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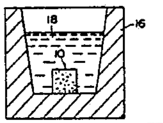
(54) Method of producing metal base composite material under promotion of matrix metal infiltration by fine pieces of third material.

(57) In producing a metal base composite material by first producing a porous preform from a reinforcing material such as short fibers, whisker, particles or mixtures thereof, and secondly infiltrating a molten matrix metal into the interstices of the porous preform, fine pieces of a third material having good affinity to the molten matrix metal are mixed in the porous preform in the process of producing the preform, and at least a part of the preform is contacted with a molten mass of the matrix metal so that the molten matrix metal infiltrates into the interstices of the porous preform with no substantial pressure being applied thereto.

FIG. 2



METHOD OF PRODUCING METAL BASE COMPOSITE MATERIAL UNDER PROMOTION OF MATRIX METAL INFILTRATION BY FINE PIECES OF THIRD MATERIAL

Background of the Invention

Field of the Invention

The present invention relates to a composite material, and more particularly, to a method of producing a metal base composite material comprising short fibers, whisker or particles as a reinforcing material and an aluminum alloy or the like as a matrix material.

Description of the Prior Art

As described in, for example, a paper titled "Forming of aluminum fiber reinforced material" distributed in the third Metal Forming Seminar held at Atami-shi on July 15-16, 1985 sponsored by the Japanese Light Metal Institution, there are known several methods of producing fiber reinforced metal base composite materials including continuous fibers as a reinforcing fiber material, such as (1) diffusion binding method, (2) plasma spray method, (3) gas phase eduction method, (4) melt infiltration method, (5) electric plating method, etc., and there are also known several methods of producing fiber reinforced metal base composite materials including discontinuous fibers as a fiber reinforcing material, such as (1) powder metallurgy method, (2) compo-casting method, (3) melt forging method, (4) semi-melt working method, (5) HIP method or the like.

Particularly when the reinforcing fibers are short fibers, the above-mentioned melt forging method (high pressure casting method) has been commonly used for the reason that it is more suitable for the mass production as compared with other methods. However, in the melt forging method it is required that a molten mass of matrix metal is pressurized to a very high pressure, and therefore a large scale production equipment is required, resulting in a high production cost of the composite materials, and thus presenting a principal obstacle for the practical use of this method.

Therefore, in the production of the composite materials including discontinuous fibers as the reinforcing fiber material there is a demand for lowering of the pressure level required for the molten mass of matrix metal, or it is further demanded to dispense with pressurization of the molten matrix metal. For realization of these demands it is required that the affinity between the reinforcing fibers and the matrix metal is largely improved.

In view of these requirements it was proposed in, for example, Japanese Patent Laying-open Publication 61-295344 to use an aluminum alloy added with a particular element as a matrix metal. However, the affinity can not be improved enough by a mere adding of a particular element to the matrix metal. Further, this method is usable only with a very limited composition of matrix metal.

Various methods have been proposed to improve the affinity between the reinforcing fibers and the matrix metal when the reinforcing fibers are continuous fibers. For example, in Japanese Patent Laying-open Publication 49-42504 it is described to improve the affinity by painting a metal powder on the surface of the reinforcing fibers. In Japanese Patent Laying-open Publications 50-109904, 52-28433, 53-38791, 57-169036 and 57-169037 it is described to improve the affinity by coating the surface of fibers with metal.

As described in these publications, when the reinforcing fibers are continuous fibers which are generally disposed in a common direction, the capillary action is available to infiltrate a molten matrix metal into the interstices among the continuous fibers, and therefore the methods proposed in the above-mentioned publications are effective.

However, when the reinforcing fibers are short fibers or a whisker, the infiltration of the molten matrix metal by the capillary action is not available. Therefore, the infiltration of the molten matrix metal into the short fibers or the whisker is not improved by the method of increasing the affinity as applied to the continuous fibers as described in, for example, Japanese Patent Laying-open Publication 59-205464. Further, it is difficult to coat short fibers or a whisker with a large amount of metal or to paint short fibers or a whisker with a large amount of metal powder, and such a process requires a high production cost. There are also these problems in the methods described in U.S. Patent Specifications 4,376,803 and 4,569,886, wherein the surface of fibers is coated with a metal oxide.

Further, as described in Japanese Patent Laying-open Publication 57-31466 and Japanese Patent

Laying-open Publication 62-67133, both being based upon the patent applications filed by the same applicant as the present application, it is already known to preheat a preform of the reinforcing material to a certain raised temperature and to infiltrate a molten matrix metal into the preform under pressure. According to this method the affinity between the reinforcing material and the molten matrix metal is increased by the preheating of the reinforcing material up to said certain temperature, so that the infiltration of the molten matrix metal into the preform improved as compared with the case where the preform is not preheated. However, in this method the preheating of the preform is an indispensable condition, and a particular means is necessary for the preheating, and therefore the improvement for higher efficiency and lower cost of production of the composite material is limited.

Further, as described in Japanese Patent Laying-open Publication 61-165265 based upon an application filed by the same applicant as the present application, it is already known to improve the infiltration of the molten matrix metal into the preform of the reinforcing material by utilizing oxidizing or deoxidizing reaction between a metal oxide included in the preform of the reinforcing material and a particular metal element included in the matrix metal. However, since the elements which react with one another in oxidizing or deoxidizing manner are relatively limited, this method is not always applicable to the production of a composite material in which the matrix metal may have any optional composition.

In all of the above-mentioned conventional methods it is generally required that the molten mass of matrix metal is pressurized to a relatively high pressure. Therefore, in these conventional methods it is not possible to produce composite materials at low cost by dispensing with a pressurizing means such as mold or the like. Further, it is not avoidable that at each casting a relatively large amount of matrix metal solidifies around a preform in the mold cavity, thereby lowering the yield rate of the casting process.

In Japanese Patent Laying-open Publication 59-500973 and "Journal of Materials Science Letters" published in April 1985 it is described to produce a composite material by pretreating a preform of reinforcing fibers by a chemical agent including fluorine, and to infiltrate a molten matrix metal into the preform. However, this method is applicable only when the reinforcing fibers are carbon fibers or principally carbonic fibers or the fibers covered with carbon or carbide. Further, in this method it is also required that the preform of the reinforcing fibers is preheated before the infiltration of a molten matrix metal.

Summary of the Invention

In view of the above-mentioned problems in the conventional methods of producing composite materials, the inventors of the present application had conducted various experimental researches and found that the above-mentioned problems can be solved by mixing fine pieces of some determinate metals or metal oxides in the preform of reinforcing materials.

Therefore, it is a primary object of the present invention to propose, based upon the various experimental researches conducted by the inventors of the present application, a method of producing a composite material at high efficiency and low cost, wherein a matrix metal is infiltrated into a reinforcing material in good condition with no pressurization of a molten mass of the matrix metal.

It is another object of the present invention to provide a method of producing a composite material having a substantially predetermined shape and dimensions at very high efficiency, low cost and very high yielding rate with no need of a mold for pressurizing the molten matrix metal or a mold for producing a composite material having a predetermined shape.

According to the present invention, the above-mentioned objects are accomplished by a method of producing a metal base composite material comprising a first process of producing a porous preform from a reinforcing material selected from a group consisting of short fibers, whisker, particles and mixtures thereof, and a second process of infiltrating a molten matrix metal into the interstices of said porous preform, wherein in said first process fine pieces of a third material having good affinity to the molten matrix metal are mixed in said porous preform, and in said second process at least a part of said preform is contacted with a molten mass of the matrix metal so that the molten matrix metal infiltrates into the interstices of said porous preform with no substantial pressure being applied thereto.

