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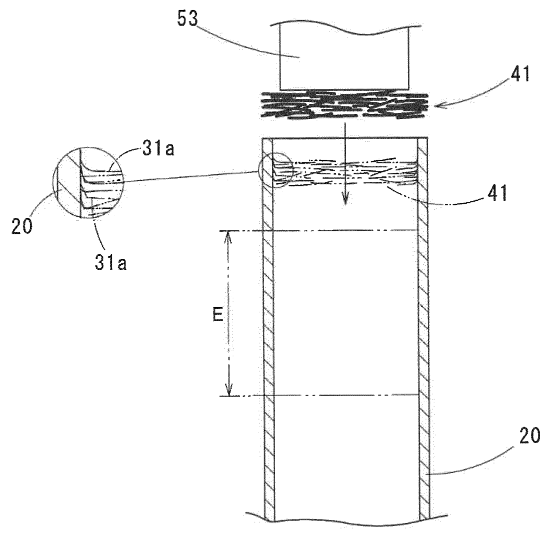
(54) **HEAT-EXCHANGE PIPE AND MANUFACTURING METHOD THEREOF**

(57) A heat-exchange pipe that is excellent in heat-exchange property in which a metal porous body is not easily dropped off form a metal pipe; which is provided with the metal pipe and the metal porous body made by joining a plurality of metal fibers bonded to an inner-wall surface of the metal pipe; at least some of the metal fibers in the metal porous body are partially bonded to the inner-wall surface of the metal pipe along a length direction, bended on the inner-wall surface of the metal pipe, and extend to leave from the inner-wall surface.

FIG. 9



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Description

BACKGROUND OF THE INVENTION

Technical Field

[0001] The present invention relates to a heat-exchange pipe configured by bonding a porous body on an inner-wall surface of a pipe and a producing method thereof. Priority is claimed on Japanese Patent Application No. 2020-041798, filed March 11, 2020, the content of which is incorporated herein by reference.

Background Art

[0002] As a heat-exchange pipe configured by bonding a porous body on an inner-wall surface of a pipe, for example as shown in Patent Literature 1, a porous aluminum composite body in which a porous aluminum body is bonded on an inner peripheral surface of an aluminum pipe which is an aluminum bulk body is disclosed. The porous aluminum body in Patent Literature 1 is made by sintering a plurality of aluminum base substances to be integrated, and its porosity is set in a range of 30% or more and 90% or less.

[0003] The aluminum base substances are aluminum fibers and aluminum powder and have a structure which are bonded to each other by columnar projections protruding outward. In this case, it is described that a fiber diameter of the aluminum fibers is in a range of 20 μm or more and 1000 μm or less, and that three-dimensional and isotropic gaps are maintained between the aluminum fibers.

Citation List

Patent Literature

[0004] Patent Literature 1: Japanese Unexamined Patent Application, First Publication No. 2016-006226

SUMMARY OF INVENTION

Technical Problem

[0005] In the porous aluminum body described in Patent Literature, since the gaps between the aluminum fibers are isotropic and the fiber diameter of the aluminum fibers is small, a heat exchange with an inner-wall surface of the pipe (aluminum pipe) is restricted, so it is difficult to exchange the heat sufficiently between an outer surface of the pipe and the porous aluminum body. Moreover, if the bonding between the porous aluminum body and the pipe is not sufficient, the porous aluminum body may drop from the pipe.

[0006] The present invention is achieved in consideration of the above circumstances, and has an object to provide a heat-exchange pipe having an excellent heat-exchange property and in which a metal porous body does not easily drop off from a metal pipe.

Solution to Problem

[0007] A heat-exchange pipe of the present invention is provided with a metal pipe and a metal porous body which is configured by joining a plurality of metal fibers and bonded to an inner-wall surface of the metal pipe. At least some of the metal fibers are partially bonded to the inner-wall surface of the metal pipe for a length direction. The metal fibers which are bonded to the inner-wall surface bend on the inner-wall surface of the metal pipe and extend from the inner-wall surface to leave.

[0008] Since some of the metal fibers which are in contact with the inner-wall surface of the metal pipe are bonded, the heat is exchanged between the metal pipe and the metal porous body in a whole of the bonded parts. Moreover, since the metal fibers extend from the inner-wall surface to leave from the bonded parts between the metal pipe and the metal porous body, the metal fibers can be arranged effectively in a center part of a cross-sectional surface of the metal pipe, so that the heat exchange with a fluid flowing in the metal pipe is favorably performed. Accordingly, this heat-exchange pipe is excellent in the heat-exchange property between the exterior and the interior of the pipe.

[0009] Furthermore, since the metal fibers are bonded to the inner-wall surface at a part of the length direction not at an end part, there is no fear of dropping off from the metal pipe and it is possible to maintain the heat-exchange performance stably for a long time.

[0010] As one aspect of the heat-exchange pipe, it is preferable that a bonding area ratio of the metal fibers to the inner-wall surface of the metal pipe be 5% or more.

[0011] If the bonding area ratio is 5% or more, the metal fibers are sufficiently bonded to the inner-wall surface of the metal pipe, they do not drop off. If it is less than 5%, since the contact of the metal fibers to the inner-wall surface of the metal pipe is small, there is a risk that the heat exchange between the metal pipe and the metal fibers may be small.

[0012] As another aspect of the heat-exchange pipe, a difference between an average area ratio of the metal fibers in a center part corresponding a half of an area of a transverse cross section of the metal pipe and an average area ratio of the metal fibers in a whole of the transverse cross section is preferably in 5% or less.

[0013] In the metal porous body, the metal fibers are preferably arranged evenly in the cross section of the metal pipe. If the metal fibers are biased to be arranged to either of the center part or an inner peripheral wall part, a fluid is concentrated and flows in a part where the area ratio of the metal fibers is small in the cross section, and the heat-exchange performance may be deteriorated. If the difference between the average area ratio in the center part of the cross section and the average area ratio in the whole cross section of the metal pipe is 5% or less, the fluid flows in the whole cross section of the metal pipe, and the heat is exchanged effectively with the metal fibers.

[0014] A producing method of a heat-exchange pipe of the present invention has a precursor formation step of stacking a plurality of metal fibers to form a precursor, an in-pipe charging step of pushing the precursor from one end of the metal pipe to charge into the metal pipe, and a sintering step of sintering the metal pipe in a state of charging the precursor; the precursor before the in-pipe charging step is formed such that an outer diameter in a state where the metal fibers are stacked is larger than an inner diameter of the metal pipe.

[0015] By forming the outer diameter of the precursor larger than the inner diameter of the metal pipe, when the precursor is pushed into the metal pipe, the metal fibers disposed on the outer peripheral part of the precursor is bent, and is in contact with the inner-wall surface of the metal pipe along the length direction. In the outer peripheral part of the precursor, the metal fibers are provided in a state of being bent at the inner-wall surface of the metal pipe and then extending to leave from the inner-wall surface. Accordingly, since the metal fibers are partially bonded to the inner-wall surface of the metal pipe and arranged to extend in a cross-sectional direction, it is possible to produce the heat-exchange pipe having an excellent heat-exchange property.

Advantageous Effects of Invention

[0016] According to the present invention, it is possible to provide a heat-exchange pipe with an excellent heat-exchange property and in which the metal porous body is not easily dropped off from the metal pipe.

