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(54) **ALUMINUM FIBER STRUCTURE AND ALUMINUM COMPOSITE MATERIAL**

(57) An aluminum composite material (1, 2, 3, 4, 5) is a composite formed of an aluminum fiber structure (10) and a composite material (70, 80, 110). The aluminum fiber structure (10) includes aluminum fibers (20) partially bound to each other, and alumina layers 30 are formed on surfaces of the aluminum fibers (20). A plurality of alumina protrusions (40) each having a height larger than a thickness of the alumina layer (30) are formed on surfaces of the aluminum fibers (20) or the alumina layers (30). The alumina protrusions (40) and at least a part of the composite material (70, 80, 110) are in contact with each other.

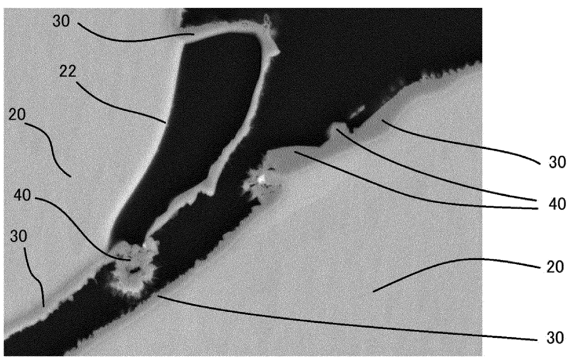

FIG. 8

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Description

TECHNICAL FIELD

[0001] The present invention relates to an aluminum fiber structure and an aluminum composite material.

BACKGROUND ART

[0002] To date, a metal fiber structure formed from metal fibers has been used as a medium for transmitting heat in a heat exchanger in some cases. Japanese Laid-Open Patent Publication No. 2011-007365 (JP2011-007365A) discloses an example in which an aluminum fiber structure formed from aluminum fibers is used as a metal fiber structure.

[0003] The aluminum fiber structure disclosed in Japanese Laid-Open Patent Publication No. 2011-007365 is produced in a method in which a mold having a predetermined shape is filled with aluminum fibers having an average fiber thickness of 50 to 200 μm and an average fiber length of 20 to 1000 mm, the aluminum fibers filling the mold are compressed to form a compressed molded body having a bulk density of 30% or more, the compressed molded body is heated at 600 to 650°C in an inert gas atmosphere, entangled aluminum fibers are thus spread and joined to each other to form a porous sintered molded body, and the surfaces of the aluminum fibers are thereafter made hydrophilic.

SUMMARY OF THE INVENTION

[0004] The aluminum fiber structure disclosed in Japanese Laid-Open Patent Publication No. 2011-007365 has a high coefficient of linear thermal expansion. Therefore, for example, in a case where the aluminum fiber structure and glass or ceramic form a composite, a difference between the coefficient of linear thermal expansion of the aluminum fiber structure and that of glass or ceramic may cause separation due to the relatively low coefficient of linear thermal expansion of the glass or ceramic when a temperature in a surrounding environment has greatly changed.

[0005] The present invention has been made in view of such circumstances, and an object of the present invention is to provide an aluminum fiber structure having a low coefficient of linear thermal expansion, and an aluminum composite material in which the aluminum fiber structure and a composite material are unlikely to separate from each other even in a case where a temperature in a surrounding environment has greatly changed.

SOLUTION TO THE PROBLEMS

[0006] An aluminum fiber structure of the present invention includes

aluminum fibers partially bound to each other, in which
alumina layers are formed on surfaces of the aluminum fibers, and
a plurality of alumina protrusions each having a height larger than a thickness of each alumina layer are formed on surfaces of the aluminum fibers or the alumina layers.

[0007] An aluminum composite material of the present invention includes

the above-described aluminum fiber structure and a composite material which form a composite, in which
the alumina protrusions and at least a part of the composite material are in contact with each other.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008]

FIG. 1 is a schematic configuration diagram schematically illustrating a first example of a configuration of an aluminum composite material according to an embodiment of the present invention.
FIG. 2 is a schematic configuration diagram schematically illustrating a second example of a configuration of an aluminum composite material according to an embodiment of the present invention.
FIG. 3 is a schematic configuration diagram schematically illustrating a third example of a configuration of an aluminum composite material according to an embodiment of the present invention.
FIG. 4 is a schematic configuration diagram schematically illustrating a fourth example of a configuration of an aluminum composite material according to an embodiment of the present invention.
FIG. 5 is a schematic configuration diagram schematically illustrating a fifth example of a configuration of an aluminum composite material according to an embodiment of the present invention.

FIG. 6 shows a photograph representing a photographed surface of an aluminum fiber structure of an aluminum composite material according to an embodiment of the present invention.

FIG. 7 shows a photograph representing a cut surface obtained by cutting the aluminum fiber structure shown in FIG. 6.

FIG. 8 shows a photograph representing a part of a cross section of the aluminum fiber structure shown in FIG. 7 in an enlarged manner.

FIG. 9 schematically illustrates a method for producing an aluminum fiber structure of an aluminum composite material according to an embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0009] Embodiments of the present invention will be described below with reference to the drawings. FIG. 1 to FIG. 5 are schematic configuration diagrams schematically illustrating various examples of a configuration of an aluminum composite material according to an embodiment of the present invention. FIG. 6 shows a photograph representing a photographed surface of an aluminum fiber structure of an aluminum composite material according to the present embodiment. FIG. 7 shows a photograph representing a cut surface obtained by cutting the aluminum fiber structure shown in FIG. 6. FIG. 8 shows a photograph representing a part of a cross section of the aluminum fiber structure shown in FIG. 7 in an enlarged manner. FIG. 9 schematically illustrates a method for producing an aluminum fiber structure of an aluminum composite material according to the present embodiment.

[0010] Aluminum composite materials 1, 2, 3, 4, 5 according to the present embodiment are each a composite formed of an aluminum fiber structure 10 and a composite material formed of a material different from aluminum. Various examples of the aluminum composite materials 1, 2, 3, 4, 5 having such configurations will be described with reference to FIG. 1 to FIG. 5.

[0011] As shown in FIG. 1, in the aluminum composite material 1 as a first example, a resin 70 is fully impregnated into the aluminum fiber structure 10. A material of the resin 70 is not particularly limited, and examples thereof include epoxy, polyolefin, styrene-based polymers, polyether, polyurea, acrylic polymers, polyurethane, polyester, polyamide, polysiloxane, polysaccharide, polypeptide, polynucleotide, polyvinyl alcohol, polyacrylamide, and mixtures thereof. Specifically, the resin 70 is fully impregnated into two aluminum fiber structures 10, and the aluminum fiber structures 10 are thus disposed at portions near the front side and the back side, respectively, of the resin 70. The aluminum fiber structures 10 do not protrude outward from the front surface and the back surface of the resin 70.