The third material for said fine pieces may be a metal or metals selected from a group consisting of Ni, Fe, Co, Cr, Mn, Cu, Ag, Si, Mg, Al, Zn, Sn, Ti and an alloy or alloys including any one of these metals as a principal component when the matrix metal is Al or an Al alloy.

The third material for said fine pieces may be a metal or metals selected from a group consisting of Ni, Cr, Ag, Al, Zn, Sn, Pb and an alloy or alloys including any one of these metals as a principal component when the matrix metal is Mg or a Mg alloy.

When said reinforcing material is particularly selected from a group consisting of short fibers, whisker, particles and mixtures thereof made of an inorganic material other than metal, and the matrix metal is a metal selected from a group consisting of Al, Mg, Al alloy and Mg alloy, the material for said fine pieces may be an oxide or oxides of a metal or metals selected from a group consisting of W, Mo, Pb, Bi, V, Cu, Ni, Co, Sn, Mn, B, Cr, Mg and Al and mixtures thereof.

According to the present invention, by the incorporation of such a third material having good affinity to the molten matrix metal being mixed in the reinforcing material in the form of fine pieces, the infiltration of the molten matrix metal into the interstices of the preform of reinforcing material is much promoted as helped by the affinity of the third material with the molten matrix metal. Further, the molten matrix metal reacts with the fine pieces of the third material and generates heat which further improves the affinity between the molten matrix metal and the reinforcing material, thereby further improving the infiltration of the molten matrix metal into the preform of reinforcing material.

According to the method of the present invention, it is not necessary to pressurize the molten matrix metal or to preheat the reinforcing material, and therefore no large scale equipment for pressurizing the molten matrix metal or for preheating the reinforcing material is required. Therefore, according to the present invention it is possible to produce a composite material including a matrix material well infiltrated in a reinforcing material at high efficiency and low cost.

Since the molten matrix metal infiltrates easily into the preform according to the method of the present invention, if the preform including a reinforcing material and fine pieces of the third material is prepared to have a predetermined shape and dimensions, the whole body of the preform can be uniformly infiltrated with the molten matrix metal by a part of the preform being brought into contact with a molten mass of the matrix metal so as immediately to provide a composite material having substantially the predetermined shape and dimensions. Therefore, as compared with the conventional melt forging method requiring pressurization of a molten matrix metal and a casting mold for defining a predetermined shape of the product and still unavoidably providing a large amount of matrix metal solidified outside the composite material portion in the casting mold, a composite material having substantially a predetermined shape and dimensions can be produced at high efficiency and low cost with very high yielding rate.

According to a result obtained by the experimental researches conducted by the inventors of the present application, the infiltration of the molten matrix metal into the preform can be improved by incorporating fine pieces of a determinate metal or metals in any optional amount. However, when the matrix metal is Al or Al alloys, the molten matrix metal can infiltrate into the reinforcing material in good condition when the fine pieces of a determinate metal or metals are included in the reinforcing material at a ratio of more than 150% by weight relative to the amount of the reinforcing material. Therefore, according to a particular feature of the present invention, the matrix metal is Al or an Al alloy, and the fine pieces of a determinate metal or metals are incorporated into the preform at a ratio more than 150% by weight relative to the amount of the reinforcing fibers.

Similarly, according to a result obtained by the experimental researches conducted by the inventors of the present application, the infiltration of the molten matrix metal into the preform can be improved by incorporating fine pieces of a determinate metal oxide or metal oxides in any optional amount. However, the molten matrix metal can infiltrate into the reinforcing material in good condition when the fine pieces of a determinate metal oxide or metal oxides are included in the reinforcing material at a ratio of more than 7.5% by weight, particularly more than 10% by weight, still more particularly more than 15% by weight, relative to the amount of the reinforcing material. Therefore, according to a particular feature of the present invention, the fine pieces of a determinate metal oxide or metal oxides are incorporated into the preform at a ratio more than 7.5% by weight, particularly more than 10% by weight, still more particularly more than 15% by weighty, relative to the amount of the reinforcing fibers.

According to a result obtained by the experimental researches conducted by the inventors of the present application, when said certain metal or metals provided in the form of fine pieces are more particularly any one of Ni, Fe, Co, Cu, Si, Zn, Sn, Ti or an alloy including one of these metals as a principal component, a molten Al or Al alloy can infiltrate into the preform in good condition. Therefore, according to another feature of the present invention, the metal to form the fine pieces of a certain determinate metal or metals is selected from a group consisting of Ni, Fe, Co, Cu, Si, Zn, Sn, Ti and an alloy including one of these metals as a principal component when the matrix metal is Al or an Al alloy.

Similarly, according to a result obtained by the experimental researches conducted by the inventors of the present application, when the metal or metals which form said certain metal oxide or metal oxides provided in the form of fine pieces are any one of W, Mo, Pb, Bi, Cu, Ni, Co, Sn, Mn, Cr or an alloy including one of these metals as a principal component, particularly when the metal or the metals which form said certain metal oxide or metal oxides provided in the form of fine pieces are any one of W, No, Pb, Co, Mn or an alloy including one of these metals as a principal component, the molten matrix metal can infiltrate into the preform in good condition. Therefore, according to another feature of the present invention, the metal or metals to form the fine pieces of a certain determinate metal oxide or metal oxides is selected from a group consisting of W, Mo, Pb, Bi, Cu, Ni, Co, Sn, Mn, Cr or an alloy including one of these metals as a principal component, particularly a group consisting of W, Mo, Pb, Co, Mn or an alloy including one of these metals as a principal component.

Further, according to a result of the experimental researches conducted by the inventors of the present application, when the matrix metal is an Al alloy, if the Al alloy includes at least one of Mg, Zr and Ca by an amount more than 0.5%, the molten matrix metal can more readily infiltrate into the preform. This composition is more effective to improve the affinity between the reinforcing material and the matrix metal when the preform is preheated. Therefore, according to another detailed feature of the present invention, the matrix metal is an Al alloy including at least one of Mg, Zr and Ca by an amount more than 0.5%.

According to a result of the experimental researches conducted by the inventors of the present application, when the matrix metal is Mg or a Mg alloy, if the preform includes fine pieces of the above-mentioned determinate metal or metals, the infiltration of the molten matrix metal into the preform is improved. Particularly if the preform includes fine pieces of the above-mentioned determinate metal or metals by an amount more than 130% by weight relative to the reinforcing material, the molten matrix metal can infiltrate into the preform in good condition. Therefore, according to still another detailed feature of the present invention, the matrix metal is Mg or a Mg alloy, and the fine pieces of a certain determinate metal or metals is incorporated into the preform by an amount of more than 130% by weight relative to the reinforcing material in the preform.

According to a result of the experimental researches conducted by the inventors of the present application, if the total volumetric ratio of the reinforcing material and the fine pieces of the determinate metal or metals in the preform is too low or too high, the good infiltration of the molten matrix metal into the preform is obstructed. Therefore, according to another detailed feature of the present invention, the total volumetric ratio of the reinforcing material and the fine pieces of the determinate metal or metals is set to 5-90%, desirably 7.5-85%.

Similarly, according to a result of the experimental researches conducted by the inventors of the present application, if the total volumetric ratio of the reinforcing material and the fine pieces of the determinate metal oxide or metal oxides in the preform is too low or too high, the good infiltration of the molten matrix metal into the preform is obstructed. Therefore, according to another detailed feature of the present invention, the total volumetric ratio of the reinforcing material and the fine pieces of the determinate metal oxide or metal oxides is set to 4-85%, desirably 5-80%.