BRIEF DESCRIPTION OF DRAWINGS

[0017]

[FIG. 1] It is a longitudinal cross-sectional view of a heat-exchange pipe of an embodiment according to the present invention.
[FIG. 2] It is a transverse cross-sectional view taken along the line A-A in FIG. 1.
[FIG. 3] It is a flowchart showing an embodiment of a producing method of the present invention.
[FIG. 4] It is a schematic view of a metal porous body (porous aluminum sintered body).
[FIG. 5] It is a schematic view of an aluminum material for sintering.
[FIG. 6] It is a schematic view showing a state in which columnar projections are made in the aluminum material for sintering.
[FIG. 7] It is a schematic view showing a state of the columnar projections.
[FIG. 8] It is a schematic view showing a step of forming a precursor.
[FIG. 9] It is a schematic view showing a state in which the precursor is pushed into an aluminum pipe. The left part surrounded by a circle is an enlarged view of a principal part.
[FIG. 10] It is a CT image of a transverse section of the heat-exchange pipe.
[FIG. 11] It is a CT image of a longitudinal section of the heat-exchange pipe.
[FIG. 12] It is a CT image showing a bonded part of a porous aluminum sintered body on an inner-wall surface of the aluminum pipe.

DESCRIPTION OF EMBODIMENTS

[0018] An embodiment of the present invention will be explained below. A heat-exchange pipe 10 of this embodiment is, as shown in FIG. 1 and FIG. 2, configured from an aluminum pipe (corresponding to a metal pipe of the present invention) 20 made of aluminum or aluminum alloy and a porous aluminum sintered body (corresponding to a metal porous body of the present invention: herein after "a porous body") 30 made of aluminum or aluminum alloy, charged in the aluminum pipe 20.

[0019] In the heat-exchange pipe 10, a heat source (not illustrated) which is high temperature or low temperature is provided outside a portion where the porous body 30 is charged; a gas or liquid fluid as a heat-transfer medium is flowed inside the aluminum pipe 20, and the fluid changes heat with the heat source when passing in the porous body 30.

[0020] The aluminum pipe 20 is an ordinary pipe having a circular cross section formed by extrusion molding or the like of Al-Mn type alloy or the like such as A3003. The aluminum pipe 20 has, for example, 5 mm to 150 mm of an outer diameter and 0.8 mm to 10 mm of a wall thickness.

[0021] The porous body 30 is, as shown in FIG. 4, integrated by sintering a plurality of aluminum base substances (metal substances) 31; a porosity is set in a range of 30% or more and 90% or less. As the aluminum base substances 31, a mixture of aluminum fibers 31a (metal fibers) and aluminum powder particles 31b is used.

[0022] On outer surfaces of the aluminum base substances 31, a plurality of columnar projections 32 protruding outward are formed; the plurality of the aluminum base substances 31 are joined by base substance joint parts 35. The base substance joint parts 35 are parts where the columnar projections 32 are joined to each other, parts where the columnar projections 32 and surfaces of the aluminum base substances 31 are joined, and parts where the surfaces of the aluminum base substances 31 are joined to each other.

[0023] In the base substance joint parts 35, eutectic element compounds 17 containing Ti-Al type compounds 16 and eutectic elements that eutectic-reactions with Al exist. In this embodiment, the Ti-Al type compounds 16 are compounds of Ti and Al: more specifically, they are Al_3Ti intermetallic compounds.

[0024] As the eutectic elements that eutectic-react with Al, for example, Ag, Au, Ba, Be, Bi, Ca, Cd, Ce, Co, Cu, Fe, Ga, Gd, Ge, In, La, Li, Mg, Mn, Nd, Ni, Pd, Pt, Ru, Sb, Si, Sm, Sn, Sr, Te, Y, Zn, and the like, are exemplified. Among them, Ni, Mg, Cu, and Si are preferable.

[0025] In this porous body 30, the aluminum base substances 31 are bonded to either or both the other aluminum base substances 31 or the inner-wall surface of the aluminum pipe 20.

[0026] The aluminum fibers 31a joined to the inner-wall surface of the aluminum pipe 20 are joined in a state of being in contact along the length direction for a range of a prescribed length (in other words, the aluminum fibers 31a are joined at a part in the length direction to the inner-wall surface); the middle of the aluminum fibers 31a are bended on the inner-wall surface of the aluminum pipe 20, and the rest which is not in contact with the inner-wall surface extends and leaves from the inner-wall surface.

[0027] It is preferable that the aluminum fibers 31a be bended at right angle to the joined part to the inner-wall surface of the aluminum pipe 20 and extend perpendicular from the inner-wall surface of the aluminum pipe 20. However, if they are separated from the inner-wall surface of the aluminum pipe 20, it is not necessary to be perpendicular to the inner-wall surface. Moreover, it is applicable that one aluminum fiber 31a that is joined in a state of being in contact at two or more portions to the inner-wall surface of the aluminum pipe 20 exists.

[0028] Since the aluminum fibers 31a are joined to the inner-wall surface of the aluminum pipe 20 in a state of being in contact in the range of the prescribed length, a joined area (total area) of the aluminum fibers 31a to the aluminum pipe 20 is preferably 5% or more to an area of the inner-wall surface of the aluminum pipe 20 in a region E where the porous body 30 is provided.

[0029] That is, in the region E where the porous body 30 is provided, where a bonding area ratio to the wall surface is a percentage of (the joined area of the aluminum fibers 31 a)/(the area of the inner-wall surface of the aluminum pipe 20), it is preferable that the bonding area ratio ≥ 5%. If the bonding area ratio is less than 5%, the aluminum fibers 31a are weakly joined to the aluminum pipe 20 and dropped off from the joined part, so that the heat transference is deteriorated and there is a risk that the porous body 30 is dropped off from the inner-wall surface of the aluminum pipe 20.

[0030] Since the porous body 30 does not perform effective heat transfer if the aluminum base substances 31 are unevenly distributed near the inner-wall surface of the aluminum pipe 20, it is preferable that the aluminum base substances 31 are arranged to be dispersed throughout the cross-sectional area of the aluminum pipe 20.

[0031] Specifically, as shown in FIG. 2, a difference between an average area ratio of the aluminum fibers 31a in a region F of a center part corresponding a half of an area of the cross section of the aluminum pipe 20 and an average area ratio of the aluminum fibers 31a in a region G of the entire cross section is 5% or less. If the difference of the average area ratios exceeds 5%, in the porous body 30, the aluminum base substances 31 may be unevenly distributed on the inner-wall surface of the aluminum pipe 20.

[0032] There are portions where the aluminum base substances 31 and the inner-wall surface of the aluminum pipe 20 are joined via the columnar projections 32. In the joined portions, the above-described eutectic element compounds 17 are present, containing Ti-Al type compounds 16 and eutectic elements that eutectic-react with Al.

[0033] Next, a producing method of the heat-exchange pipe 10 of the present embodiment will be explained. FIG. 3 shows the flowchart.

[0034] As the aluminum base substances 31, as described above, the aluminum fibers 31a and the aluminum powder particles 31b are used.

[0035] Here, the aluminum fibers 31a of the aluminum base substances 31 are made by a melt-spinning method. That is, a material made of aluminum or aluminum alloy is heated and melted, and extruded from a nozzle into the air or water at a constant rate to cool and solidify it; and it is cut at a prescribed length.

[0036] A fiber diameter R of the aluminum fibers 31a is in a range of 20 μm or more and 1000 μm or less; preferably, in a range of 50 μm or more and 500 μm or less. A fiber length L of the aluminum fibers 31a is in a range of 0.2 mm or more and 100 mm or less; preferably, in a range of 1 mm or more and 50 mm or less.

[0037] The aluminum fibers 31a can be in a range of 4 or more and 2500 or less of a rate L/R between the length L and the fiber diameter R, for example.

[0038] If the fiber diameter R of the aluminum fibers 31a is less than 20 μm, the joined area between the aluminum fibers to each other is small, and a sintering strength may be insufficient. On the other, if the fiber diameter R of the aluminum fibers 31a exceeds 1000 μm, the number of contact points where the aluminum fibers are in contact with each other lacks and the sintering strength may also lack.