[0012] As shown in FIG. 2, in the aluminum composite material 2 as a second example, the resin 70 is partially impregnated into the aluminum fiber structure 10. Specifically, the resin 70 is partially impregnated into two aluminum fiber structures 10, and thus, the aluminum fiber structures 10 are disposed at portions near the front side and the back side, respectively, of the resin 70, and the aluminum fiber structures 10 protrude outward from the front surface and the back surface, respectively, of the resin 70.

[0013] As shown in FIG. 3, in the aluminum composite material 3 as a third example, two aluminum fiber structures 10 are adhered by an adhesive layer 80 formed of an adhesive such as a metal paste other than aluminum, e.g. silver paste, copper paste, or nickel paste, silver solder, copper brazing, tin, or solder.

[0014] As shown in FIG. 4, in the aluminum composite material 4 as a fourth example, a metal component 90 such as a copper plate is adhered to one surface of the aluminum fiber structure 10 by the adhesive layer 80 formed of an adhesive such as metal paste other than aluminum.

[0015] As shown in FIG. 5, in the aluminum composite material 5 as a fifth example, the metal component 90 is adhered to one surface of the aluminum fiber structure 10 by the adhesive layer 80 formed of an adhesive such as metal paste other than aluminum, and an alumina plate 100 is adhered to the other surface of the aluminum fiber structure 10 by an adhesive layer 110 formed of an adhesive such as glass (for example, water glass, frit glass, glass paste).

[0016] Next, a configuration of the aluminum fiber structure 10 will be described. As shown in FIG. 6 to FIG. 8, in the aluminum fiber structure 10 of the present embodiment, aluminum fibers 20 are partially bound to each other, and an alumina layer 30 is formed on the surface of the aluminum fiber 20. Furthermore, as shown in FIG. 8, a plurality of alumina protrusions 40 each having a height larger than the thickness of the alumina layer 30 are formed on the surfaces of the aluminum fibers 20 or the alumina layers 30. In FIG. 8, reference numeral 22 represents a portion of the surface of the aluminum fiber 20 in which neither the alumina layer 30 nor the protrusion 40 is formed.

[0017] In the aluminum fiber structure 10 having such a configuration, a portion of the aluminum fiber structure 10 in which the alumina layers 30 are formed is likely to expand or contract due to temperature change whereas a portion thereof in which the plurality of alumina protrusions 40 are formed is unlikely to expand or contract due to temperature change. Thus, in the entirety of the aluminum fiber structure 10, the coefficient of linear thermal expansion is partially non-uniform, so that the coefficient of linear thermal expansion can be reduced as a whole.

[0018] The aluminum fiber 20 has a length ranging from 0.2 to 15 mm and a diameter ranging from 0.01 to 0.100 mm. The length of the aluminum fiber 20 can be actually measured and confirmed by observing a photograph with use of an

SEM, an optical microscope, or the like.

[0019] The alumina layer 30 is formed by oxidizing the aluminum fiber 20 in an air atmosphere. In general, the alumina layer 30 is uniformly formed on the surface of the aluminum fiber 20. The thickness of the alumina layer 30 having such a configuration ranges from 10 nm to 10 μm, preferably ranges from 100 nm to 7 μm, and more preferably ranges from 1 μm to 5 μm.

[0020] The protrusions 40 are formed by an eluted substance from the aluminum fibers 20 by sintering the aluminum fibers 20 at 700°C or higher. A method for producing the aluminum fiber structure 10 by sintering the aluminum fibers 20 will be described below. In a case where a temperature at which the aluminum fibers 20 are sintered is lower than 700°C, a sufficient amount of alumina is not eluted from the aluminum fibers 20, and the protrusion 40 having a sufficient height cannot be obtained.

[0021] As described above, a height of the protrusion 40 at the surface of the aluminum fiber 20 or the alumina layer 30 is larger than the thickness of the alumina layer 30. Specifically, the height of the protrusion 40 at the surface of the aluminum fiber 20 or the alumina layer 30 ranges from 10 nm to 10 μm, preferably ranges from 100 nm to 7 μm, and more preferably ranges from 1 μm to 5 μm. Thus, strength for adhering the aluminum fiber 20 and the protrusion 40 becomes high. In a case where the height of the protrusion 40 at the surface of the aluminum fiber 20 or the alumina layer 30 is excessively small, specifically, in a case where the height of the protrusion 40 is less than 10 nm, a difference between the thickness of the alumina layer 30 and the height of the protrusion 40 does not become large, and a problem arises that the aluminum fiber structure 10 having a partially non-uniform coefficient of linear thermal expansion cannot be formed. In a case where the height of the protrusion 40 at the surface of the aluminum fiber 20 or the alumina layer 30 is excessively large, specifically, in a case where the height of the protrusion 40 is larger than 10 μm, a problem arises that a large gap may be formed between the aluminum fibers 20.

[0022] On the cross-section of the aluminum fiber structure 10 as shown in FIG. 7 and FIG. 8, a coverage at a portion covered by the protrusion 40 on the surface of the aluminum fiber 20 is preferably 20% or more and more preferably 40% or more in total. The surface of the aluminum fiber 20 is almost entirely covered by the alumina layer 30, and the protrusion 40 is formed on a part of the alumina layer 30. A coverage at a portion covered by the protrusion 40 on the surface of the aluminum fiber 20 can be calculated by dividing a length of the alumina layer 30 at a portion covered by the protrusion 40 (specifically, a portion from a peak rise starting point of the protrusion 40 to a descending end point thereof), by the entire length of the alumina layer 30, on the cross-section of the aluminum fiber structure 10. In a case where the coverage of the protrusions 40 at the surfaces of the aluminum fibers 20 is less than 20%, a proportion of the protrusions 40 in the aluminum fiber structure 10 is relatively small, and a problem arises that the coefficient of linear thermal expansion of the aluminum fiber structure 10 is not reduced.

[0023] At least a part of the plurality of the protrusions 40 are each in contact with the alumina layers 30 of a plurality of the aluminum fibers 20 in a straddling manner. In this case, the aluminum fibers 20 are connected with each other by the protrusion 40, so that the aluminum fibers 20 are unlikely to move relative to each other, and thus, the coefficient of linear thermal expansion of the aluminum fiber structure 10 can be further reduced. Furthermore, when the aluminum fiber structure 10 and a composite material (for example, the resin 70, the adhesive layer 80, the adhesive layer 110 as described above) form a composite, the composite material that has entered a gap of the aluminum fiber structure 10 comes into contact with the protrusion 40.