According to a result of the experimental researches conducted by the inventors of the present application, even when the volumetric ratio of the fine pieces of the determinate metal or metals in the preform is high, the molten matrix metal can infiltrate into the preform in good condition. However, the volumetric ratio of the reinforcing material decreases along with the amount of the fine pieces of the determinate metal or metals in the preform, and when the fine pieces are made of some certain metal or metals, the composition of the matrix metal is largely changed by the metal or metals of the fine pieces. Therefore, according to still another detailed feature of the present invention, the volumetric ratio of the fine pieces of the determinate metal of metals in the preform is desirably set to be less than 85%.

Similarly, according to a result of the experimental researches conducted by the inventors of the present application, even when the volumetric ratio of the fine pieces of the determinate metal oxide or metal oxides in the preform is high, the molten matrix metal can infiltrate into the preform in good condition. However, when the fine pieces are made of some certain metal oxide or metal oxides, the composition of the matrix metal is largely changed by the metal oxide or metal oxides of the fine pieces. Therefore, according to still another detailed feature of the present invention, the volumetric ratio of the fine pieces of the determinate metal oxide or metal oxides in the preform is set to be less than 45%, desirably less than 40%.

According to still another detailed feature of the present invention, the preform has a predetermined shape and dimensions, and only a part thereof is dipped into a bath of molten matrix metal. According to this method, a composite material having a predetermined shape and dimensions can be produced at high efficiency, low cost and very high yielding rate with no need of a casting mold for pressurizing the molten matrix metal for defining the predetermined shape of the product.

Although the preheating of the preform is not necessary in the present invention, the preform may be preheated to a temperature which is lower than the conventional preheating temperature in order to further improve the affinity of the reinforcing material to the matrix metal. Such a lower preheating temperature is desirable in order to avoid oxidization of the fine pieces of the determinate metal or metals. The fine pieces of the determinate metal or metals according to the present invention may be in an optional shape such as short fibers, whisker or powder.

Brief Description of the Drawings

In the accompanying drawings,

Fig. 1 is a perspective view showing a preform made of a reinforcing material and fine pieces of a third material such as a determinate metal or metal oxide;

Fig. 2 is a schematic view showing the manner of production of a composite material from the preform shown in Fig. 1 according to the present invention;

Fig. 3 is a perspective view showing a composite material produced by the method shown in Fig. 2;

Fig. 4 is a perspective view showing a cylindrical preform made of a reinforcing material and fine pieces of a third material such as a determinate metal or metal oxide;

Fig. 5 is a schematic view showing the manner of dipping a lower end of the preform in a bath of a molten matrix metal; and

Fig. 6 is a schematic view showing the manner of preform being raised from the bath of the molten matrix metal.

Description of the Preferred Embodiments

The present invention will now be described with respect to some preferred embodiments with reference to the attached drawings.

Embodiment 1

As the reinforcing material alumina short fibers having 3 microns mean fiber diameter and 1mm mean fiber length ("Safil RG", product of ICI, 95% Al_2O_3, 5% SiO_2), silicon carbide whisker having 0.1-1.0 micron fiber diameter and 50-200 microns fiber length (product of Tokai Carbon Kabushiki Kaisha), and silicon nitride particles having 10 microns mean particle diameter (product of Kojundo Kagaku Kabushiki Kaisha) were prepared. Further, metal fibers and metal powder as shown in Table 1 were prepared. Then the above-mentioned reinforcing material and the metal fibers or the above-mentioned reinforcing material and the metal powder were mixed and formed into a preform of a rectangular parallelepiped shape of 20 x 20 x 40mm by compression. Fig. 1 shows such a preform 10 in a perspective view, wherein 12 indicates the reinforcing material and 14 indicates the metal fibers.

Two kinds of preforms were prepared by changing the mixing ratio of the reinforcing material and the metal fibers or the metal powder so that in the first type preform the volumetric ratio of the reinforcing material is 5%, the mass ratio of the metal fibers or the metal powder relative to the reinforcing material is 600%, and the overall volumetric ratio of the preform is 13-62%, and in a second type preform the volumetric ratio of the reinforcing material is 15%, the mass ratio of the metal fibers or the metal powder relative to the reinforcing material is 200%, and the overall volumetric ratio of the preform is 23-72%.

Then, except the preforms in which the metal fibers are Zn fibers and Sn fibers and the metal powder is Pb powder, each preform was preheated to 200°C and was then placed into a vessel 16 as shown in Fig. 2. Then a molten aluminum alloy was poured to form a bath thereof, and then the molten aluminum alloy was solidified with no pressurization. The aluminum alloy was prepared in seven different types which were JIS AC1A including 0.1% Mg, JIS AC4C including 0.3% Mg, JIS AC4D including 0.5% Mg, JIS AC8A including 1% Mg, JIS AC7B including 10% Mg, JIS AC4C added with 0.3% Ca, and JIS AC4C added with 0.3% Zr.

Then the composite material portion 20 corresponding to the portion of the preform was cut out from the solidified body, and the reinforcing material was cut along a phantom plane 22, and the cut section was polished and investigated by the naked eye and a microscope to evaluate the quality of composite structure.

The results of the evaluation are shown in Tables 2-4. In these tables a double circle (◎) indicates that both the macroscopic composite condition and the microscopic composite condition were good, a single circle (O) indicates that the macroscopic composite condition was good, a triangle (Δ) indicates that only partial composite was accomplished, and a cross (X) indicates that no composite structure was accomplished. (These indications are the same in the subsequent Tables 5-7, 10 and 11.)

From Tables 2-4 it will be understood that, regardless of the types and the volumetric ratio of the reinforcing material and the composition of the aluminum alloy, when the preform includes the metal fibers or the metal powder made of Ni, Fe, Co, Cr, Mn, Cu, Ag, Si, Mg, Al, Zn, Sn, Ti or an alloy including one of these metals as a principal component, a good composite quality is obtained, particularly when the metal fibers or the metal powder is made of Ni, Fe, Co, Cu, Si, Zn, Sn or an alloy including one of these metals as a principal component. Further, when the matrix aluminum alloy includes more than 0.5% Mg or more than 0.5% in total of Mg, Ca and Zr, a much better composite quality is obtained.

Although not included in the shown embodiment, metal fibers or metal powder other than those shown in Table 1 and consisting of an alloy including the above-mentioned determinate metal as a principal component provides a good composite quality, and when the matrix metal includes more than 0.5% Ca or Zr, the composite quality is further improved.

Comparison Example 1

By the same alumina short fibers as used in Embodiment 1 preforms were prepared to include only the alumina short fibers at 5%, 15% and 30% by volume. Further, by the same silicon carbide whisker as used in Embodiment 1 preforms were prepared to include only the silicon carbide whisker at 5%, 15% and 40% by volume. Further, by the same silicon nitride particles as used in Embodiment 1 preforms were prepared to include only the silicon nitride particles at 5%, 15% and 50% by volume. By using these preforms it was tried to produce composite materials in the same manner and under the same conditions as adopted in Embodiment 1. No good composite material was obtained from these preforms. Further, it was tried to produce composite materials from the preforms of the above-mentioned comparison purpose with an aluminum alloy by employing a high pressure casting device in the same manner and under the same conditions as in Embodiment 1 except that the aluminum alloy was pressurized to various raised pressures. As a result it was found that in order to obtain a composite material having good quality the molten aluminum alloy must be pressurized to at least 500kg/cm^2.

Embodiment 2

Alumina short fibers having 3 microns mean fiber diameter and 1mm mean fiber length ("Safil RF, product of ICI, 96-97% Al_2O_33, 3-4% SiO_2), silicon nitride whisker having 0.1-0.6 micron mean fiber diameter and 20-200 microns mean fiber length (product of Tateho Kagaku Kogyo Kabushiki Kaisha) and tungsten carbide particles having 10 microns mean particle diameter (product of Kojundo Kagaku Kabushiki Kaisha) were prepared. Further, the metal fibers and the metal powder shown in Table 1 were prepared as the metal fibers and the metal powder herein referred to. Then in the same manner as Embodiment 1 the above-mentioned reinforcing materials and the metal fibers or the metal powder were mixed, and preforms having 20 x 20 x 40 mm dimensions were prepared by compression forming.

