating the heating body 23, and a temperature inside the carbonization furnace 20 is not increased and tensile strength and modulus of the carbon fiber are decreased, so that there may be a problem in that energy efficiency of the carbonization process is decreased.

[0036] FIG. 3 illustrates an example of the form of the heating body 23 according to the present invention. A structure of the heating body 23 may have a shape of any one of a plate and a hollow column structure. For example, when the structure of the heating body 23 is provided in a plate shape, one or more plates may be provided, the heating body 23 may be formed of only one surface or two upper and lower surfaces. Further, the heating body 23 may be formed of three surfaces including any one of upper/lower/right surfaces and upper/lower/left surfaces. When the heating body 23 is provided in the plate shape, one or more holes may be formed in a part of the plate, and the hole may have a form of any one of a circle, a polygon, and an ellipse, but it is noted that the form of the hole is not limited. Further, according to some exemplary embodiments, the heating body 23 may be provided in a plate shaped like a net.

[0037] Further, the heating body 23 may have the form of a hollow column and a cross section of the column may have the form of any one of a circle, a quadrangle, a polygon, and an ellipse, but it is noted that the form of the cross section of the column of the heating body is not limited. Herein, when the heating body 23 is provided in a three-dimensional shape, the surface forming the shape may be formed with one or more holes, and the hole may have the form of any one of a circle, a polygon, and an ellipse, but it is noted that the form of the hole is not limited thereto. In this case, a space in which the precursor is accommodated may be divided into two or more spaces, and an inlet through which the precursor enters and an outlet through which the precursor is taken out may be formed in the divided spaces, respectively. The division of the accommodation space of the precursor in the heating body 23 complexly enables the direct heating and the indirect heating of the precursor and increases a movement distance of the precursor, so that the precursor is irradiated by the microwaves or the radiant heat of the heating body for a long time and is carbonized and graphitized, thereby minimizing external and internal temperature gradients and achieving an effect in that a generation of a crack of the carbon fiber is decreased.

[0038] Further, the carbonization furnace 20 may further include a chamber (not illustrated) including all of the main body 21, the micro emitting unit 22, and the heating body 23 inside thereof. The chamber may be positioned outside the main body 21, and when the chamber may further include the configuration, for example, a manipulating unit and an operating unit, required for the carbonization of the precursor, in addition to the main body 21, the micro emitting unit 22, and the heating body 23, a shape and a size of the chamber are not limited.

[0039] Further, one or more carbonization furnaces 20 may be positioned at one side of the heat treatment furnace 10. One or more carbonization furnaces 20 are serially connected, so that a movement distance of the precursor within the carbonization furnace 20 is increased and the precursor is irradiated by the microwaves for a long time and is carbonized or graphitized to manufacture carbon fiber. One or more carbonization furnaces 20 are serially connected, so that only the outer surface of the precursor is heated by the high-temperature microwave radiant heat in a moment and the inner side of the precursor is not heated, thereby solving the problem in that a large temperature gradient between the inner side and the outer side is generated.

<Experimental Example 1>

[0040] Tensile strength and modulus were compared by using carbon fiber manufactured by using a carbonization furnace including a heating body having a volume of about 8% of a volume of a main body and the carbon fiber manufactured by using the carbonization furnace including the heating body having a volume of about 0.1% to 5% of a volume of the main body according to the exemplary embodiment of the present invention.

[0041] To this end, an experiment was performed on one carbon fiber product manufactured by using the carbonization furnace including the heating body having the volume of about 8% and two carbon fiber products according to the exemplary embodiment of the present invention.

[0042] In Comparative Example 1, Example 1, and Example 2, polyacrylonitrile fiber was prepared as a precursor and was heat treated in an air atmosphere at a temperature of 280°C for two hours.

[0043] In Comparative Example 1, stabilized polyacrylonitrile fiber was inserted into a carbonization furnace including a heating body having a volume corresponding to about 8% of a volume of a main body and then a carbonization process was performed in a nitrogen atmosphere at a temperature of 800°C to 1,500°C for 20 minutes or longer. In this case, applied power of microwaves was set to 1.2 kW.