[0024] Furthermore, in the present embodiment, a space factor of the aluminum fibers 20 in the aluminum fiber structure 10 ranges from 20% to 90%. Such a space factor of the aluminum fibers 20 can be obtained by calculating a proportion of an area occupied by the aluminum fibers 20 to an area inside the outer edge of the aluminum fiber structure 10, on the cut surface obtained by cutting the aluminum fiber structure 10. In a case where the space factor of the aluminum fibers 20 in the aluminum fiber structure 10 ranges from 20% to 90%, the aluminum fiber structure 10 can have both a light weight and strength. That is, in a case where the space factor of the aluminum fibers 20 in the aluminum fiber structure 10 is less than 20%, sufficient strength cannot be obtained. Meanwhile, in a case where the space factor of the aluminum fibers 20 in the aluminum fiber structure 10 is more than 90%, a problem arises that the weight cannot be reduced. In a case where the space factor of the aluminum fibers 20 in the aluminum fiber structure 10 is 20% or more, an amount of the aluminum fibers 20 is sufficient and appropriate uniformity can thus be obtained. In a case where the space factor of the aluminum fibers 20 in the aluminum fiber structure 10 is 90% or less, flexibility can be obtained as desired in addition to appropriate uniformity being obtained.

[0025] Furthermore, in the aluminum fiber structure 10 of the present embodiment, a plasma-resistant layer may be formed on the surfaces of the alumina layer 30 and the protrusion 40. In the present embodiment, the plasma-resistant layer may include metal oxide or aluminum nitride. The metal oxide includes, for example, at least one of zirconium oxide, yttrium oxide, magnesium oxide, zinc oxide, sapphire, and quartz glass. In this case, a composite material formed of the aluminum fiber structure 10 and the plasma-resistant layer can be provided, and the composite material has excellent plasma resistance. Such a composite material formed of the aluminum fiber structure 10 and the plasma-resistant layer can be produced by applying glaze containing zirconia, yttria, or the like to the alumina layer 30 and the protrusion 40 of the aluminum fiber structure 10 and thereafter heating the obtained product at a high temperature.

[0026] As shown in FIG. 9(a), the aluminum fibers 20 are formed into a sheet-like shape in a molding container 50, and pressed. Thus, the aluminum fibers 20 can be brought into close contact with each other. Furthermore, as shown in FIG. 9(b), the aluminum fibers 20 are heated at 700°C or higher in sintering equipment 60 and thus sintered. Thus, the aluminum fiber structure 10 is formed. A method for heating the aluminum fibers 20 is, but is not limited to, a method for heating the surfaces of the aluminum fibers 20 by hot air or the like. As a method for heating the aluminum fibers 20, an electric heating method may be used. As described above, in a case where the aluminum fibers 20 are sintered at 700°C or higher, alumina is eluted from the aluminum fibers 20, and the eluted alumina is solidified at ordinary temperature to form the protrusions 40. The aluminum fiber structure 10 is placed in an air atmosphere, and thus, the aluminum fibers 20 are oxidized to form the alumina layers 30.

[0027] In summary, in the aluminum fiber structure 10 of the present embodiment, the aluminum fibers 20 are partially bound to each other, and the alumina layer 30 is formed on the surface of the aluminum fiber 20. The plurality of alumina protrusions 40 each having the height larger than the thickness of the alumina layer 30 are formed on the surfaces of the aluminum fibers 20 or the alumina layers 30. In the aluminum fiber structure 10 having such a configuration, a portion of the aluminum fiber structure 10 in which the alumina layers 30 are formed is likely to expand or contract due to temperature change whereas a portion thereof in which the plurality of alumina protrusions 40 are formed is unlikely to expand or contract due to temperature change. Thus, in the entirety of the aluminum fiber structure 10, the coefficient of linear thermal expansion is partially non-uniform, so that the coefficient of linear thermal expansion can be reduced as a whole.

[0028] In the aluminum composite materials 1, 2, 3, 4, 5 in which the aluminum fiber structure 10 having such a configuration, and a composite material formed of the composite material (for example, the resin 70, the adhesive layer 80, the adhesive layer 110) different from aluminum form a composite, the alumina protrusions 40 and at least a part of the composite material are in contact with each other. Even in a case where a temperature in a surrounding environment greatly changes, the aluminum fiber structure 10 and the composite material are unlikely to separate from each other. More specifically, the composite material that has entered a gap of the aluminum fiber structure 10 is caught by the protrusion 40 of the aluminum fiber structure 10. Therefore, even in a case where a composite material that does not easily adhere to aluminum is used, the aluminum fiber structure 10 can be firmly adhered to the composite material.

[0029] For example, in the aluminum composite materials 1 as the first and the second examples, the resin 70 that has entered a gap of the aluminum fiber structure 10 is caught by the protrusion 40 of the aluminum fiber structure 10. Therefore, even in a case where the resin 70 is a material that does not easily adhere to aluminum, the aluminum fiber structure 10 can be firmly adhered to the resin 70.

[0030] In the aluminum composite materials 3 and 4 as the third and the fourth examples, the adhesive that has entered a gap of the aluminum fiber structure 10 is caught by the protrusion 40 of the aluminum fiber structure 10, so that the aluminum fiber structure 10 can be firmly adhered to the adhesive layer 80. Thus, in the aluminum composite material 3 as the third example, the two aluminum fiber structures 10 are unlikely to separate from each other. In the aluminum composite material 4 as the fourth example, the aluminum fiber structure 10 is unlikely to separate from the metal component 90 such as a copper plate. Also in a case where adhesion between the metal component 90 and the adhesive layer 80 is weak, since the aluminum fiber structure 10 has a low coefficient of linear thermal expansion, the aluminum fiber structure 10 is unlikely to separate from the metal component 90 even if the metal component 90 expands.

[0031] In the aluminum composite material 5 as the fifth example, the adhesive that has entered a gap of the aluminum fiber structure 10 is caught by the protrusion 40 of the aluminum fiber structure 10, so that the aluminum fiber structure 10 can be firmly adhered to each of the adhesive layers 80 and 110. Thus, the aluminum fiber structure 10 is unlikely to separate from each of the metal component 90 and the alumina plate 100. In this case, even in a case where there is a difference between the coefficient of linear thermal expansion of the metal component 90 and that of the alumina plate 100, since the aluminum fiber structure 10 has a low coefficient of linear thermal expansion, separation between the metal component 90 and the aluminum fiber structure 10 and separation between the alumina plate 100 and the aluminum fiber structure 10 are unlikely to occur in the entirety of the aluminum composite material 5.

Examples

[0032] The present invention will be described below in more detail by means of examples and comparative examples.

<Example 1>

[0033] An aluminum fiber structure was produced in the following procedure. Firstly, a plurality of aluminum fibers which were formed of A1070 as a material, had a fiber diameter of 50 μm, and had an average length of 2 mm were formed into a sheet-like shape. Thereafter, the aluminum fibers were heated at 700°C in sintering equipment and thus sintered. Thus, an aluminum fiber structure was produced.

[0034] When a cut surface obtained by cutting the produced aluminum fiber structure was observed by a microscope, it was found that an alumina layer was formed on the surface of the aluminum fiber, and a plurality of alumina protrusions each having a height larger than the thickness of the alumina layer were formed on the surfaces of the alumina layers or the aluminum fibers. On the cross-section of the aluminum fiber structure, a coverage of the total of the alumina layers and the protrusions on the surfaces of the aluminum fibers was 24%, and a space factor of the aluminum fibers in the aluminum fiber structure was 75%. The physical property values of the aluminum fiber structure having such a configuration are as indicated below in Table 1.