[0039] If the ratio L/R between the length L and the fiber diameter R of the aluminum fibers 31a is less than four, when the aluminum fibers 31a are piled and arranged in the producing method of the porous aluminum sintered body, it is difficult to make a bulk density DP of the porous body 30 to be 50% or less of a true density DT of the aluminum fibers, and it may be difficult to obtain the porous body 30 having the high porosity. On the other, if the ratio L/R between the length L and the diameter R of the aluminum fibers 31a exceeds 2500, the aluminum fibers cannot be dispersed evenly, and there may be a risk that the porous body 30 having the even porosity is not easily obtained.

[0040] In order to further increase the porosity, the ratio L/R between the length L and the fiber diameter R of the aluminum fibers 31a is preferably 10 or more. In order to obtain the porous body 30 having a more uniform porosity, the ratio L/R between the length L and the diameter R of the aluminum fibers 31a is preferably 500 or less.

[0041] Atomized powder can be used as the aluminum powder particles 31b. A particle diameter of the aluminum powder particles 31b is in a range of 5 μm or more and 500 μm or less, preferably in a range of 20 μm or more and 200 μm or less.

[0042] By adjusting a mixing ratio of the aluminum fibers 31a and the aluminum powder particles 31b, the porosity can be adjusted. That is, by increasing the ratio of the ratio of the aluminum fibers 31a, the porosity of the porous body 30 can be increased. For example, it is preferable that the ratio of the aluminum powder particles 31b be 15% by mass or less and the ratio of the aluminum fibers 31a be 85% by mass or more in the aluminum base substances 31.

[0043] As the aluminum fibers 31a and the aluminum powder particles 31b, other than pure aluminum, aluminum alloy may be used. For example, aluminum base substances made of A3003 alloy (Al-0.6% by mass of Si-0.7% by mass of Fe-0.1% by mass of Cu-1.5% by mass of Mn-0.1 % by mass of Zn alloy), A5052 alloy (Al-0.25% by mass of Si-0.40% by mass of Fe- 0.10% by mass of Cu- 0.10% by mass of Mn-2.5% by mass of Mg alloy-0.2% by mass Cr-0.1% by mass of Zn alloy) that are regulated by JIS or the like can be suitably used.

[0044] It is not necessary that the aluminum fibers 31a and the aluminum powder particles 31b have the same composition. For example, the aluminum fibers 31a made of pure aluminum and the aluminum powder particles 31b made of JIS A3003alloy can be appropriately adjusted in accordance with the purpose.

[0045] Titanium powder particles 42 and eutectic element powder particles 43 are fixed to the aluminum base substances 31 composed of the aluminum fibers 31a and the aluminum powder particles 31b configured as described above to make an aluminum material 40 for sintering.

[0046] The aluminum material 40 for sintering includes, as shown in FIG. 5, the aluminum base substances 31 (in FIG. 5 FIG. 6, the aluminum fiber 31a is shown in the left and the aluminum powder particle 31b is shown in the right) and the plurality of titanium powder particles 42 and the eutectic-element powder particles (nickel powder particles, magnesium powder particles, copper powder particles, and silicon powder particles) 43 fixed on the outer surface of the aluminum base substances 31.

[0047] As the titanium powder particles 42, either one of or both metal-titanium powder particles and titanium hydride powder particles can be used. As the eutectic-element powder particles 43, metal-nickel powder particles, metal-magnesium powder particles, metal-copper powder particles, metal-silicon powder particles, and alloy powder of these are used.

[0048] In the aluminum material 40 for sintering, a content of the titanium powder particles 42 is in a range of 0.01% by mass or more and 20% by mass or less.

[0049] A particle diameter of the titanium powder particles 42 is in a range of 1 μm or more and 50 μm or less, preferably in a range of 5 μm or more and 30 μm or less. Since the particle diameter of the titanium hydride powder particles can be made smaller than the metal titanium powder particles, it is preferable to use the titanium hydride powder particles in a case of making the particle diameter of the titanium powder particles 42 fixed on the outer surface of the aluminum base substrates 31 minute.

[0050] Gaps between the titanium powder particles 42 and 42 fixed on the outer surface of the aluminum base substances 31 are preferably in a range of 5 μm or more and 100 μm or less.

[0051] Contents of components of the eutectic-element powder particles 43 in the aluminum material 40 for sintering are as followings: the nickel powder particles are in a range of 0.01% by mass or more and 5.0% by mass or less, the magnesium powder particles are in a range of 0.01% by mass or more and 5.0% by mass or less, the copper powder particles are in a range of 0.01% by mass or more and 5.0% or less, and the silicon powder particles are in a range of 0.01% by mass or more and 15.0% by mass or less.

[0052] The nickel powder particles are in a range of 1 μm or more and 20 μm or less, preferably in a range of 2 μm or more and 10 μm or less. The magnesium powder particles are in a range of 20 μm or more and 500 μm or less, preferably in a range of 20 μm or more and 100 μm or less. The copper powder particles are in a range of 5 μm or more and 500 μm or less, preferably in a range of 20 μm or more and 100 μm or less. The silicon powder particles are in a range of 5 μm or more and 200 μm or less, preferably in a range of 10 μm or more and 100 μm or less.

[0053] As shown in FIG. 3, steps are carried out in order. First, in the normal temperature, the aluminum base substances 31 composed of the aluminum fibers 31a and the aluminum powder particles 31b, the titanium powder particles 42, and the eutectic-element powder particles (e.g., the nickel powder particles, the magnesium powder particles, the copper powder particles, and the silicon powder particles) 43 are mixed (a mixing step).

[0054] At this time, a binder solution is sprayed. As a binder, it is preferable to be burned and resolved when it is heated to 500°C in the air: in particular, it is preferable to use an acrylic resin and a cellulose polymer. As a solvent of the binder, various solvents such as an aqueous solvent, an alcohols solvent, or an organic solvent can be used.

[0055] In this mixing step, for example, using various blenders such as an automatic mortar, a pan-type oscillating granulator, a shaker mixer, a pot mill, a high-speed mixer, a V-type mixer or the like, the aluminum base substances 31, the titanium powder particles 42, and the eutectic-element powder particles 43 are mixed while fluidizing.

[0056] Next, a mixture which is obtained in the mixing step is dried (a drying step). By the mixing step and the drying step, on the aluminum base substances 31 shown in the upper part of FIG. 5 that is composed of the aluminum fibers 31a and the aluminum powder particles 31b, the titanium powder particles 42 and the eutectic-element powder particles 43 are dispersed and fixed as shown in the lower part, to produce the aluminum material 40 for sintering which is the present embodiment.

[0057] Next, the aluminum material 40 for sintering is sprayed into a cylindrical carbon container 50 shown in FIG. 8 and filled without adding pressure (a material-spraying step). The carbon container 50 includes, for example, a cylindrical body 51 and a bottom lid 52 that can open and close a bottom part of the cylindrical body 51. The cylindrical body 51 is formed to have an inner diameter larger than an inner diameter of the aluminum pipe 20.

[0058] By spraying the aluminum material 40 for sintering on the bottom lid 52, the aluminum fibers 30a of the aluminum base substances 31 are arranged so that most of the aluminum fibers 30a lie on the bottom lid 52, in other words, substantially in parallel with a surface of the bottom lid 52, and is sequentially piled from below.

[0059] In a state in which the aluminum material 40 for sintering is filled up to a predetermined height in the carbon container 50, they are charged into a degreasing furnace and heated in the atmosphere to remove the binder (a binder removal step).

[0060] The process from the mixing step to the binder removal step explained above is a precursor formation step.