By changing the mixing ratio between the reinforcing material and the metal fibers or the metal powder two types of preforms were prepared so that in a first type preform the volumetric ratio of the reinforcing material is 5%, the mass ratio of the metal fibers or the metal powder relative to the reinforcing material is 500%, and the overall volumetric ratio of the preform is 12-53%, and in a second type preform the volumetric ratio of the reinforcing material is 15%, the mass ratio of the metal fibers or the metal powder relative to the reinforcing material is 150%, and the overall volumetric ratio of the preform is 21-58%.

Then, in the same manner as in Embodiment 1, the preforms including Zn fibers and Sn fibers as the metal fibers were preheated to 150 °C, the preform including Pb powder as the metal powder was preheated to 100 °C, and other preforms were preheated to 400 °C. Then each preheated preform was placed in a vessel, and a molten magnesium alloy at 700 °C was poured into the vessel, and solidified with no pressurizing. The magnesium alloy was prepared in three different types of MC-2, MC-7 and MC-8 according to JIS.

Then in the same manner as in Embodiment 1 the composite material portion was cut out from the solidified body corresponding to the preform portion, and then after polishing the cut out cross section the section was examined by the naked eye and microscope to evaluate the composite condition. The results of evaluation are shown in Tables 5-7.

From Tables 5-7 it will be understood that when the matrix metal is a magnesium alloy, a good composite condition is obtained when the preform includes the metal fibers or the metal powder made of

Ni, Cr, Ag, Zn, Sn, Pb or an alloy including one of these metals as a principal component.

Although not shown as embodiments, it has been confirmed that a good composite condition is obtained when the preform includes the metal fibers or the metal powder made of other alloys including one of Ni, Cr, Ag, Zn, Sn and Pb, or Al.

Comparison Example 2

By the same aluminum short fibers as used in Embodiment 2 preforms were prepared to include only the aluminum short fibers at 5%, 15% and 40% by volume. Further, by the same silicon nitride whisker as used in Embodiment 2 preforms were prepared to include only the silicon nitride whisker at 5%, 15% and 40% by volume. Still further, by the same silicon carbide particles as used in Embodiment 2 preforms were prepared to include only the silicon carbide particles at 5%, 15% and 40% by volume. By using these preforms it was tried to produce composite materials in the same manner and under the same conditions as adopted in Embodiment 2. No good composite material was obtained from these preforms.

Further, it was tried to produce composite materials from the preforms of the above-mentioned comparison purpose with a magnesium alloy by employing a high pressure casting device in the same manner and under the same conditions as in Embodiment 2 except that the magnesium alloy was pressurized to various pressures. As a result it was found that in order to obtain a composite material having a good quality the molten magnesium alloy must be pressurized at least to 500 kg/cm^2.

Embodiment 3

As shown from the above Embodiments 1 and 2 it is desirable that the preform includes the determinate metal fibers or powder. Therefore, investigations were conducted to determine what amount of the metal fibers or the metal powder is appropriate.

The reinforcing materials shown in Tables 8 and 9, and the matrix metals, the metal fibers and the metal powder shown in Table 10 and 11 were prepared. By using these materials composite materials were produced in the same manner as in Embodiments 1 and 2 with no preheating of the preforms. The composite materials thus obtained were evaluated about the composite conditions in the same manner as in Embodiments 1 and 2. The metal fibers and the metal powder were the same as those shown in Table 1. The mass ratio of the metal fibers or the metal powder relative to the reinforcing material was set to 0%, 50%, 100%, 150%, 200%, 250% and 300%. The results of evaluation are shown in Tables 10 and 11.

From Tables 10 and 11 it will be understood that, regardless of the kinds of the reinforcing material, the metal fibers and the metal powder and the composition of the matrix metal, the mass ratio of the metal fibers or the metal powder relative to the reinforcing material should desirably be more than 150%, particularly more than 200%, when the matrix metal is an aluminum alloy, and more than 130%, particularly 180%, when the matrix metal is a magnesium alloy.

Embodiment 4

With regard to the combinations of the reinforcing material and the metal fibers or the metal powder which provided the good composite condition in Embodiment 1 (these combinations bearing the double circle mark (◎) or the circle mark (○) in all of the Tables 2-4) cylindrical preforms such as 24 shown in Fig. 4 having 40 mm outer diameter, 30 mm inner diameter and 50 mm length were prepared in the same manner as in Embodiment 1 so that the volumetric ratio of the reinforcing material and the mass ratio of the metal fibers or the metal powder relative to the reinforcing material are the same as in the first type preform and the second type preform in Embodiment 1. In Fig. 4, 26 indicates the reinforcing material, and 28 indicates the metal fibers. For the matrix metal the same seven kinds of molten aluminum alloys as those used in Embodiment 1 were prepared.

Then each preform was preheated to the same temperature as in Embodiment 1, and then each preform 24 was held at a top portion thereof by a pincette-shaped holder 30 as shown in Fig. 5, and a bottom end portion of each preform was brought into contact with a bath of the molten aluminum alloy at 700 °C contained in a vessel 32. Then the molten aluminum alloy infiltrated into the whole body of each preform from the lower end to the upper end thereof in 3-10 seconds. After the molten aluminum alloy has completely infiltrated into the whole body of the preform, the preform was removed from the bath of the molten aluminum alloy as shown in Fig. 6 and was held in that condition until the molten aluminum alloy solidified. During this process the molten aluminum alloy was maintained in the preform as attached thereto under the surface tension.

Then the dimensions of the composite material cylindrical body were measured. The outer diameter, the inner diameter and the length were 39-41 mm, 28-30 mm and 48-50 mm, respectively. It was confirmed that the composite material cylindrical body had substantially the same shape and dimensions as the preform. Each composite material cylindrical body was cut for the inspection of the composite condition. It was confirmed that in all of the composite material cylindrical bodies the aluminum alloy has sufficiently infiltrated up to all surfaces of the preform.

Embodiment 5

With regard to the combinations of the reinforcing material and the metal fibers or the metal powder which provided the good composite condition in Embodiment 2 (these combinations bearing the double circle mark (◎) or the circle mark (○) in all of the Tables 5-7) cylindrical preforms having 80 mm outer diameter, 70 mm inner diameter and 40 mm length were prepared in the same manner as in Embodiment 2 so that the volumetric ratio of the reinforcing material and the mass ratio of the metal fibers or the metal powder relative to the reinforcing material are the same as in the first type preform and the second type preform in Embodiment 2. For the matrix metal the same three kinds of molten magnesium alloys as those used in Embodiment 2 were prepared.

Then each preform was preheated to the same temperature as in Embodiment 2, and then each preform 24 was brought into contact with a bath of the molten magnesium alloy at 700 °C contained in a vessel in the same manner as in Embodiment 4. Then the molten magnesium alloy infiltrated into the whole body of each preform from the lower end to the upper end thereof in 3-8 seconds. After the molten aluminum alloy has completely infiltrated into the whole body of the preform, the preform was removed from the bath of the molten aluminum alloy and was held in that condition until the molten magnesium alloy solidified. During this process the molten magnesium alloy was maintained in the preform as attached thereto under the surface tension.