<Examples 2 to 4>

[0035] Aluminum fiber structures were each produced in the same method as for Example 1 except that aluminum fibers were heated in sintering equipment at 750°C, 800°C, and 850°C, respectively, and thus sintered. When a cut surface obtained by cutting each of the produced aluminum fiber structures of Examples 2 to 4 was observed by a microscope, it was found that an alumina layer was formed on the surface of the aluminum fiber, and a plurality of alumina protrusions each having a height larger than the thickness of the alumina layer were formed on the surfaces of the alumina layers or the aluminum fibers. The physical property values of the produced aluminum fiber structures of Examples 2 to 4 are as indicated below in Table 1.

<Examples 5 to 8>

[0036] Aluminum fiber structures were each produced in the same method as for Example 1 except that the fiber diameter and the average length of the plurality of aluminum fibers were as indicated in Table 1, and the aluminum fibers were heated in sintering equipment at a temperature (800°C or 900°C) indicated in Table 1 and thus sintered. When a cut surface obtained by cutting each of the produced aluminum fiber structures of Examples 5 to 8 was observed by a microscope, it was found that an alumina layer was formed on the surface of the aluminum fiber, and a plurality of alumina protrusions each having a height larger than the thickness of the alumina layer were formed on the surfaces of the alumina layers or the aluminum fibers. The physical property values of the produced aluminum fiber structures of Examples 5 to 8 are as indicated below in Table 1.

<Example 9>

[0037] As in Example 1, aluminum fibers were formed into a sheet-like shape, and the aluminum fibers were thereafter heated at 900°C in sintering equipment and thus sintered. Glaze containing yttria was applied to the surface of the aluminum fiber structure, and the obtained product was thereafter heated at a high temperature. When a cut surface obtained by cutting the aluminum fiber structure thus produced was observed by a microscope, it was found that an alumina layer was formed on the surface of the aluminum fiber, and a plurality of alumina protrusions each having a height larger than the thickness of the alumina layer were formed on the surfaces of the alumina layers or the aluminum fibers. In such an aluminum fiber structure, a plasma-resistant layer containing yttrium oxide was formed on the surfaces of the alumina layers and the protrusions. The physical property values of the produced aluminum fiber structure of Example 9 are as indicated below in Table 1.

<Example 10>

[0038] As in Example 1, aluminum fibers were formed into a sheet-like shape, and the aluminum fibers were thereafter heated at 900°C in sintering equipment and thus sintered. Glaze containing zirconia was applied to the surface of the aluminum fiber structure, and the obtained product was thereafter heated at a high temperature. When a cut surface obtained by cutting the aluminum fiber structure thus produced was observed by a microscope, it was found that the alumina layer was formed on the surface of the aluminum fiber, and a plurality of alumina protrusions each having a height larger than the thickness of the alumina layer were formed on the surfaces of the alumina layers or the aluminum fibers. In such an aluminum fiber structure, a plasma-resistant layer containing zirconium oxide was formed on the surfaces of the alumina layers and the protrusions. The physical property values of the produced aluminum fiber structure of Example 10 are as indicated below in Table 1.

<Comparative examples 1 to 2>

[0039] Aluminum fiber structures of Comparative examples 1 to 2 were produced in the same method as for Example 1 except that aluminum fibers were heated in sintering equipment at 680°C and 600°C, respectively, and thus sintered. When a cut surface obtained by cutting each of the produced aluminum fiber structures of Comparative examples 1 to 2 was observed by a microscope, it was found that an alumina layer was formed on the surface of the aluminum fiber, but no alumina protrusions were formed on the surfaces of the alumina layers or the aluminum fibers. The physical property values of the produced aluminum fiber structures of Comparative examples 1 to 2 are as indicated below in Table 1.

<Comparative example 3>

[0040] As Comparative example 3, a plate-like aluminum body formed of A1070 as a material was used.

<Evaluations>

[0041] The coefficient of linear thermal expansion at 40°C was measured for each of the aluminum fiber structures of Examples 1 to 10 and Comparative examples 1 to 3. The examination results are indicated below in Table 1 and Table 2. In Table 1 and Table 2, the coverage refers to a coverage of the protrusion portions at the surfaces of the aluminum fibers on the cross-section obtained by cutting the aluminum fiber structure, and was calculated by dividing a length of the alumina layer at a portion (specifically, a portion from a peak rise starting point of the protrusion to a descending end point thereof) covered by the protrusion, by the entire length of the alumina layer, on the cross-section of the aluminum fiber structure. In Comparative examples 1 to 3, the coverage was 0%, and this means that no alumina protrusions were formed. In Table 1 and Table 2, the space factor refers to a space factor of the aluminum fibers in the aluminum fiber structure, and was defined as a proportion of an area occupied by the aluminum fibers to an area inside the outer edge of the aluminum fiber structure, on the cut surface obtained by cutting the aluminum fiber structure.

[Table 1]

Items		Ex. 1	Ex. 2	Ex. 3	Ex. 4	Ex. 5	Ex. 6	Ex. 7
Aluminum fiber	Material	A1070	A1070	A1070	A1070	A1070	A1070	A1070
	Fiber diameter μm	50 μm	50 μm	50 μm	50 μm	70 μm	140 μm	15 μm
	Average length mm	2 mm	2 mm	2 mm	2 mm	5 mm	15 mm	0.3 mm
Sintering temperature		700°C	750°C	800°C	850°C	800°C	900°C	900°C
Plasma-resistant layer		absent	absent	absent	absent	absent	absent	absent
Coverage		24%	42%	68%	84%	70%	88%	92%
Space factor		75%	73%	72%	73%	50%	23%	86%
Coefficient of linear thermal expansion (ppm/°C)		21.5	20.5	18.2	15.4	17.6	19.4	20.4

[Table 2]

Items		Ex. 8	Ex. 9	Ex. 10	Comp. Ex. 1	Comp. Ex. 2	Comp. Ex. 3
Aluminum fiber	Material	A5052	A1070	A1070	A1070	A1070	A1070
	Fiber diameter μm	50 μm	50 μm	50 μm	50 μm	50 μm	
	Average length mm	2 mm	2 mm	2 mm	2 mm	2 mm	
Sintering temperature		900°C	900°C	900°C	680°C	600°C	
Plasma-resistant layer		absent	Y_2O_3	Zr_2O_3	absent	absent	absent
Coverage		86%	81%	83%	0%	0%	0%
Space factor		48%	76%	75%	74%	76%	
Coefficient of linear thermal expansion (ppm/°C)		16.4	16.9	16.6	23.1	23.7	23.9

[0042] When the cut surface obtained by cutting each of the aluminum fiber structures of Examples 1 to 10 was observed by a microscope, it was found that the alumina layer was formed on the surface of the aluminum fiber, and a plurality of alumina protrusions each having the height larger than the thickness of the alumina layer were formed on the surfaces of the alumina layers or the aluminum fibers. Meanwhile, when the cut surface obtained by cutting each of the aluminum fiber structures of Comparative examples 1 to 3 was observed by a microscope, it was found that the alumina layer was formed on the surface of the aluminum fiber, but no alumina protrusions were formed on the surfaces of the alumina layers or the aluminum fibers. Furthermore, the coefficients of linear thermal expansion of the aluminum fiber structures of Examples 1 to 10 and Comparative examples 1 to 3 were measured. The coefficient of linear thermal expansion was 22.0 or less in each of the aluminum fiber structures of Examples 1 to 10 whereas the coefficient of linear thermal expansion was more than 23.0 in each of the aluminum fiber structures of Comparative examples 1 to 3. According to the above-described results, it was found that, in a case where the aluminum fibers were heated at 700°C or higher in sintering equipment and thus sintered, the coefficient of linear thermal expansion of the aluminum fiber structure was able to be reduced.