[0044] In Example 1, stabilized polyacrylonitrile fiber was inserted into a carbonization furnace including a heating body having a volume corresponding to about 0.13% of a volume of a main body and then a carbonization process was performed in a nitrogen atmosphere at a temperature of 800°C to 1,500°C within one minute. In this case, applied power of microwaves was set to 1 kW. Further, in Example 2, stabilized polyacrylonitrile fiber was inserted to a carbonization furnace including a heating body having a volume corresponding to about 1.8% of a volume of a main body and then a carbonization process was performed in a nitrogen atmosphere at a temperature of 800°C to 1,500°C within five minutes, and applied power of microwaves was set to 1.8 kW.

[0045] In order to compare a mechanical property after the carbonization, tensile strength and elasticity of one string of the fiber were repeatedly measured by about 50 times using the Favimat equipment and an average of the measured tensile strength and elasticity were calculated.

[Table 1]

		Example 1	Example 2	Comparative Example 1
Carbon condition	Volume (%) of heating body	0.13	1.8	8.6
	Applied power (kW)	1	1.8	1.2
	Time (min)	1	<5	>20

(continued)

		Example 1	Example 2	Comparative Example 1
Carbon fiber property	Tensile strength	>2.5	>2.5	-1.5
	Modulus	>190	>180	-90

[0046] Referring to the Table above, in Comparative Example 1, 20 minutes or longer are required for increasing a temperature of the heating body to 800°C to 1,500°C, and due to the large volume of the heating body and the long temperature increasing time, the tensile strength of the carbon fiber was measured to 1.5 or less and modulus of the carbon fiber was measured to 90 or less. Accordingly, it can be seen that when the volume of the heating body is large, elasticity of the manufactured carbon fiber is inadequate and a property and energy efficiency of the carbon fiber are degraded.

[0047] In order to increase a temperature of the heating body to 800°C to 1,500°C, one minute is required in Example 1 and five minutes or shorter is required in Example 2. In this case, tensile strength and modulus of the carbon fiber of Example 1 and Example 2 are 2.5 or more and 190 or more, so that it can be seen that elasticity of the carbon fiber is excellent and a property and energy efficiency are improved.

[0048] As a result, according to the determination based on the result, it can be seen that the volume of the heating body is closely related to the property and the energy efficiency of the carbon fiber, and as the volume of the heating body is small, the heating body is heated even by a small output of the microwaves within a short time, so that the tensile strength and the modulus of the carbon fiber are increased.

<Experimental Example 2>

[0049] Temperatures were compared between Comparative Example 2 that is a carbonization furnace including no heating body and Example 3 that is the carbonization furnace including the heating body having the volume of 0.1% to 5% of the volume of the main body according to the exemplary embodiment of the present invention. Herein, the heating body of Example 3 includes silicon carbide (SiC) having a volume corresponding to about 0.13% of a volume of a main body.

[0050] The carbonization furnaces of Comparative Example 2 and Example 3 have the same size, and a time at which an internal temperature of the carbonization furnace reaches 1,000°C by applying microwaves of 1.2 kW was measured.

[Table 2]

	Comparative Example 2	Example 3
Existenance of heating body	X	O
Reach time at 1,000°C (minute)	Not reach	2

[0051] Referring to the Table, it can be seen that in Comparative Example 2, the carbonization furnace has a temperature lower than 300°C even after ten minutes, but in Example 3, the carbonization furnace reaches a temperature of 1,000°C after two minutes.

[0052] That is, in Comparative Example 2, the carbonization furnace fails to reach the temperature at which the stabilized fiber becomes fiber having high reactivity to microwaves, and in Example 3, the temperature inside the carbonization furnace reaches a temperature region in which fiber having high reactivity to microwaves is manufactured by only the heating body within a short time, so that it is possible to effectively manufacture carbonized fiber.

[0053] Accordingly, when the stabilized fiber passing the stabilization operation in the heat treatment furnace moves to the carbonization furnace, the stabilized fiber enters the region in which the stabilized fiber has high reactivity to the microwaves at a high speed by an increase in a temperature of the heating body, so that there may be an effect in that energy efficiency is improved and a carbonization property of the carbon fiber is adjusted by a simpler method by the microwave.

[0054] The present invention has been described with reference to the exemplary embodiment of the present invention, but those skilled in the art may appreciate that the present invention may be variously corrected and changed within the range without departing from the spirit and the area of the present invention described in the appending claims.