Then the dimensions of the composite material cylindrical body were measured. The outer diameter, the inner diameter and the length were 79.5-80.5 mm, 69-70 mm and 39-40 mm, respectively. It was confirmed that the composite material cylindrical body had substantially the same shape and dimensions as the preform. Each composite material cylindrical body was cut for the inspection of the composite condition. It was confirmed that in all of the composite material cylindrical bodies the aluminum alloy has sufficiently infiltrated up to all surfaces of the preform.

Embodiment 6

As the reinforcing material alumina short fibers having 3 microns mean fiber diameter and 1 mm mean fiber length ("Safil RG", product of ICI, 95% Al_2O_3, 5% SiO_2), silicon carbide whisker having 0.1-1.0 micron fiber diameter and 50-200 microns fiber length (product of Tokai Carbon Kabushiki Kaisha), and silicon nitride particles having 10 microns mean particle diameter (product of Kojundo Kagaku Kabushiki Kaisha) were prepared.

Then the above-mentioned reinforcing material was mixed with a sol of oxides (Al_2O_3, ZrO_2, Fe_2O_3, CeO_2, SiO_2) (product of Nissan Kagaku Kabushiki Kaisha) and the mixture was formed under pressure and dried, thereby producing a first type preform including the above-mentioned reinforcing material and fine pieces of the above-mentioned oxides.

The above-mentioned reinforcing material was mixed with a water solution or an ethanol solution of chlorides ($MnCl_2 \bullet 4H_2O$, $NiCl_2 \bullet 6H_2O$, $TiCl_4$, $CuCl_2$, $ZnCl_2$, $SnCl_2 \bullet 2H_2O$) (product of Nihon Shinkinzoku Kabushiki Kaisha) and the mixture was formed under suction and heated in the atmosphere at 500 °C so that the chlorides were converted into oxides, thereby producing a second type preform including the reinforcing material and fine pieces of the oxides converted from the above-mentioned chlorides.

The above-mentioned reinforcing material was mixed with Ta_2O_5 powder having 1.5 micron mean particle diameter (product of Mitsui Kinzoku Kabushiki Kaisha), Nb_2O_5 powder having 5 microns mean particle diameter (product of Mitsui Kinzoku Kabushiki Kaisha), PbO powder having 1-2 microns particle diameter (product of Kojundo Kagaku Kabushiki Kaisha), V_2O_5 powder having 5 microns mean particle diameter (product of Kojundo Kagaku Kabushiki Kaisha), Bi_2O_3 powder having 6 microns mean particle diameter (product of Kojundo Kagaku Kabushiki Kaisha), Co_3O_4 powder having 74 microns mean particle diameter (product of Sumitomo Kinzoku Kozan Kabushiki Kaisha) and MgO powder having 0.05 micron mean particle diameter (product of Ube Kosan Kabushiki Kaisha) in water, respectively, and the mixture was formed under compression and dried, thereby producing a third type preform including the above-mentioned reinforcing material and fine pieces of the above-mentioned oxide.

The above-mentioned reinforcing material was mixed in a water solution including polyvinyl alcohol, and the well agitated mixture was formed to a body by suction and dried, and the formed body was soaked in a water solution dissolving Cr_2O_3 (product of Nippon Denko Kabushiki Kaisha), H_3BO_3 (product of Kenei Seiyaku Kabushiki Kaisha) and para-ammonium molybdate (product of Nihon Shinkinzoku Kabushiki Kaisha), and the water solution was heated in the atmosphere to 500° C for an hour, so that fine pieces of oxides of Cr, B and Mo are generated while water and polyvinyl alcohol were evaporated, thereby producing a fourth type preform including the above-mentioned reinforcing material and fine pieces of the above-mentioned oxides.

Further, the above-mentioned reinforcing material was mixed into a water solution of polyvinyl alcohol and the well agitated mixture was formed to a body by suction and dried, and the body thus formed was soaked in a methane ammonium wolframate solution (product of Nihon Shinkinzoku Kabushiki Kaisha), and then the body was heated in the atmosphere to 700° C for one hour, so that fine pieces of oxide of W are generated while water was evaporated, thereby producing a fifth type preform including the above-mentioned reinforcing material and fine pieces of the above-mentioned oxides.

The preform produced in the above-mentioned manner was also as shown in Fig. 1 by 10, wherein 12 also indicates the reinforcing material and 14 indicates in this case the fine pieces of the metal oxide. In this case, two kinds of preforms were prepared by changing the mixing ratio of the reinforcing material and the metal oxide powder so that in a first kind preform the volumetric ratio of the reinforcing material is 5% and the mass ratio of the metal oxide relative to the reinforcing material is 15%, and in a second kind preform the volumetric ratio of the reinforcing material is 15% and the mass ratio of the metal oxide relative to the reinforcing material is 15%. Each preform has a rectangular parallelepiped shape of 20 x 20 x 40mm, and the fine pieces of the metal oxide were distributed substantially uniformly in the body of the preform.

Then the preform which includes an oxide of B as the metal oxide was preheated to 400° C while the other preforms were preheated to 600° C, and each said preform 10 was placed in a vessel 16 also as shown in Fig. 2, and then a molten matrix metal was poured into the vessel so as to form a bath 18 thereof, and then the molten matrix metal was solidified. The matrix alloy was prepared in eight different types of aluminum alloy which were JIS AC1A including 0.1% Mg, JIS AC4C including 0.3% Mg, JIS AC4D including 0.5% Mg, JIS AC8A including 1% Mg, JIS AC7B including 10% Mg, and JIS AC4C added with 0.3% Mg, 0.3% Ca, and 0.3% Zr, respectively, and magnesium alloys prepared in three different types which were JIS FC-2, JIS MC-7 and JIS MC-8.

Then a composite material 20 was cut out from the solidified body prepared in the above-mentioned manner corresponding to the portion occupied by the preform, and then the composite material was cut also along a phantom plane 22 at a central portion thereof in Fig. 3. Then the cutout section was polished and investigated by the naked eye and a microscope for evaluation of the composite quality.

The results of the evaluation are given in Tables 12-14 with respect to the composite materials in which the matrix metal was the aluminum alloy, and in Tables 15-17 with respect to the composite materials in which the matrix metal was the magnesium alloy. In these Tables a double circle (◎) indicates that both the macroscopic composite condition and the microscopic composite condition were goods, a single circle (○) indicates that the macroscopic composite condition was good, a triangle (△) indicates that only partial composite was accomplished, and a cross (X) indicates that no composite structure was accomplished. (These indications are the same in the subsequent Table 20.)

From Table 12-17 it will be understood that regardless of the types and the volumetric ratio of the reinforcing material and the composition of the aluminum alloy, when the preform includes the fine pieces of an oxide or oxides of W, Mo, Pb, Bi, V, Cu, Ni, Co, Sn, Mn, B, Cr, Mg or Al, particularly the fine pieces of an oxide or oxides of W, Mo, Pb, Co or Mn, a good composite quality is obtained. Further, when the matrix metal is an aluminum alloy, a much better composite quality is obtained when the aluminum alloy includes more than 0.5% Mg or more than 0.5% in total of Mg, Ca and Zr.

Although not included in the shown embodiment, it was confirmed that a good composite quality is obtained when the aluminum alloy includes more than 0.5 Mg, Ca or Zr.

Comparison Example 3

By the same alumina short fibers as used in Embodiment 6 preforms were prepared to include only the alumina short fibers at 5%, 15% and 30% by volume. Further, by the same silicon carbide whisker as used in Embodiment 6 preforms were prepared to include only the silicon carbide whisker at 5%, 15% and 40% by volume. Further, by the same silicon nitride particles as used in Embodiment 6 preforms were prepared to include only the silicon nitride particles at 5%, 15% and 50% by volume. By using these preforms it was tried to produce composite materials in the same manner and under the same conditions as adopted in Embodiment 6. However, no good composite material was obtained from these preforms.