<Example 11>

[0043] An aluminum composite material as shown in FIG. 2 was produced by adhering two aluminum fiber structures by a resin. In the aluminum composite material of Example 11, the resin was partially impregnated into the aluminum fiber structure. Specifically, the resin was partially impregnated into the two aluminum fiber structures, and thus, the aluminum fiber structures were disposed at portions near the front side and the back side, respectively, of the resin, and the aluminum fiber structures protruded outward from the front surface and the back surface, respectively, of the resin. As the aluminum fiber structure, the aluminum fiber structure of Example 1 was used, and each aluminum fiber structure had a thickness of 3.0 mm and a space factor of 75%. For the resin as the adhesive layer, epoxy resin was used, and the adhesive layer had a thickness of 125 μm.

<Example 12>

[0044] An aluminum composite material as shown in FIG. 3 was produced by adhering two aluminum fiber structures by an adhesive layer formed of a silver paste adhesive. As the aluminum fiber structure, the aluminum fiber structure of Example 1 was used, and each aluminum fiber structure had a thickness of 3.0 mm and a space factor of 75%. The adhesive layer formed of the silver paste adhesive had a thickness of 12 μm.

<Example 13>

[0045] An aluminum composite material as shown in FIG. 4 was produced by adhering a copper plate to one surface of an aluminum fiber structure by an adhesive layer formed of a copper paste adhesive. As the aluminum fiber structure, the aluminum fiber structure of Example 3 was used, and the aluminum fiber structure had a thickness of 1.0 mm and a space factor of 72%. The adhesive layer formed of the copper paste adhesive had a thickness of 48 μm. As the copper plate, a copper plate which was formed of C1100 as a material, and had a thickness of 5.0 mm and a space factor of 100% was used.

<Example 14>

[0046] An aluminum composite material as shown in FIG. 5 was produced by adhering a copper plate to one surface of an aluminum fiber structure by an adhesive layer formed of a copper paste adhesive and adhering an alumina plate to the other surface of the aluminum fiber structure by an adhesive layer formed of a glass paste adhesive. As the aluminum fiber structure, the aluminum fiber structure of Example 3 was used, and the aluminum fiber structure had a thickness of 1.0 mm and a space factor of 72%. The adhesive layer formed of the copper paste adhesive had a thickness of 48 μm. As the copper plate, a copper plate which was formed of C1100 as a material, and which had a thickness of 0.5 mm and a space factor of 100% was used. The adhesive layer formed of the glass paste adhesive had a thickness of 27 μm. As the alumina plate, an alumina plate having a thickness of 1.0 mm and a space factor of 100% was used.

<Comparative example 4>

[0047] An aluminum composite material as shown in FIG. 5 was produced by adhering a copper plate to one surface of an aluminum plate instead of the aluminum fiber structure as in Example 14 by an adhesive layer formed of a copper paste adhesive, and adhering an alumina plate to the other surface of the aluminum plate by an adhesive layer formed of a glass paste adhesive. As the aluminum plate, an aluminum plate having a thickness of 1.0 mm and a space factor of 100% was used. The adhesive layer formed of the copper paste adhesive had a thickness of 43 μm. As the copper plate, a copper plate which was formed of C1100 as a material, and which had a thickness of 0.5 mm and a space factor of 100% was used. The adhesive layer formed of the glass paste adhesive had a thickness of 34 μm. As the alumina plate, an alumina plate having a thickness of 1.0 mm and a space factor of 100% was used.

<Comparative example 5>

[0048] An alumina composite material was produced by adhering a copper plate to one surface of an alumina plate by an adhesive layer formed of a glass paste adhesive. As the alumina plate, an alumina plate having a thickness of 1.0 mm and a space factor of 100% was used. The adhesive layer formed of the glass paste adhesive had a thickness of 32 μm. As the copper plate, a copper plate which was formed of C1100 as a material, and which had a thickness of 0.5 mm and a space factor of 100% was used.

<Evaluations>

[0049] Adhesiveness and adhesion strength were evaluated for the aluminum composite materials and the alumina composite material according to Examples 11 to 14 and Comparative examples 4 to 5. For the adhesiveness, the aluminum composite materials and the alumina composite material according to Examples 11 to 14 and Comparative examples 4 to 5 were subjected to a heat shock test (the number of times of cycling between -40°C and 120°C was 500, and a retention time was 30 minutes in total), and whether or not separation occurred was visually checked. A case where no separation occurred was evaluated as "good", and a case where separation partially occurred or floating occurred in the composite member was evaluated as "poor". For the adhesion strength, a rate of change between the adhesion strength before the heat shock test and the adhesion strength after the heat shock test was calculated for the aluminum composite materials and the alumina composite material according to Examples 11 to 14 and Comparative examples 4 to 5. For measuring such adhesion strength, tensile strength was measured in accordance with JIS K 6854-2:1999 (ISO8510-2:1990). A case where a rate of change between the adhesion strengths before and after the heat shock test was less than 10% was evaluated as "excellent", a case where a rate of the change was less than 30% was evaluated as "good", and a case where a rate of the change was 30% or more was evaluated as "poor". The evaluation results are indicated below in Table 3.

[Table 3]

Items	Ex. 11	Ex. 12	Ex. 13	Ex. 14	Comp. Ex. 4	Comp. Ex. 5
Adhesiveness	good	good	good	good	poor	poor
Adhesion strength	excellent	excellent	excellent	good	poor	poor

[0050] As indicated in the evaluation results in Table 3, in a case where the aluminum fiber structure was used for the aluminum composite material, the adhesiveness and the adhesion strength were good. Specifically, separation was unlikely to occur, and even temperature change in a surrounding environment was unlikely to cause change in the adhesion strength. Meanwhile, in a case where the aluminum plate or the alumina plate instead of the aluminum fiber structure was used for the aluminum composite material, the adhesiveness and the adhesion strength were poor as compared with a case where the aluminum fiber structure was used. Thus, in a case where the aluminum fiber structure was used for the aluminum composite material, even when a temperature in a surrounding environment greatly changed, separation between the aluminum fiber structure and the composite material was unlikely to occur.