[0061] Then, the aluminum material 40 for sintering is taken out from the carbon container 50 and filled in the aluminum pipe 20 (an in-pipe charging step). The aluminum material 40 for sintering becomes a state of mutually fixed in the carbon container 50 in the binder removal step; by being taken out from the carbon container 50, it becomes a precursor 41 having a disc shape or a columnar shape in accordance with the filled height. The precursor 41 has an outer diameter larger than the inner diameter of the aluminum pipe 20. The outer diameter is preferably larger than the inner diameter of the aluminum pipe 20 at 1 mm or more and 10 mm or less, for example.

[0062] Since the precursor 41 has the larger outer diameter than the inner diameter of the aluminum pipe 20, as shown in FIG. 9, using a push-in rod 53, when the precursor 41 is loaded into the aluminum pipe 20 so as to pushing the precursor 41 from one end of the aluminum pipe 20, as shown in a double-dotted chain lines in FIG. 9, an outer peripheral part of the precursor 41 is bended at substantially orthogonal on the inner-wall surface of the aluminum pipe 20, and the outer peripheral part that is bended is in close contact with the inner-wall surface of the aluminum pipe 20.

[0063] On the contact portions to the inner-wall surface of the aluminum pipe 20, the aluminum fibers 31a of the precursor 41 is in contact substantially along an axial direction of the aluminum pipe 20. Inside the aluminum pipe 20, the aluminum fibers 31a leave from the inner-wall surface of the aluminum pipe 20 and extend along substantially a cross sectional direction of the aluminum pipe 20.

[0064] Although a thickness of the precursor 41 may be a lump of a size corresponding to a loading region E of the porous body 30 provided in the aluminum pipe 20 in the heat-exchange pipe 10 as a product, a plurality of precursors 41 having a thickness smaller than a thickness of a final product may be prepared for one product, or a plurality of the precursors 41 may be pushed into the aluminum pipe 20 one by one, or a plurality of the precursors 41 may be pushed into the aluminum pipe 20 to be loaded.

[0065] Thereafter, the aluminum pipe 20 loaded with the precursor 41 is charged in a sintering furnace in at an inert gas atmosphere, and held in a temperature range of 575 to 665°C for 0.5 to 60 minutes in accordance with the kind and addition amount of the added eutectic-element powder particles 43 (sintering step). The retention time is preferably 1 to 20 minutes.

[0066] In the sintering step, although the aluminum base substances 31 in the aluminum material 40 for sintering formed into the precursor 41 is melted, since oxide films are formed on the surface of the aluminum base substances, the melted aluminum is held by the oxide films and the shape of the aluminum base substances 31 is maintained.

[0067] In portions of the outer surface of the aluminum base substances 31 where the titanium powder particles 42 are fixed, the oxide films are broken by the reaction with titanium, and the melted aluminum inside is ejected outward. The ejected melted aluminum generates a compound having a high melting point and is solidified by the reaction with titanium.

[0068] As a result, as shown in the lower stage of FIG. 6, a plurality of columnar projections 32 are formed on the outer surface of the aluminum base substances 31. In the columnar projection 32, a Ti-Al type compound 16 is present; and growth of the columnar projections 32 more than necessary is suppressed by the Ti-Al type compound 16.

[0069] In a case of using titanium hydride as the titanium powder particles 42, the titanium hydride is decomposed at about 300 to 400°C, and the generated titanium reacts with the oxide film on the surface of the aluminum base substances 31.

[0070] In the present embodiment, by the eutectic-element powder particles 43 fixed on the outer surface of the aluminum base substances 31, portions where the melting point falls down are locally formed on the aluminum base substances 31. Accordingly, in accordance with the types and the addition amount of the added eutectic-element powder particles 43, even under a condition of comparative low temperature such as 575 to 655°C, the columnar projections 32 are reliably formed.

[0071] The adjacent aluminum base substances 31 and 31 are joined via the columnar projections 32 of each other by integrated in a melted state or solid-phase sintered, and the porous body 30 in which the plurality of the aluminum base substances 31 and 31 are joined via the columnar projections 32 is produced as shown in FIG. 4.

[0072] In the base substance joint parts 35 where the aluminum base substances 31 and 31 are joined via the columnar projections 32, as shown in FIG. 7, the Ti-Al type compound (Al_3Ti intermetallic compound) 16 and the eutectic-element compound 17 exist.

[0073] On the inner-wall surface of the aluminum pipe 20, the precursor 41 is bended and in contact at the outer peripheral part, some of the aluminum fibers 31a of the aluminum base substances 31 are in contact along the length direction, and the aluminum fibers 31a and the aluminum pipe 20 are joined by sintering in this state. Accordingly, the aluminum fibers 31a are joined in a state of being in linearly contact.

[0074] Some of the columnar projections 32 of the aluminum base substances 31 are also joined to the aluminum pipe 20. In a case in which the titanium powder particles 42 and the eutectic-element powder particles 43 are in contact with the surface of the aluminum pipe 20, the columnar projections 32 are formed also from the surface of the aluminum pipe 20, and the aluminum pipe 20 and the porous body 30 are joined.

[0075] In the heat-exchange pipe 10 having above-described structure, since the aluminum fibers 31a of the porous body 30 are bended on the inner-wall surface of the aluminum pipe 20 and some of them are joined to the inner-wall surface of the aluminum pipe 20 in a state of being in linearly contact, the heat exchange is rapidly carried out between the porous body 30 and the inner-wall surface.

[0076] In the inside of the aluminum pipe 20, since the aluminum fibers 31a extend toward a direction leaving from the inner-wall surface of the aluminum pipe 20, e.g., along the radial direction, the heat-exchange performance with the heat-transfer medium is also excellent.

[0077] Moreover, since the aluminum fibers 31a are joined on the inner-wall surface of the aluminum pipe 20 in the state of being in contact along the length direction, it is not easily peeled off from the aluminum pipe 20, and it is possible to maintain the heat-exchange performance stably for a long time.

[0078] Since the Ti-Al type compound 16 exists in the portion which is joined by the columnar projections 32, the oxide films on the surface of the aluminum pipe 20 and the porous body 30 are removed by this Ti-Al type compound 16, so that the joining strength between the aluminum pipe 20 or the porous bodies 30 themselves is improved.

[0079] Furthermore, since growth of the columnar projections 32 is restrained by the Ti-Al type compound 16, it can be restrained that the melted aluminum from ejecting to the porous body 30 to maintain the porosity of the porous body 30.

[0080] Particularly, in the present embodiment, since Al_3Ti exists as the Ti-Al type compound 16, the oxide film formed on the surface of the aluminum pipe 20 and the porous body 30 is reliably removed, and it is possible to drastically improve the joining strength between the aluminum pipe 20 and the porous body 30.

[0081] In the present embodiment, since the eutectic-element compound 17 exists in the columnar projections 32, the melting point of the aluminum base substances 31 is partially reduced so that the columnar projections 32 tend to be formed thick; as a result, the joining strength between the aluminum pipe 20 and the porous body 30 can be further improved.

[0082] In the present embodiment, since the content of the titanium powder particles 42 is 0.01% by mass or more and 20% by mass or less in the aluminum material 40 for sintering, the columnar projections 32 can be formed with appropriate intervals on the outer surface of the aluminum base substances 31, so it is possible to reliably join the aluminum pipe 20 and the porous body 30.

[0083] In the present embodiment, since the interval between the plurality of titanium powder particles 42 and 42 fixed on the outer surface of the aluminum base substances 31 is in a range of 5 μm or more and 100 μm, the interval between the columnar projections 32 is appropriate, and it is possible to obtain the porous body 30 having sufficient strength and high porosity.

[0084] In the present embodiment, since the content of the eutectic-element powder particles 43 are in a range of 0.01% by mass or more and 5.0 % by mass or less, the magnesium powder particle are in a range of 0.01% by mass or more and 5.0% by mass or less, the copper powder particles are in a range of 0.01% by mass or more and 5.0% by mass or less, and the silicon powder particles are in a range of 0.01% by mass or more and 15.0% by mass or less in the aluminum material 40 for sintering; accordingly, the portions where the melting point is partially reduced in the aluminum base substances 31 can be formed with the appropriate intervals and the unnecessary melted aluminum can be restrained from flowing out, so it is possible to obtain the porous body 30 having the sufficient strength and the high porosity.