Claims

1. An apparatus for manufacturing carbon fiber by using microwaves, the apparatus comprising:

   a heat treatment furnace which stabilizes a precursor; and
   a carbonization furnace which is positioned at one side of the heat treatment furnace and carbonizes the stabilized precursor,
   wherein the carbonization furnace carbonizes the precursor by using microwaves as a heat source.

2. The apparatus of claim 1, wherein the carbonization furnace includes:

   a main body;
   a micro emitting unit which is positioned inside or outside the main body, and emits microwaves to the stabilized precursor; and
   a heating body which is positioned inside the main body and is heated by the microwaves.

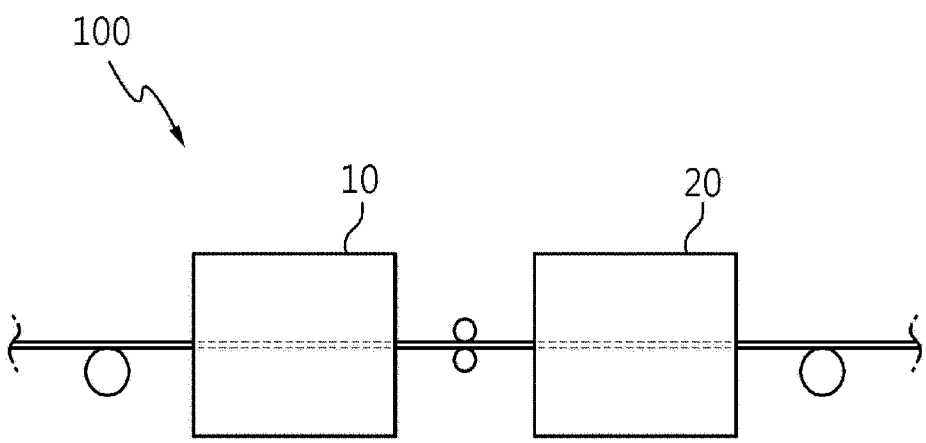
3. The apparatus of claim 2, wherein the heating body occupies 0.1% to 5% of a volume of the main body.

4. The apparatus of claim 1, wherein one or more carbonization furnaces are positioned at one side of the heat treatment furnace.

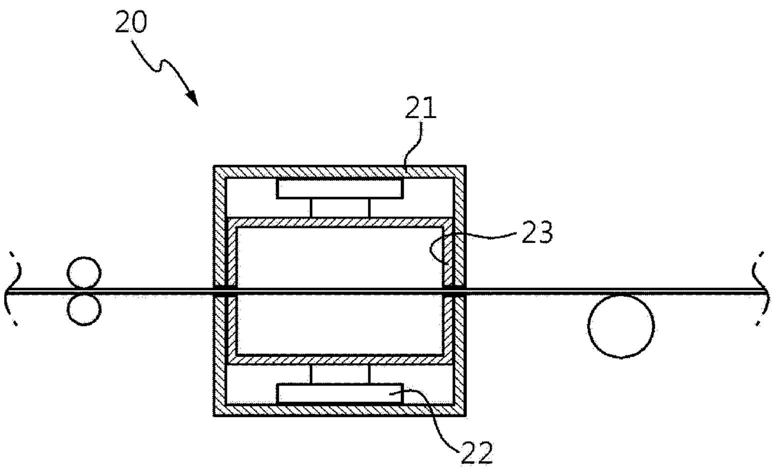
5. The apparatus of claim 1, wherein a continuous process is performed by rollers positioned at one side and the other side of each of the heat treatment furnace and the carbonization furnace.

6. The apparatus of claim 1, wherein the carbonization furnace has a carbonization temperature of 400°C to 1,500°C.

[FIG. 1]



[FIG. 2]