Claims

1. An aluminum fiber structure comprising

aluminum fibers partially bound to each other, wherein
alumina layers are formed on surfaces of the aluminum fibers, and
a plurality of alumina protrusions each having a height larger than a thickness of each alumina layer are formed on surfaces of the aluminum fibers or the alumina layers.

2. The aluminum fiber structure according to claim 1, wherein at least a part of the plurality of protrusions are each in contact with the alumina layers of a plurality of the aluminum fibers in a straddling manner.

3. The aluminum fiber structure according to claim 1 or 2, wherein the height of each protrusion at the surfaces of the aluminum fibers or the alumina layers ranges from 10 nm to 10 μm.

4. The aluminum fiber structure according to any one of claims 1 to 3, wherein the thickness of each alumina layer ranges from 10 nm to 10 μm.

5. The aluminum fiber structure according to any one of claims 1 to 3, wherein 20% or more of surfaces of the aluminum fibers on a cross-section of the aluminum fiber structure is covered by the protrusions.

6. The aluminum fiber structure according to any one of claims 1 to 5, wherein 40% or more of the surfaces of the aluminum fibers on the cross-section of the aluminum fiber structure is covered by the protrusions in total.

7. The aluminum fiber structure according to any one of claims 1 to 6, wherein a plasma-resistant layer is formed on surfaces of the alumina layers and the protrusions.

8. The aluminum fiber structure according to claim 7, wherein the plasma-resistant layer includes metal oxide or aluminum nitride.

9. The aluminum fiber structure according to any one of claims 1 to 8, wherein the protrusions are formed by an eluted substance from the aluminum fibers when the aluminum fibers are sintered at 700°C or higher.

10. The aluminum fiber structure according to any one of claims 1 to 9, wherein a space factor of the aluminum fibers in the aluminum fiber structure ranges from 20% to 90%.

11. An aluminum composite material comprising

the aluminum fiber structure according to any one of claims 1 to 10 and a composite material which form a composite, wherein
the alumina protrusions and at least a part of the composite material are in contact with each other.