Further, it was tried to produce composite materials from the preforms of the above-mentioned comparison purpose with the matrix metal by employing a high pressure casting device in the same manner and under the same conditions as in Embodiment 6 except that the matrix metal was pressurized to various raised pressures. As a result it was found that in order to obtain a composite material having good quality the molten matrix metal must be pressurized to at least 500 g/cm^2.

Embodiment 7

As shown from the above Embodiment 6 it is desirable that the preform includes fine pieces of a determinate metal oxide or metal oxides. Therefore, investigations were conducted to determine what amount of the metal oxide or metal oxides is appropriate.

Preforms were prepared from the reinforcing material shown in Tables 18 and 19 and the fine pieces of metal oxides shown in Table 20. Then by using these preforms with the molten matrix metals shown in Table 20 it was tried to produce composite materials in the same manner as in Embodiment 6. Then the composite condition of each composite material thus obtained was evaluated in the same manner as in Embodiment 6. The mass ratio of the fine pieces of the metal oxide relative to the reinforcing material was set to 0%, 2.5%, 5%, 7.5%, 10%, 15%, 20% and 30%. The results of evaluation are shown in Table 20.

From Table 20 it will be understood that, regardless of the kinds of the reinforcing material and the composition of the metal oxide, the mass ratio of the fine pieces of the metal oxide relative to the reinforcing material should be more than 7.5%, particularly more than 10%, and still more particularly more than 15%.

Embodiment 8

With regard to the combinations of the reinforcing material and the fine pieces of the metal oxides which provided the good composite condition in Embodiment 6 (these combinations bearing the double circle mark (◎) or the circle mark (○) in all of the Tables 12-17) cylindrical preforms such as the one shown again in Fig. 4 having 40 mm outer diameter, 30 mm inner diameter and 50 mm length were prepared in the same manner as in Embodiment 6 so that the volumetric ratio of the reinforcing material and the mass ratio of the metal oxide relative to the reinforcing material are the same as in the first kind preform and the second kind preform in Embodiment 6. In this case, also as seen in Fig. 4, 26 indicates the reinforcing material and 28 now indicates the fine pieces of the metal oxide. For the matrix metal the same eight kinds of molten aluminum alloys and the same three kinds of molten magnesium alloys as those used in Embodiment 6 were prepared.

Then each preform was preheated to the same temperature as in Embodiment 6, and then each preform 24 was held at a top portion thereof by a pincette-shaped holder 30 also as shown in Fig. 5, and a bottom end portion of each preform was brought into contact with a bath 34 of the molten matrix metal at 700°C contained in the vessel 32. Then the molten matrix metal infiltrated into the whole body of each preform from the lower end to the upper end thereof in 10-30 seconds. After the molten matrix metal had completely infiltrated into the whole body of the preform, the preform was removed from the bath of the molten matrix metal also as shown in Fig. 6 and was held in that condition until the molten matrix metal solidified. During this process the molten matrix metal was maintained in the preform as attached thereto under the surface tension.

Then the dimensions of the composite material cylindrical body were measured. The outer diameter, the inner diameter and the length were 40-41 mm, 29-30 mm and 49-50 mm, respectively. It was confirmed that the composite material cylindrical body had substantially the same shape and dimensions as the preform. Each composite material cylindrical body was cut for the inspection of the composite condition. It was confirmed that in all of the composite material cylindrical bodies the matrix metal has sufficiently infiltrated up to all surfaces of the preform.

From the foregoing it will be appreciated that according to the present invention the composite material can be produced in high quality in which the matrix metal is sufficiently infiltrated into the interstices of the reinforcing material at high efficiency and low cost with no need of pressurization of the molten matrix metal so that a composite material product having a predetermined shape and dimensions is directly produced at very high efficiency and yielding rate.

Further, although the preforms have been preheated in the above Embodiments 1, 2 and 4, it was confirmed that the composite material is obtained also in good condition when the preform is not preheated.

Although the invention has been described in detail with respect to some preferred embodiments thereof, it is to be noted that various other embodiments are possible within the scope of the present invention.

Table 1

Fiber/Powder	Dia. (µm)	Length (mm)	Manufacturer
Ni fiber	20	1	Tokyo Seikou K.K.
Stainless steel fiber(1)	20	1	"
Ti fiber	20	1	"
Cu-Zn fiber(2)	60	3	Aishin Seiki K.K.
Al-Mg fiber(3)	60	3	"
Zn fiber	90	3	"
Sn fiber	90	3	"
W powder	1.0	-	Nihon Shinkinzoku K.K.
Mo Powder	5	-	"
Ta Powder	10	-	Koujundo Kagaku K.K.
Nb powder	3	-	"
V powder	6	-	"
Zr powder	74	-	"
Co powder	2~3	-	"
Mn powder	2~3	-	"
Si powder	43	-	"
Cr powder	2~3	-	"
Ag powder	75	-	"
Mg powder	75	-	Fukuda Kinzoku K.K.
Pb powder	75	-	"
Notes:			

(1) JIS SUS430
(2) Cu-40%Zn
(3) Al-5%Mg

Table 2

Alumina short fiber vol.%	Matrix metal	Metal fiber						Metal powder							
		Ni	SUS	Sn	Cu-Zn	Zn	Al-Mg	Ti	Co	Si	Cr	Mn	Mg	Ag	Nb
5	AC1A	◎	◎	○	○	○	○	○	○	○	○	○	○	○	×
15		○	○	○	○	○	○	○	○	○	○	○	○	○	×
5	AC4C	◎	◎	◎	◎	◎	○	◎	◎	◎	○	○	○	○	×
15		◎	○	○	○	○	○	○	○	○	○	○	○	○	×
5	AC4D	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	×
15		◎	◎	◎	◎	◎	○	○	○	○	○	○	○	○	×
5	AC8A	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	×
15		◎	◎	◎	◎	◎	○	◎	◎	◎	○	○	○	○	×
5	AC7B	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	△
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	△
15	AC4C+ 0.3%Ca	◎	◎	◎	◎	◎	○	◎	◎	◎	○	○	○	○	×

Notes: SUS: JIS SUS430
Cu-Zn: Cu-40%Zn
Al-Mg: Al-5%Mg

Table 3

SiC whisker	Matrix	Metal fiber						Metal powder								
vol.%	metal	Ni	SUS	Sn	Cu-Zn	Zn	Al-Mg	Ti	Co	Si	Cr	Mn	Mg	Ag	Nb	Pb
5	AC1A	◎	◎	◎	◎	○	○	○	○	○	○	○	○	○	×	×
15		◎	○	○	○	○	○	○	○	○	○	○	○	○	×	×
5	AC4C	◎	◎	◎	◎	◎	○	◎	◎	◎	○	○	○	○	×	×
15		◎	◎	○	○	○	○	◎	◎	○	○	○	○	○	×	×
5	AC4D	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	×	×
15		◎	◎	◎	◎	◎	○	◎	◎	◎	○	○	○	○	×	×
5	AC8A	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	△	△
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○	○	○	×	△
5	AC7B	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	△	△
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	△	△
15	AC4C+ 0.3%Zr	◎	◎	◎	◎	◎	○	◎	◎	◎	○	○	○	○	×	×

Notes : SUS: JIS SUS430
Cu-Zn: Cu-40%Zn
Al-Mg: Al-5%Mg

Table 4

Si_3N_4 particle	Matrix			Metal fiber				Metal powder								
vol.%	metal	Ni	SUS	Sn	Cu-Zn	Zn	Al-Mg	Ti	Co	Si	Cr	Mn	Mg	Ag	Nb	Pb
5	AC1A	◎	◎	◎	◎	◎	○	◎	◎	○	○	○	○	○	×	×
15		◎	◎	○	○	○	○	○	○	○	○	○	○	○	×	×
5	AC4C	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○	○	○	×	×
15		◎	◎	◎	○	○	○	◎	◎	◎	○	○	○	○	×	×
5	AC4D	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	×	×
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○	○	○	×	×
5	AC8A	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	△	△
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	△	△
5	AC7B	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	△	△
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	△	△
15	AC4C+ 0.3%Ca	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	×	△