[0085] In accordance with the kinds and the addition amount of the added eutectic-element powder particles, the columnar projections 32 is reliably formed even in the comparatively low temperature condition such as 575 to 665°C, so that the temperature condition for the sintering step can be set low.

[0086] In the present embodiment, since the aluminum fibers 31a and the aluminum powder particles 31b are used as the aluminum base substances 31, by adjusting the mixture ratio of them, the porosity of the porous body 30 can be controlled.

[0087] The porous body 30 of the present embodiment has the porosity in a range of 30% or more and 90% or less, so that a surface area of a porous aluminum composite body 10 used as a heat-transfer member can be maintained, and the heat-transfer efficiency can be drastically improved.

[0088] The present invention is not limited to the above-described embodiments and various modifications may be made without departing from the scope of the present invention.

[0089] For example, in the above embodiment, the pipe is made of aluminum and loaded with the porous aluminum sintered body having the aluminum fibers and aluminum powder; however, it is not limited to aluminum and various metals which can be sintered can be used. In the present invention, a metal porous body in which a plurality of metal fibers are joined is bonded to the metal pipe.

[0090] Although the metal porous body is configured from a mixed body of the metal fibers and the metal powder in the above-described embodiment, the metal porous body may be formed from only the metal fibers. In that case, the metal fibers are mutually joined by sintering and the metal-wire fibers and the inner-wall surface of the metal pipe are bonded.

[0091] The metal pipe is not limited to have the circular cross section, but the cross section may be polygon or the like.

Examples

[0092] An aluminum pipe that is made of JIS A3003 aluminum alloy; aluminum fibers and aluminum powder as aluminum base substances; titanium powder; and Mg powder as eutectic-element powder were prepared. An inner diameter of the aluminum pipe was 18 mm. Many kinds of the aluminum fibers were manufactured in a range of 300 μm of a diameter and 10 mm to 25 mm of a length.

[0093] Aluminum material for sintering was produced by mixing the aluminum base substances, the titanium powder and the eutectic-element powder, and a precursor of disk shape with a diameter 22 mm was produced. The precursor was pushed into the aluminum pipe, and then they were sintered at 600°C for 30 minutes, to produce a heat-exchange pipe in which the porous aluminum sintered body was joined on the aluminum pipe in a range of a predetermined length was produced.

[0094] An X-ray CT (computed tomography) image of the cross section of the obtained heat-exchange pipe was analyzed using an image processing software (ExFact VR 2.1 made by Nihon Visual Science, Inc.) as follows.

[0095] An average area ratio occupied by the porous aluminum sintered body in the whole cross section and an average area ratio occupied by the porous body in the center part region of the cross section were measured. Regarding the cross section, using an orthogonal cross-sectional function of the software, an average value of results of extracting 36 images at about 0.7 mm intervals and analyzing them was shown.

[0096] For a bonding area ratio of the porous aluminum sintered body on the inner-wall surface of the aluminum pipe, using a cylindrical panoramic function of the software, cylindrical panoramic images of portions where the porous aluminum sintered body and the aluminum pipe are joined were extracted, and a ratio of an area occupied by the portions where the porous aluminum sintered body was joined for the whole area was measured.

[0097] Furthermore, a columnar rod having an outer diameter 14 mm was inserted into the aluminum pipe, it was observed whether the porous aluminum sintered body was peeled from the aluminum pipe and dropped off by adding 10 N of force.

[0098] These results are shown in Table 1.

[Table 1]

No.	CROSS SECTION AVERAGE AREA RATIO (%)		WALL SURFACE BONDING AREA RATIO (%)	PEEL OFF OBSERVATION
	WHOLE	CENTER PART		
1	20.0	23.6	19.0	NO
2	20.2	15.4	12.4	NO
3	19.1	16.6	6.4	NO
4	20.5	25.4	2.0	SLIGHTLY PEELED
5	10.3	11.2	9.3	NO
6	9.8	13.5	6.1	NO
7	8.9	13.2	1.2	SLIGHTLY PEELED
8	27.6	22.9	32.1	NO
9	29.7	28.5	24.5	NO
10	28.5	29.9	11.1	NO
11	27.9	29.7	4.5	SLIGHTLY PEELED

[0099] Although there were some slight peelings in the drop-off test of the porous aluminum body, this is a severe test which is impossible in a normal flowing of a fluid, and it is considered not to be a practical problem. Moreover, if it is firmly bonded on the aluminum pipe like this, the heat-exchange property is also considered to be excellent.

[0100] CT images of No. 1 show a transverse cross-sectional view in FIG. 10, a vertical cross-sectional view in FIG. 11, and the inner-wall surface of the aluminum pipe in FIG. 12. In these drawings, the porous aluminum sintered body is white portions excepting an outermost peripheral portion in FIG. 10 and upper and lower thick linear portions in FIG. 11. In FIG. 10, more portions in which the porous aluminum sintered body is long (the aluminum fibers) exist than in FIG. 11. In FIG. 11, a lot of spots of the transvers cross section of the aluminum fibers appears in spots. Moreover, as seen from FIG. 12, also on the inner-wall surface of the aluminum pipe, the long portions of the porous aluminum body (the aluminum fibers) are bonded.

Industrial Applicability

[0101] A heat-exchange pipe in which the heat-exchange property is excellent and a metal porous body is not easily dropped off from the metal pipe can be provided.

Reference Signs List

[0102]

10	Heat-exchange pipe
20	Aluminum pipe (Metal pipe)
30	Porous aluminum sintered body (Metal porous body)
31	Aluminum base substance
31a	Aluminum fiber
31b	Aluminum powder
40	Aluminum material for sintering
41	Precursor
50	Carbon container
53	Push-in rod

Claims

1. A heat-exchange pipe comprising

   a metal pipe and
   a metal porous body which is configured by joining a plurality of metal fibers and bonded to an inner-wall surface of the metal pipe, wherein
   at least some of the metal fibers are partially bonded to the inner-wall surface of the metal pipe for a length direction, and the metal fibers which are bonded to the inner-wall surface bend on the inner-wall surface of the metal pipe and extend from the inner-wall surface to leave.

2. The heat-exchange pipe according to claim 1, wherein a bonding area ratio of the metal fibers to the inner-wall surface of the metal pipe is 5% or more.

3. The heat-exchange pipe according to claim 1, wherein in a transverse cross section across an axis of the metal pipe, a difference between an average area ratio of the metal fibers in a center part corresponding a half of an area of the metal porous body and an average area ratio of the metal fibers in a whole of the transverse cross section is 5% or less.

4. A producing method of a heat-exchange pipe, comprising

   a precursor formation step of stacking a plurality of metal fibers to form a precursor,
   an in-pipe charging step of pushing the precursor from one end of a metal pipe to charge into the metal pipe, and
   a sintering step of sintering the metal pipe in a state of charging the precursor,

   wherein
   the precursor before the in-pipe charging step is formed such that an outer diameter in a state where the metal fibers are stacked is larger than an inner diameter of the metal pipe.

5. The heat-exchange pipe according to claim 2, wherein in a transverse cross section across an axis of the metal pipe, a difference between an average area ratio of the metal fibers in a center part corresponding a half of an area of the metal porous body and an average area ratio of the metal fibers in a whole of the transverse cross section is 5% or less.

6. The heat-exchange pipe according to claim 1 wherein the metal porous body further includes metal powder particles bonded to the metal fibers.