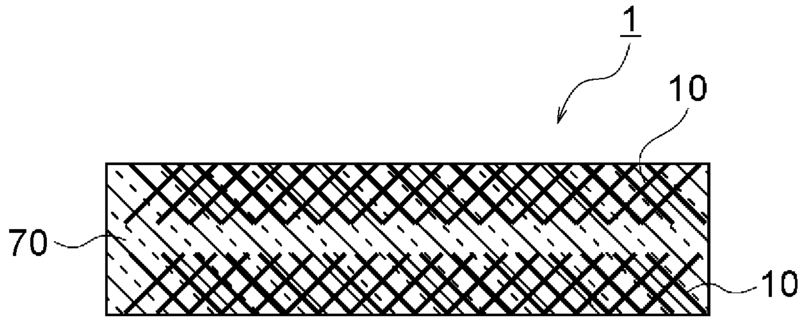

FIG. 1

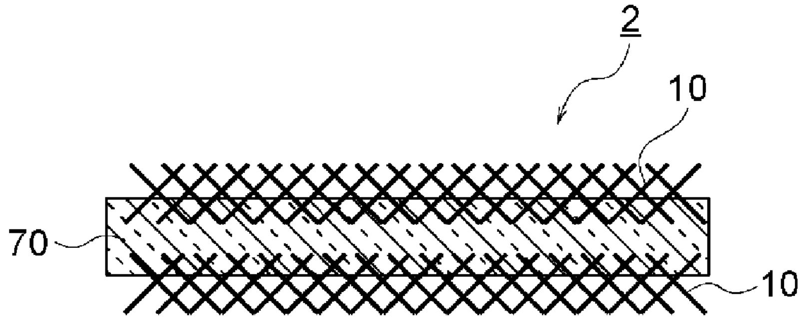

FIG. 2

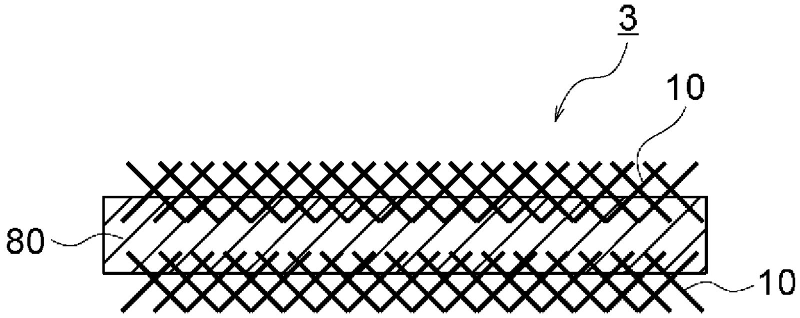

FIG. 3

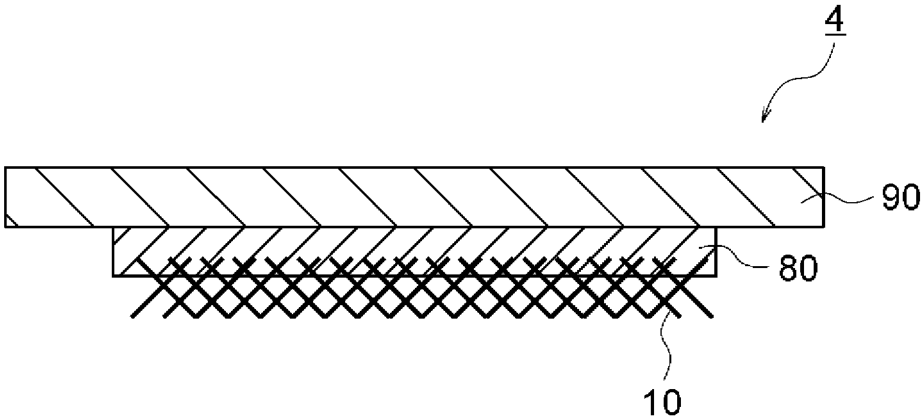

FIG. 4

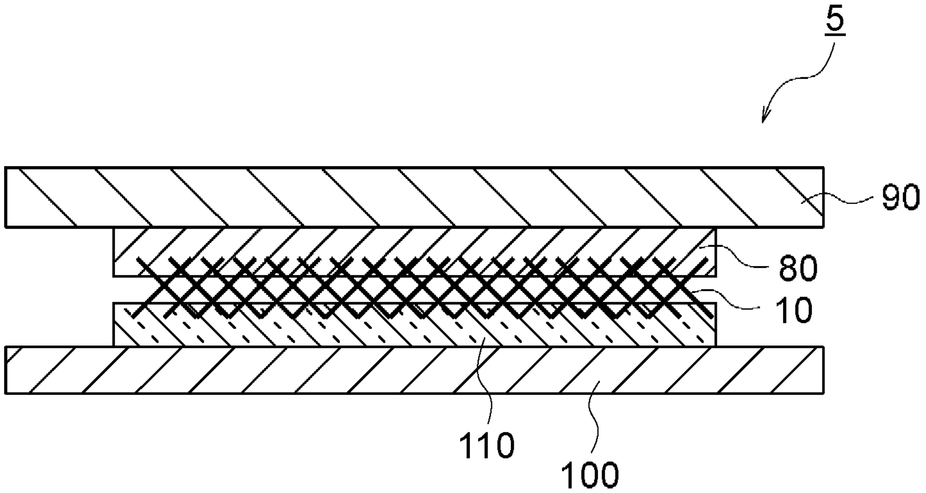

FIG. 5

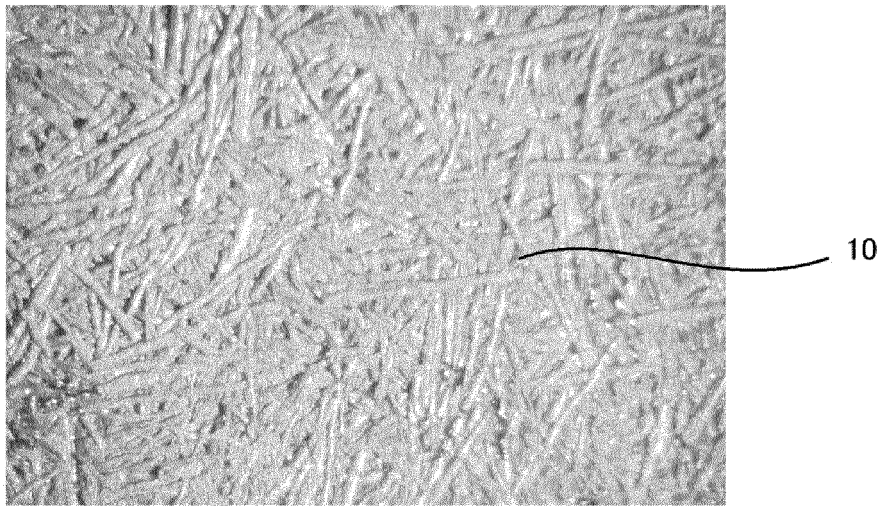

FIG. 6

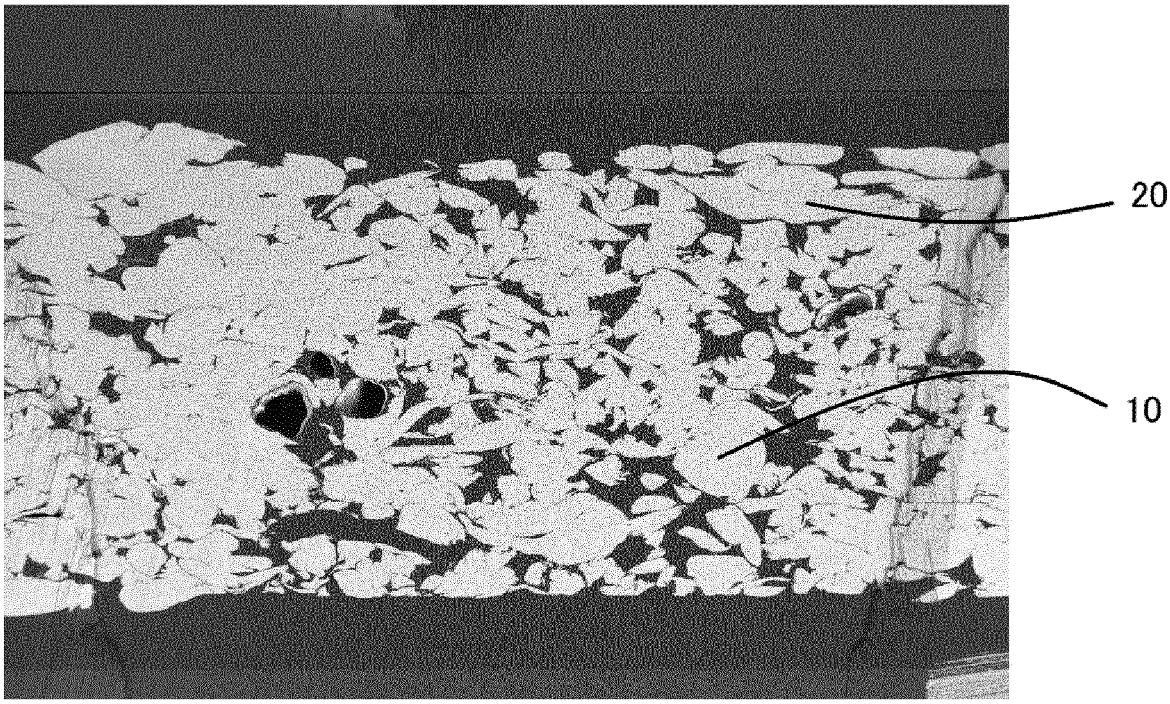

FIG. 7

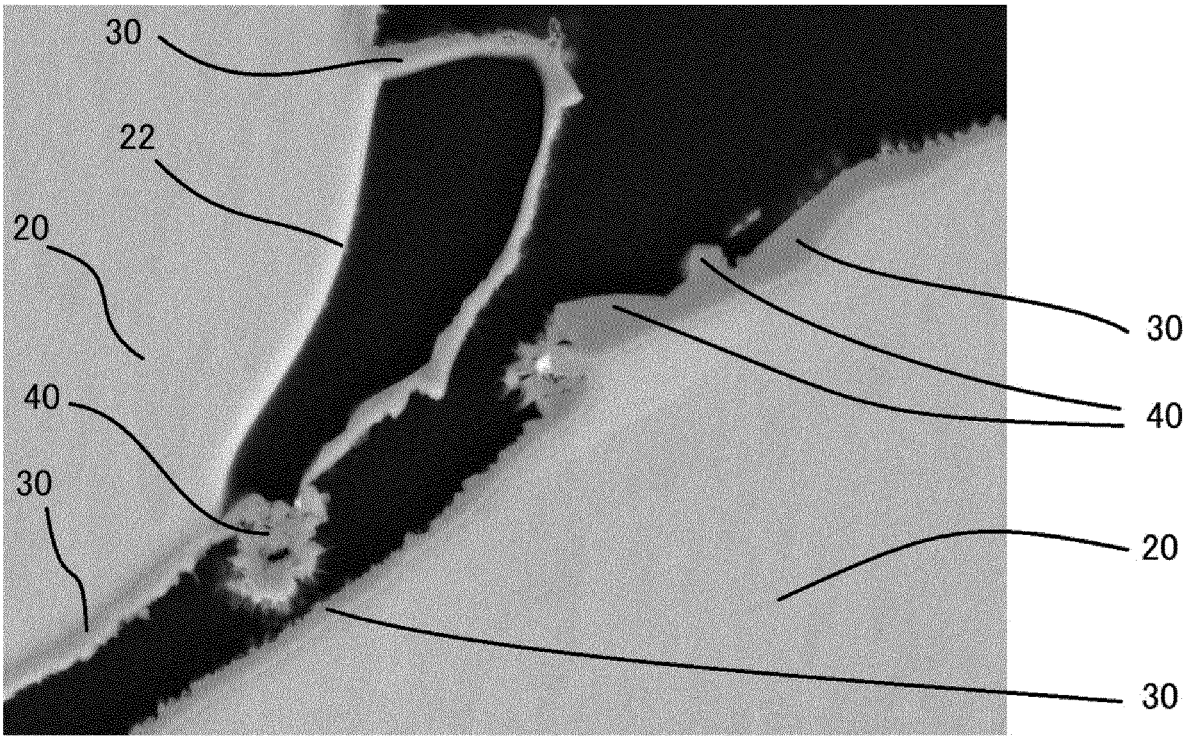

FIG. 8

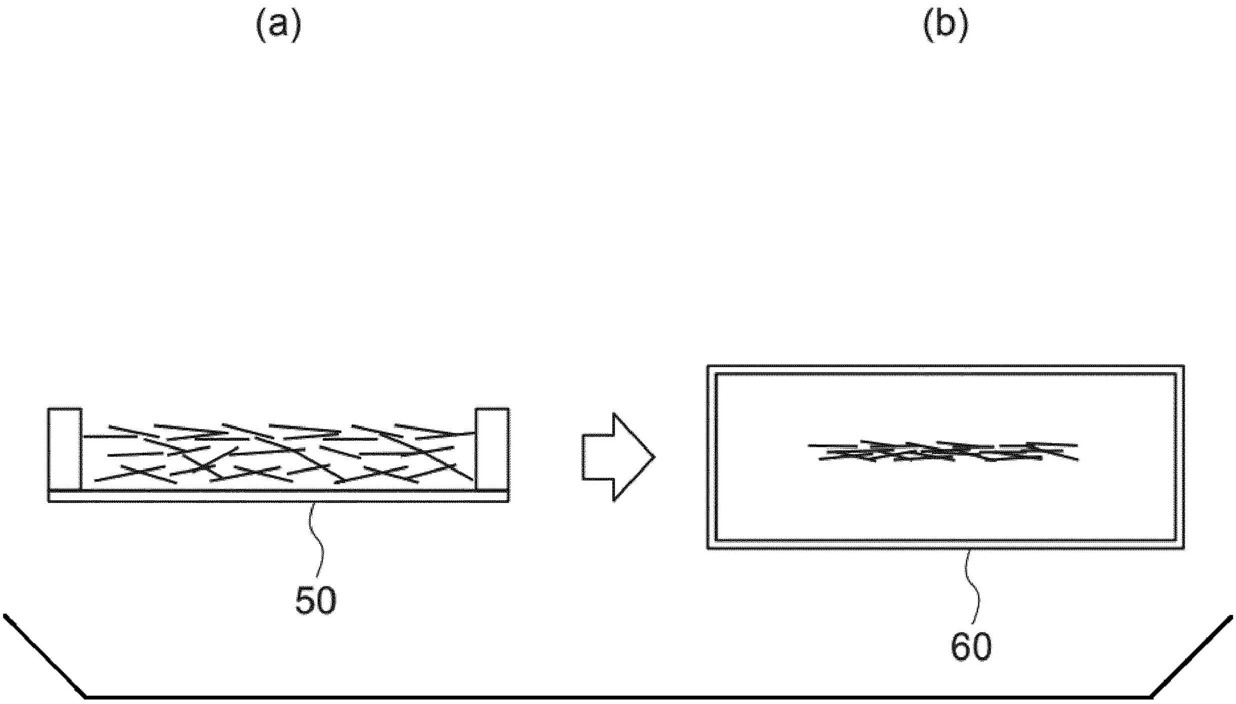

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No. **PCT/JP2022/009679**

A. CLASSIFICATION OF SUBJECT MATTER

F28F 21/08(2006.01)i; ***C22C 1/08***(2006.01)i; ***D04H 1/4234***(2012.01)i; ***F28D 15/04***(2006.01)i; ***B22F 3/10***(2006.01)i; ***B22F 3/11***(2006.01)i; ***B22F 1/00***(2022.01)i; ***B22F 1/14***(2022.01)i; ***B22F 1/16***(2022.01)i

FI: C22C1/08 F; B22F1/14 600; B22F1/00 N; B22F1/16; B22F3/11 C; B22F3/10 F; D04H1/4234; F28F21/08 A; F28D15/04 G

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)

F28F21/08; C22C1/08; D04H1/4234; F28D15/04; B22F3/10; B22F3/11; B22F1/00; B22F1/14; B22F1/16

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 1971-2022
Registered utility model specifications of Japan 1996-2022
Published registered utility model applications of Japan 1994-2022

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.
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Y	JP 2009-266983 A (SUMITOMO ELECTRIC INDUSTRIES, LTD.) 12 November 2009 (2009-11-12) paragraphs [0011]-[0051], table 1, fig. 1-7	1-6, 10-11
Y	JP 7-147889 A (NDC CO., LTD.) 13 June 1995 (1995-06-13) paragraphs [0007]-[0010], claims 1-4	2-6, 10-11
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Y	JP 2016-13521 A (MITSUBISHI MATERIALS CORP.) 28 January 2016 (2016-01-28) paragraph [0048], fig. 3, 4	10-11