Notes :
SUS: JIS SUS430
Cu-Zn: Cu-40%Zn
Al-Mg: Al-5%Mg

Table 5

WC particle	Matrix	Metal fiber						Metal powder								
vol.%	metal	Ni	Al-Mg	Sn	Zn	SUS	Cu-Zn	Ti	Cr	Ag	Pb	Si	Mu	Mg	Nb	Co
5	MC-2	◎	◎	◎	◎	△	△	△	◎	◎	◎	△	△	△	△	△
15		◎	◎	◎	◎	△	△	△	◎	◎	◎	×	×	×	×	×
5	MC-7	◎	◎	◎	◎	△	△	△	◎	◎	◎	△	△	△	△	△
15		◎	◎	◎	◎	△	△	△	◎	◎	◎	×	×	×	×	×
5	MC-8	◎	◎	◎	◎	△	△	△	◎	◎	◎	△	△	△	△	△
15		◎	◎	◎	◎	△	△	△	◎	◎	◎	×	×	×	×	×

Notes : SUS: JIS SUS430
Cu-Zn: Cu-40%Zn
Al-Mg: Al-5%Mg

Table 6

Si_3N_4 whisker	Matrix	Metal fiber						Metal powder								
vol.%	metal	Ni	Al-Mg	Sn	Zn	SUS	Cu-Zn	Ti	Cr	Ag	Pb	Si	Mu	Mg	Nb	Co
5	MC-2	◎	◎	◎	◎	△	△	△	◎	◎	◎	△	△	△	△	△
15		◎	◎	◎	◎	△	△	△	◎	◎	◎	×	×	×	×	×
5	MC-7	◎	◎	◎	◎	△	△	△	◎	◎	◎	△	△	△	△	△
15		◎	◎	◎	◎	△	△	△	◎	◎	◎	×	×	×	×	×
5	MC-8	◎	◎	◎	◎	△	△	△	◎	◎	◎	△	△	△	△	△
15		◎	◎	◎	◎	△	△	△	◎	◎	◎	×	×	×	×	×

Notes : SUS: JIS SUS430

Cu-Zn: Cu-40%Zn

Al-Mg: Al-5%Mg

Table 7

Almina short fiber vol.%	Matrix metal	Metal fiber						Metal powder								
		Ni	Al-Mg	Sn	Zn	SUS	Cu-Zn	Ti	Cr	Ag	Pb	Si	Mu	Mg	Nb	Co
5	MC-2	◎	◎	◎	◎	△	△	△	◎	◎	◎	△	△	△	△	△
15		◎	◎	◎	◎	△	△	△	◎	◎	◎	△	△	△	△	△
5	MC-7	◎	◎	◎	◎	△	△	△	◎	◎	◎	△	△	△	△	△
15		◎	◎	◎	◎	△	△	△	◎	◎	◎	△	△	△	△	△
5	MC-8	◎	◎	◎	◎	△	△	△	◎	◎	◎	△	△	△	△	△
15		◎	◎	◎	◎	△	△	△	◎	◎	◎	△	△	△	△	△

Notes : SUS: JIS SUS430

Cu-Zn: Cu-40%Zn

Al-Mg: Al-5%Mg

Table 8

Material	Dimentions	Manufacturar
Alumina-silica short fiber	mean fiber dia.:2.8 μm.mean fiber length:2mm	Isolite-Babcock Refractories K.K.
Potassium-Titanate whisker	fiber dia.:10 ~30μm.fiber length: 80~ 350μm	Kubota Tekko K.K.
TiC particle	mean particle dia.: 1.2 μm	Nihon Shin Kinzoku K.K.
Mineral fiber	mean fiber dia.:5 μm,mean fiber length: 800μm	Nitto Boseki K.k.
Si_3N_4 whisker	fiber dia.: 0.1 ~ 0.6μm,fiber length: 20~ 200μm	Tateho Kagaku Kogyo K.K.
Graphite particle	mean particle dia.:10 μm	Nihon Kokuen Kogyo K.K.
Cryst. alumina-silica short fiber	mean fiber dia.:2.8 μm,mean fiber length:2mm	Isolite-Babcock Refractories K.K.
Graphite whisker	fiber dia.: 0.1 ~ 1.0μm,fiber length: 10~ 200μm	Nikkiso K.K.
BN particle	mean particle dia.: 8 μm	Showa Denko K.K.
Glass fiber	mean fiber dia.: 13 μm,mean fiber length:3mm	Nihon Muki Seni Kogyo K.K.
SiC whisker	fiber dia.:0.05 ~ 1.5μm,fiber length: 20~ 200μm	Tateho Kagaku Kogyo K.K.
Cr_3C_2 particle	mean particle dia.: 6 μm	Nihon Shin Kinzoku K.K.

Table 9

Material	Dimentions	Manufacturer
Alumina short fiber	mean fiber dia.: 3µm.mean fiber length:2mm	Nichiasu K.K.
SiC whisker	mean fiber dia.: 0.2µm.mean fiber length: 7µm	Shinetsu Kagaku K.K.
TiC particle	mean particle dia.:1.2µm	Nihon Shinkinzoku K.K.
Cryst. alumina-silica short fiber	mean fiber dia.: 2.8µm,mean fiber length: 2µm	Isolite-Babcock Refractories K.K.
Graphite whisker	fiber dia.:0.1~1.0µm,fiber length: 10~200µm	Nikkiso K.K.
Si_3N_4 particle	mean particle dia.: 10µm	Kojundo Kagaku K.K.
ZrO_2 fiber	mean fiber dia.: 5µm,mean fiber length:2mm	Shinagawa Shirorenga K.K.

Table 10

Reinforcing material	Matrix metal	Metal fiber/Metal powder	Mass ratio relative to reinforcing material						
Vol %			0	50	100	150	200	250	300 (%)
Alumina-silica short fiber	AC4D	SUS fiber	×	Δ	Δ	◎	◎	◎	◎
Potassium-titanete whisker	AC8A	Ni particle	×	×	Δ	○	◎	◎	◎
TiC particle	AC7B	Cu fiber	×	×	Δ	○	◎	◎	◎
Mineral fiber	AC7B	Sn fiber	×	Δ	◎	◎	◎	◎	◎
Si_3N_4 whisker	AC8A	Zn fiber	×	Δ	○	◎	◎	◎	◎
Graphite particle	AC4D	Co powder	×	Δ	○	◎	◎	◎	◎
Cryst. alumina-silica short fiber	AC4C+0.3%Cu	Si powder	×	Δ	◎	◎	◎	◎	◎
Graphite whisker	AC4D	Cr powder	×	×	Δ	◎	◎	◎	◎
BN particle	AC8A	Al-Mg fiber	×	Δ	Δ	◎	◎	◎	◎
Grass fiber	AC4C+0.3%Zr	Mn powder	×	×	Δ	○	◎	◎	◎
SiC whisker	AC7B	Ag powder	×	×	Δ	◎	◎	◎	◎
Cr_3C_2 particle	AC4C+0.2%Mg	Mg powder	×	×	Δ	○	◎	◎	◎