7. A heat-exchange pipe comprising

   a metal pipe, and
   a porous body which is configured by sintering a plurality of metal base substances and bonded to an inner-wall surface of the metal pipe, wherein
   the metal base substances includes metal fibers, and the metal fibers bonded to the inner-wall surface partially leave from the inner-wall surface.

8. The heat-exchange pipe according to claim 7 wherein the metal base substances further include metal powder particles.

9. The heat-exchange pipe according to claim 8 wherein a ratio of the metal powder particles in the metal base substances is 15% by mass or less.

10. The heat-exchange pipe according to claim 8 wherein a particle diameter of the metal powder particles is 5 μm or more and 500 μm or less.

11. The heat-exchange pipe according to claim 7 wherein the metal base substances are made of aluminum or aluminum alloy, and are joined by a base substance joint part contains a eutectic-element compound including eutectic element that eutectic-reactions with Ti-Al type compounds and Al.

12. The heat-exchange pipe according to claim 7, wherein a ratio L/R between a length L and a fiber diameter R of the metal fibers I 10 or more and 500 or less.

FIG. 1

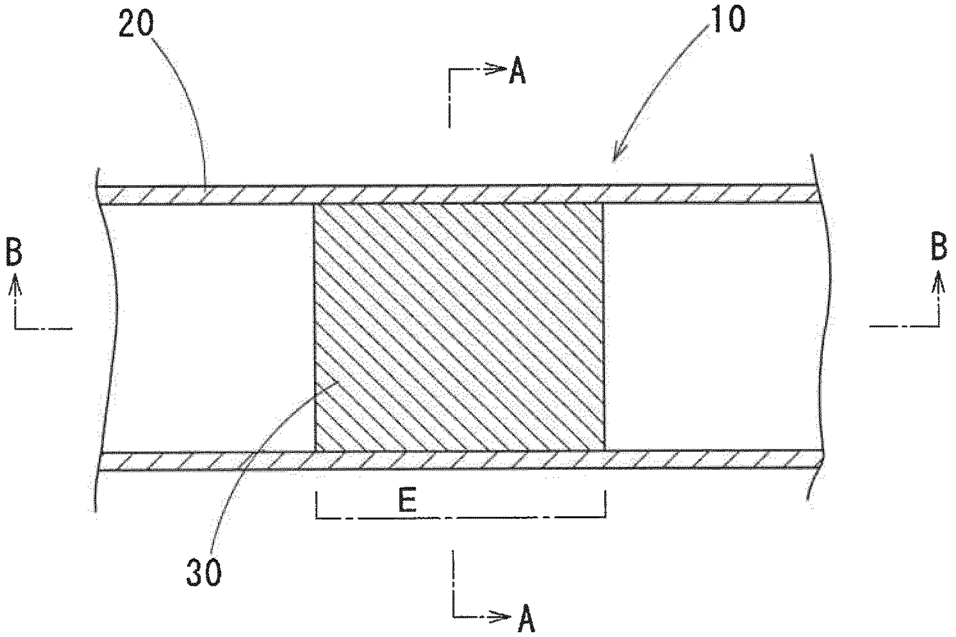


FIG. 2

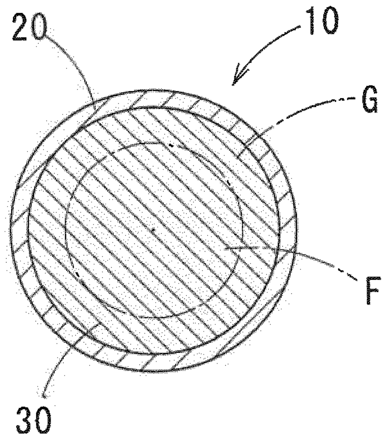


FIG. 3

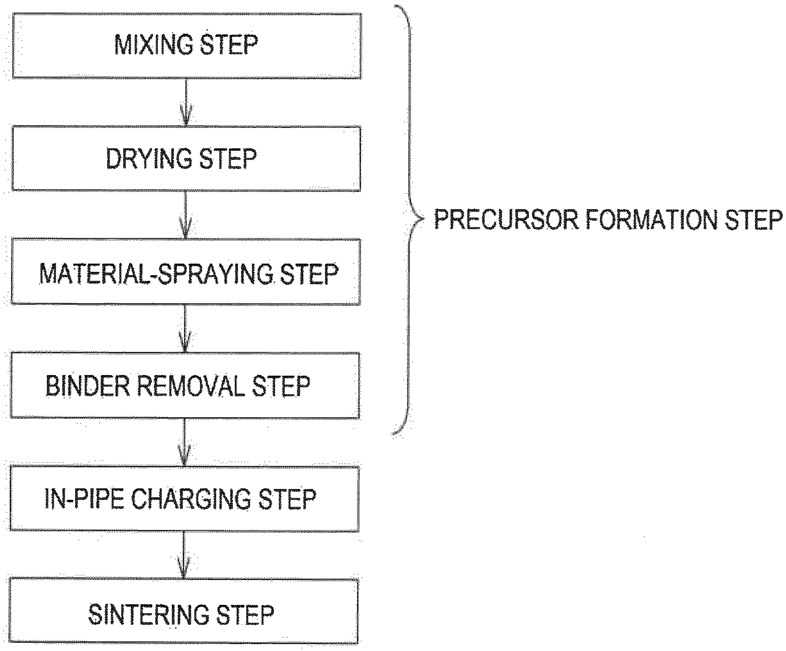
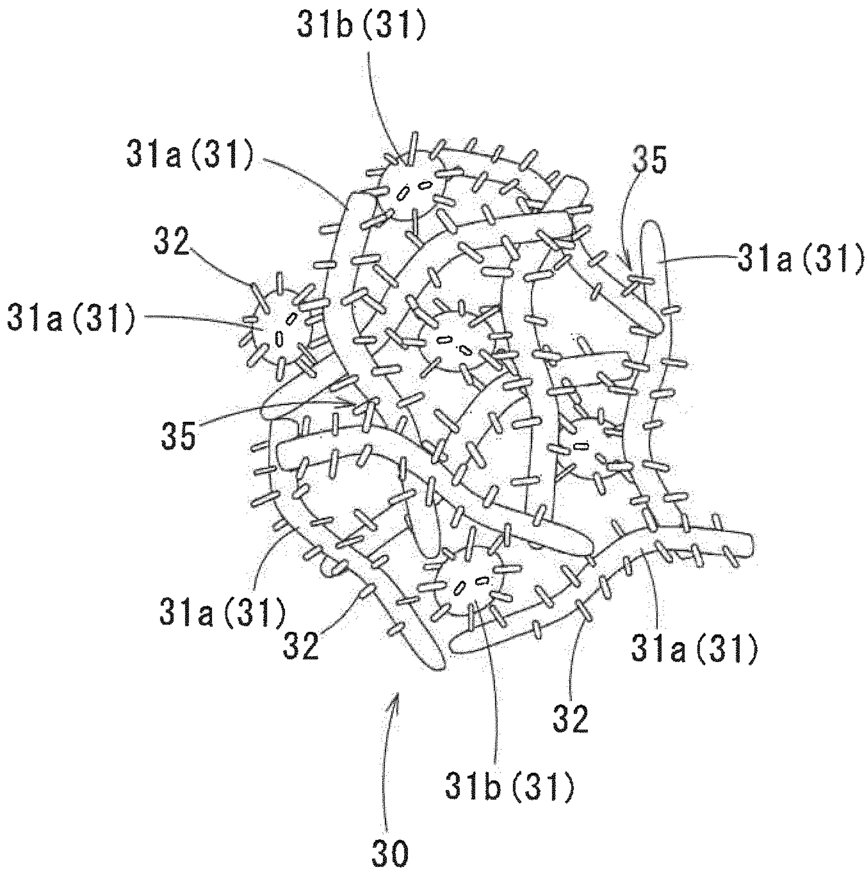