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

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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
25 March 2022	**05 April 2022**

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

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/009679

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	CN 102618968 A (LUOYANG INST SCIENCE & TECHNOLOGY) 01 August 2012 (2012-08-01) paragraph [0016], abstract	11
A	JP 2014-194074 A (MITSUBISHI MATERIALS CORP.) 09 October 2014 (2014-10-09) entire text, all drawings	1-11
A	JP 3-278891 A (NDC CO., LTD.) 10 December 1991 (1991-12-10) entire text, all drawings	1-11
A	JP 7-80289 A (NDC CO., LTD.) 28 March 1995 (1995-03-28) entire text, all drawings	1-11
A	JP 2009-260168 A (SUMITOMO ELECTRIC INDUSTRIES, LTD.) 05 November 2009 (2009-11-05) entire text, all drawings	1-11
A	JP 8-67990 A (HITACHI, LTD.) 12 March 1996 (1996-03-12) entire text, all drawings	1-11
A	JP 2001-62302 A (IBIDEN CO., LTD.) 13 March 2001 (2001-03-13) entire text, all drawings	1-11
A	JP 4787253 B2 (K2R KK) 05 October 2011 (2011-10-05) entire text, all drawings	1-11

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/009679

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
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JP 2009-260168 A	05 November 2009	(Family: none)	
JP 8-67990 A	12 March 1996	(Family: none)	
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JP 4787253 B2	05 October 2011	US 2009/0297408 A1 US 2014/0194274 A1 WO 2007/004592 A1 EP 1905861 A1 CN 101223295 A	

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