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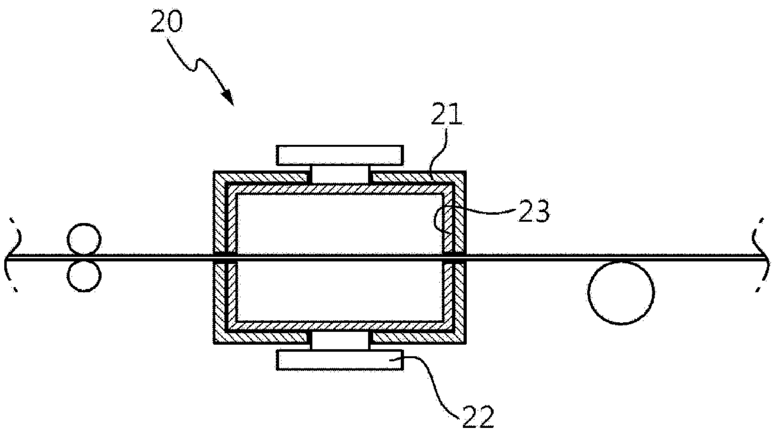
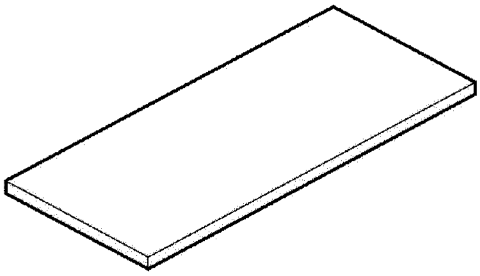


(b)

[FIG. 3]



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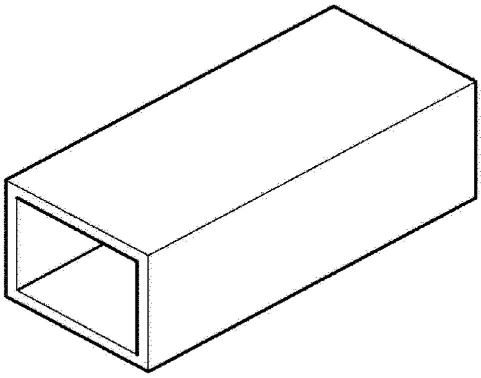

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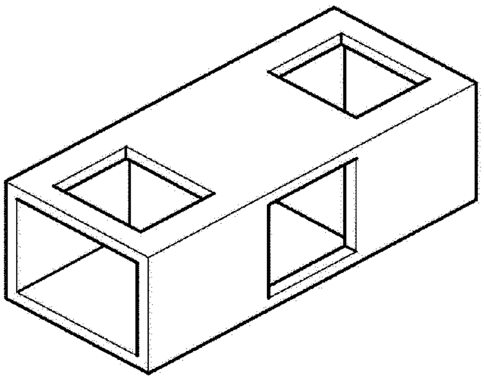

(c)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2017/015018

A. CLASSIFICATION OF SUBJECT MATTER

D01F 9/22(2006.01)i, D01F 9/32(2006.01)i, D06M 10/00(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)
D01F 9/22; D01F 9/32; H05B 6/64; D01F 9/12; D01F 6/18; D01F 9/127; D06M 10/02; D06M 14/36; D06M 10/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean Utility models and applications for Utility models: IPC as above
Japanese Utility models and applications for Utility models: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS (KIPO internal) & Keywords: precursor, heat treatment, carbonization, microwave, heating body, carbon fiber

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2016-0130732 A1 (TOHO TENAX CO., LTD.) 12 May 2016 See claims 1, 5; paragraphs [0057]-[0138]; and figure 1.	1,4-6 2,3
Y	JP 2014-067575 A (MICRO DENSHI K.K. et al.) 17 April 2014 See claim 1; and paragraphs [0001], [0059], [0070], [0074].	2,3
A	KR 10-2012-0070327 A (KOREA INSTITUTE OF ENERGY RESEARCH) 29 June 2012 See the entire document.	1-6
A	KR 10-2013-0130388 A (KOREA INSTITUTE OF SCIENCE AND TECHNOLOGY) 02 December 2013 See the entire document.	1-6
A	KR 10-1309730 B1 (POSTECH ACADEMY-INDUSTRY FOUNDATION et al.) 17 September 2013 See the entire document.	1-6

☐ 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
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 MARCH 2018 (28.03.2018)	**28 MARCH 2018 (28.03.2018)**
Name and mailing address of the ISA/KR Korean Intellectual Property Office Government Complex-Daejeon, 189 Seonsa-ro, Daejeon 302-701, Republic of Korea Facsimile No. +82-42-481-8578	Authorized officer Telephone No.

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

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2017/015018

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