MIXING STEP
DRYING STEP
MATERIAL-SPRAYING STEP
BINDER REMOVAL STEP
PRECURSOR FORMATION STEP
IN-PIPE CHARGING STEP
SINTERING STEP

FIG. 4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31b (31)
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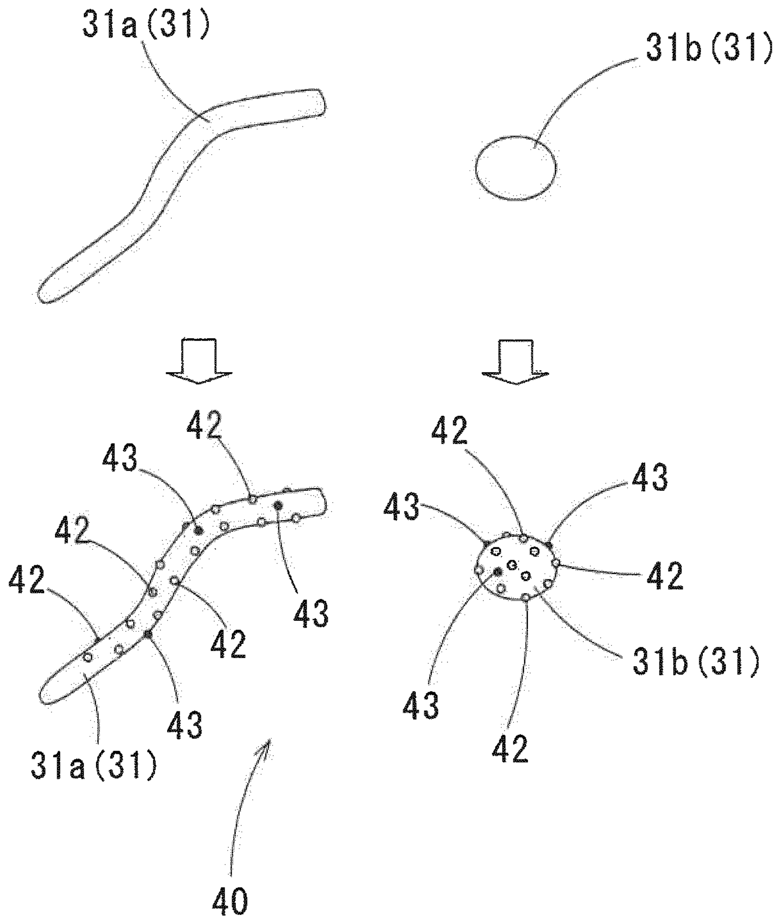
FIG. 5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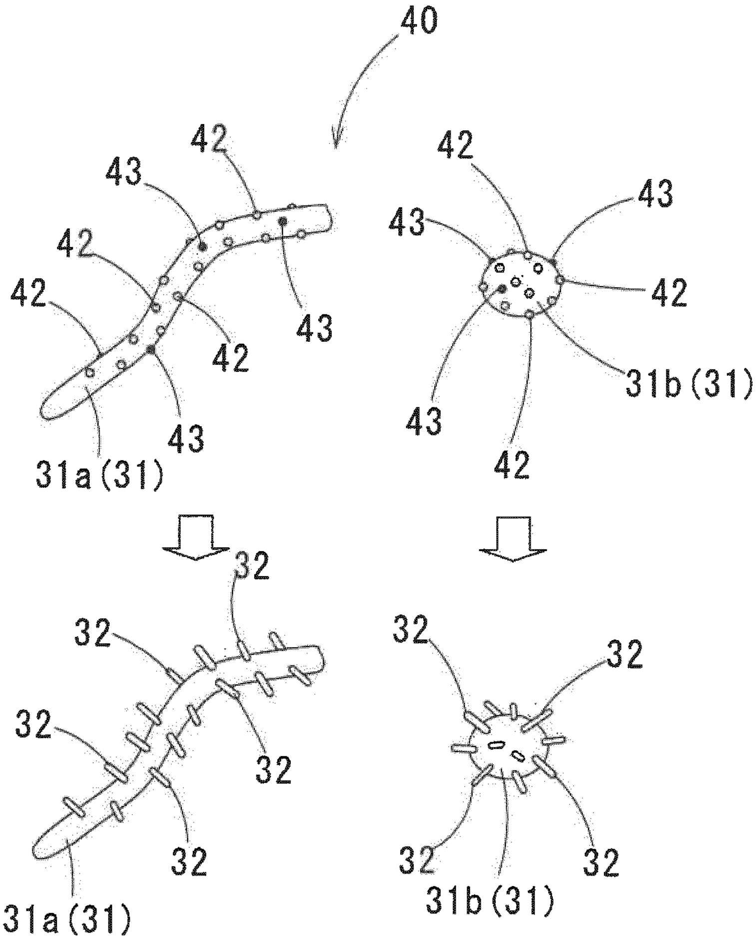
31b(31)

FIG. 6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31a (31)
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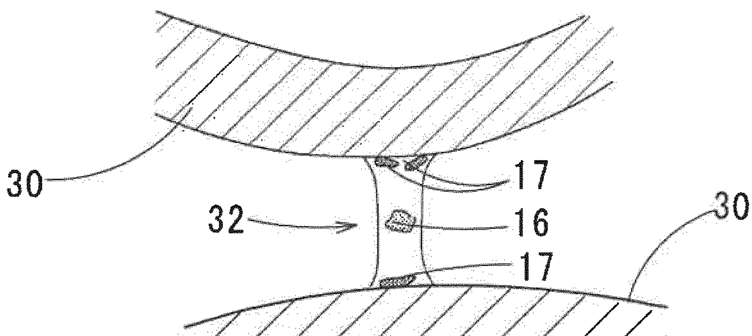
31b (31)

FIG. 7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32
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17
30

FIG. 8

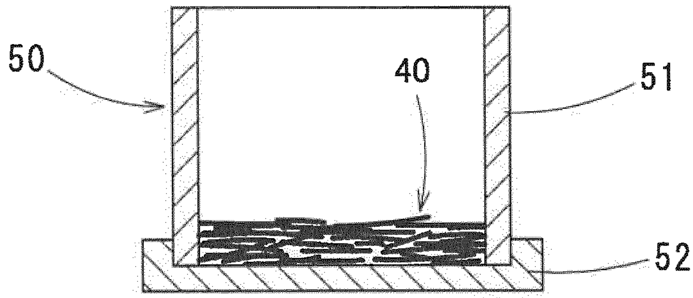


FIG. 9

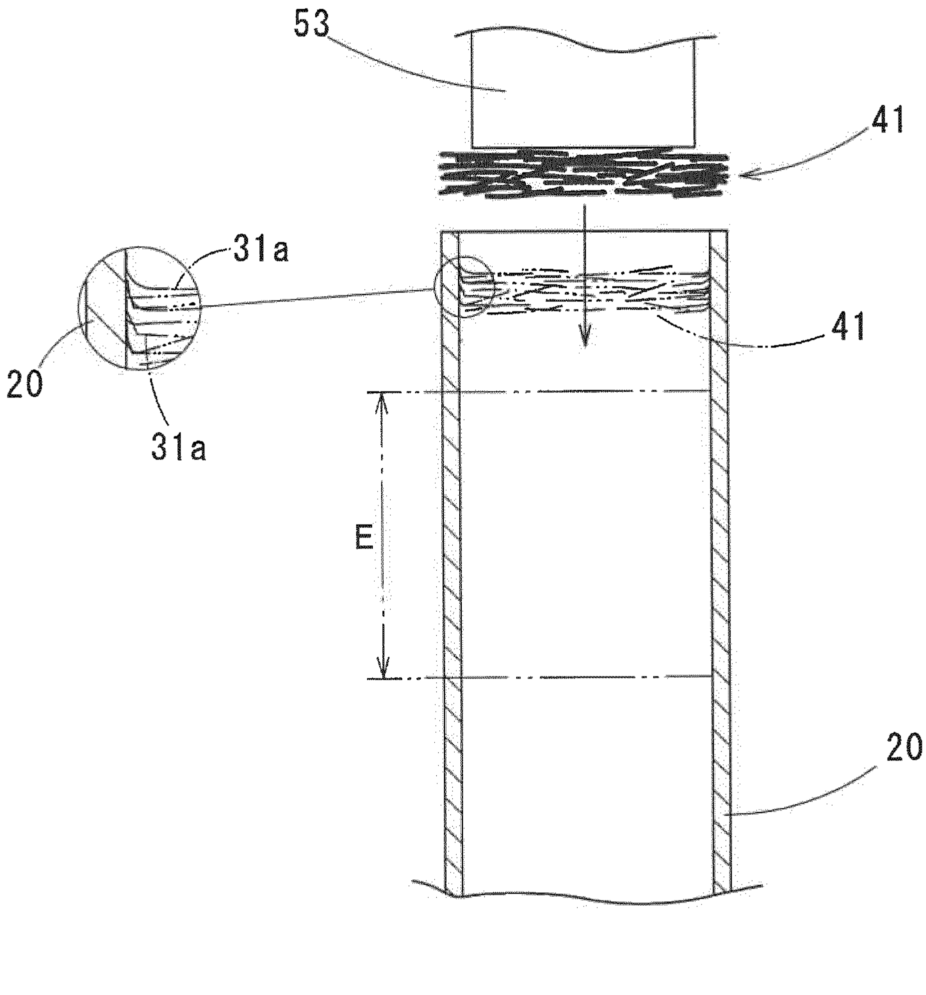


FIG. 10

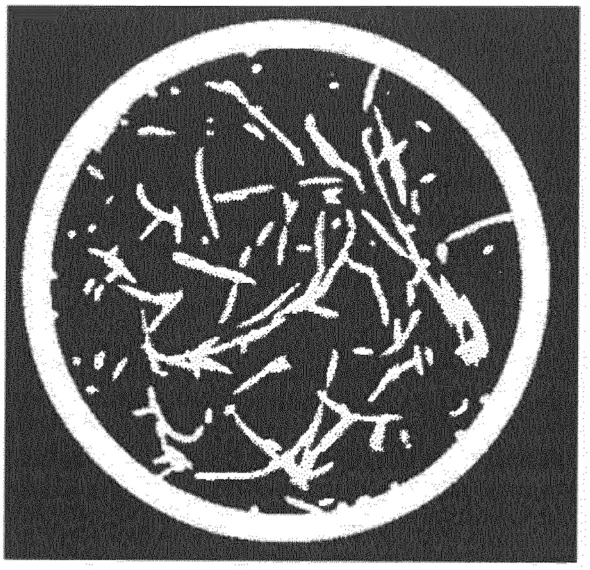


FIG. 11

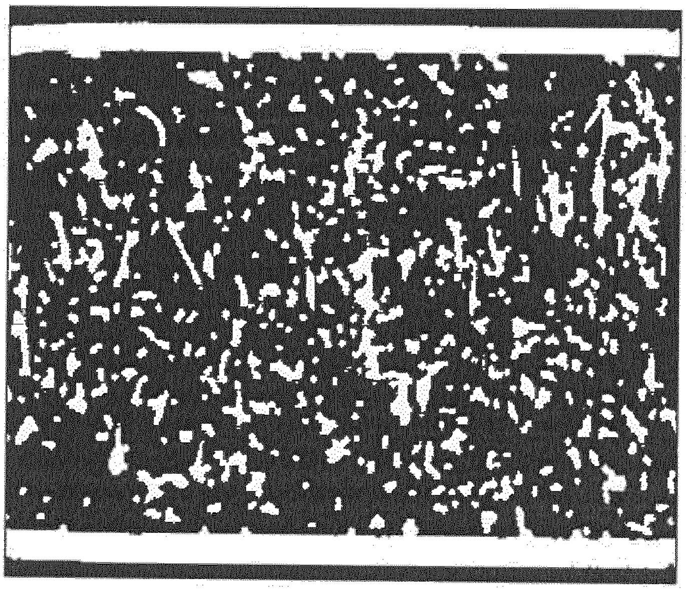
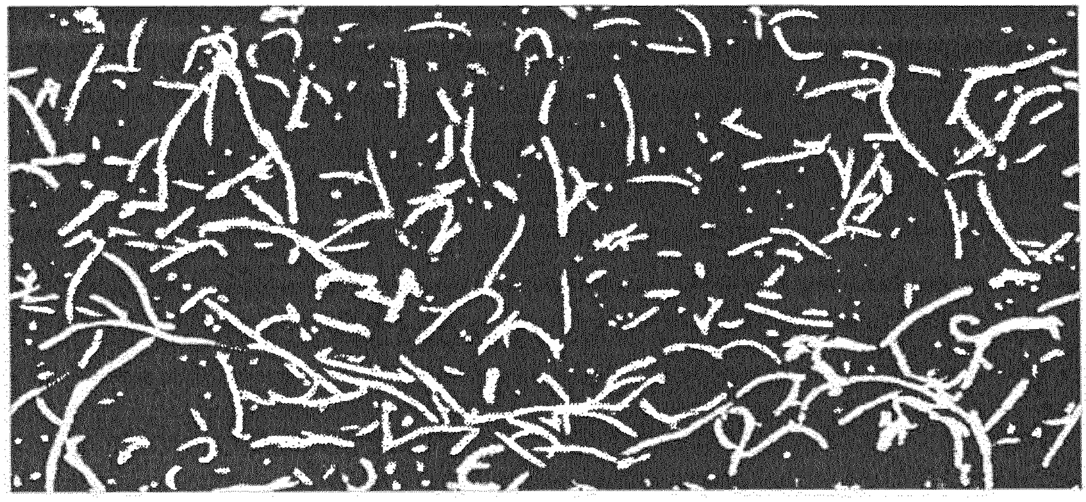


FIG. 12



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2021/006554

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. B22F1/00(2006.01)i, B22F7/08(2006.01)i, C22C21/00(2006.01)i, C22C1/08(2006.01)i, B22F3/11(2006.01)i
FI: B22F3/11C, B22F1/00N, C22C1/08F, B22F3/11A, B22F7/08Z, C22C21/00J
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)
Int.Cl. B22F1/00, B22F3/11, B22F7/08, C22C21/00, C22C1/08

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

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2021
Registered utility model specifications of Japan	1996-2021
Published registered utility model applications of Japan	1994-2021

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 2011-7365 A (TAISEI KOGYO KK) 13 January 2011 (2011-01-13), paragraphs [0002]-[0075], fig. 1-5	1-5, 7 6, 8-12
Y	WO 2016/002870 A1 (MITSUBISHI MATERIALS CORPORATION) 07 January 2016 (2016-01-07), paragraphs [0009], [0026]-[0069]	6, 8-12
A	JP 2003-126228 A (KOGI CORP.) 07 May 2003 (2003-05-07), paragraphs [0005]-[0009]	1-12

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

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"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
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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
22 March 2021	30 March 2021

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

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

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2021/006554

JP 2011-7365 A	13 January 2011	(Family: none)
WO 2016/002870 A1	07 January 2016	EP 3165864 A1 paragraphs [0013], [0043]-[0097] JP 2016-14508 A US 2017/0153072 A1 CN 106662409 A
JP 2003-126228 A	07 May 2003	(Family: none)

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

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2020041798 A **[0001]**
- JP 2016006226 A **[0004]**