Table 11

Reinforcing material	Matrix metal	Metal fiber/Metal powder	Mass ratio relative to reinforcing material						
vol %			0	30	80	130	180	230	280
Alumina short fiber	MC-2	Ni fiber	×	Δ	Δ	◎	◎	◎	◎
SiC whisker	MC-7	Zn particle	×	Δ	Δ	◎	◎	◎	◎
TiC particle	MC-8	Cr fiber	×	×	Δ	○	◎	◎	◎
Cryst. alumina-silica short fiber	MC-2	Al-Mg fiber	×	Δ	○	◎	◎	◎	◎
Graphite whisker	MC-7	Ag fiber	×	Δ	Δ	◎	◎	◎	◎
Si_3N_4 particle	MC-8	Sn fiber	×	×	Δ	◎	◎	◎	◎
ZrO_2 fiber	MC-5	Pb powder	×	×	Δ	○	◎	◎	◎

Table 12

Alumina short fiber vol. %	Matrix metal	Metal element forming oxide												
		W	Mo	Pb	Co	Mn	Bi	Cu	Ni	Sn	Cr	V	B	Mg
5	AC1A	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○	○
15		◎	◎	◎	◎	◎	○	○	○	○	○	○	○	○
5	AC4C	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○	○
15		◎	◎	◎	◎	◎	○	○	○	○	○	○	○	○
5	AC4D	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○	○
5	AC8A	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○	○
5	AC7B	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
5	AC4C +0.3%Ca	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○	○

Table 13

SiC whisker vol.%	Matrix metal	Metal element forming oxide												
		W	Mo	Pb	Co	Mn	Bi	Cu	Ni	Sn	Cr	V	B	Mg
5	AC1A	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○	○
15		◎	◎	◎	◎	◎	◎	◎	○	○	○	○	○	○
5	AC4C	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○	○
15		◎	◎	◎	◎	◎	◎	◎	○	○	○	○	○	○
5	AC4D	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○
5	AC8A	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○
5	AC7B	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
5	AC4C +0.3%Zr	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○

Table 14

Si_3N_4 particle vol.%	Matrix metal	Metal element forming oxide												
		W	Mo	Pb	Co	Mn	Bi	Cu	Ni	Sn	Cr	V	B	Mg
5	AC1A	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○	○
15		◎	◎	◎	◎	◎	◎	◎	◎	○	○	○	○	○
5	AC4C	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○	○
15		◎	◎	◎	◎	◎	◎	◎	◎	○	○	○	○	○
5	AC4D	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○
5	AC8A	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○
5	AC7B	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
5	AC4C +0.3%Mg	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○

Table 15

Alumina short fiber Vol.%	Matrix metal	Metal element forming oxide											
		W	Mo	Pb	Co	Mn	Bi	Cu	Ni	Sn	Cr	V	B
5	MC-2	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○
5	MC-7	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○
5	MC-8	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○

Table 16

SiC whisker Vol. %	Matrix metal	Metal element forming oxide											
		W	Mo	Pb	Co	Mn	Bi	Cu	Ni	Sn	Cr	V	B
5	MC-2	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○
5	MC-7	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○
5	MC-8	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○

Table 17

Si_3N_4 particle vol.%	Matrix metal	Metal element forming oxide											
		W	Mo	Pb	Co	Mn	Bi	Cu	Ni	Sn	Cr	V	B
5	MC-2	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○
5	MC-7	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○
5	MC-8	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
15		◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	○

Table 18

Material	Dimentions	Manufacturer
Alumina-silica short fiber	mean fiber dia.: 2.8µm.mean fiber length:2mm	Isolite-Babcock Refractories K.K.
Potassium-Titanate whisker	fiber dia.: 10~30µm.fiber length: 80~ 350µm	Kubota Tekkou K.K.
TiC particle	mean particle dia.:1.2µm	Nihon Shin Kinzoku K.K.
Mineral fiber	mean fiber dia.: 5µm,mean fiber length: 800µm	Nitou Bouseki K.K.
Glass fiber	mean fiber dia.:13µm,mean fiber length:3mm	Nihon Mukiseni Kogyo K.K.
Si_3N_4 whisker	fiber dia.:0.1~ 0.6µm,fiber length: 20~ 200µm,	Tateho Kagaku Kogyo K.K.
Cr_3C_2 particle	mean particle dia.:6µm	Nihon Shin Kinzoku K.K.

Table 19

Material	Dimentions	Manufacturer
Alumina short fiber	mean fiber dia.: 3µm.mean fiber length:2mm	Nichiasu K.K.
Si_3N_4 whisker	fiber dia.:0.1~0.6 µm.fiber length: 20~ 200µm	Tateho Kagaku Kogyo K.K.
WC particle	mean particle dia.: 10µm	Nihon Shinkinzoku K.K.
Cryst. alumina-silica short fiber	mean fiber dia.: 2.8µm,mean fiber length: 2µm	Isolite-Babcock Refractories K.K.
ZrO_2 fiber	mean fiber dia.: 5µm,mean fiber length: 2µm	Shinagawa Shirorenga K.K.
Graphite particle	mean particle dia.: 10µm	Nihon Kokuen Kogyo K.K.
BN particle	mean particle dia.:8µm	Showa Denkou K.K.
SiC whisker	fiber dia.: 0.05~ 1.5µm,fiber length: 20~200mm	Tateho Kagaku Kogyo K.K.
TiC particle	mean particle dia.:1.2µm	Nihon Shinkinzoku K.K.

Table 20

Reinforcing material vol.%	Matrix metal	Oxide	Mass ratio relative to reinforcing material							
			0	2.5	5	7.5	10	15	20	30 (%)
Alumina-silica short fiber	AC4D	W oxide	×	Δ	Δ	◎	◎	◎	◎	◎
Potassium-Titanate whisker	AC8A	Mo oxide	×	×	Δ	○	◎	◎	◎	◎
TiC particle	AC7B	Pb oxide	×	×	Δ	○	○	◎	◎	◎
Alumina short fiber	MC-2	Co oxide	×	Δ	Δ	◎	◎	◎	◎	◎
Si_3N_4 whisker	MC-7	Mn oxide	×	Δ	Δ	◎	◎	◎	◎	◎
WC particle	MC-8	W oxide	×	×	Δ	○	◎	◎	◎	◎
Mineral fiber	AC4C+0.3%Ca	Mo oxide	×	Δ	○	◎	◎	◎	◎	◎
Glass fiber	AC4C+0.2%Mg	Cu oxide	×	Δ	Δ	◎	◎	◎	◎	◎
Potassium-Titanate whisker	AC4C+0.3%Mg	Sn oxide	×	×	Δ	○	◎	◎	◎	◎
Si_3N_4 whisker	AC8A	V oxide	×	×	Δ	○	◎	◎	◎	◎
Cr_3C_2 particle	AC7B	Mg oxide	×	×	Δ	○	◎	◎	◎	◎
Cryst. alumina-silica short fiber	MC-8	Al oxide	×	Δ	Δ	◎	◎	◎	◎	◎
ZrO_2 fiber	MC-8	B oxide	×	Δ	Δ	◎	◎	◎	◎	◎
Graphite particle	MC-7	Cr oxide	×	Δ	Δ	◎	◎	◎	◎	◎
Alumina short fiber	MC-7	Bi oxide	×	Δ	Δ	◎	◎	◎	◎	◎
BN particle	MC-5	Ni oxide	×	×	Δ	○	◎	◎	◎	◎
SiC whisker	MC-2	Pb oxide	×	×	Δ	○	◎	◎	◎	◎
TiC particle	MC-2	Mo oxide	×	×	Δ	○	◎	◎	◎	◎

Claims

1. A method of producing a metal base composite material comprising a first process of producing a porous preform from a reinforcing material selected from a group consisting of short fibers, whisker, particles and mixtures thereof, and a second process of infiltrating a molten matrix metal into the interstices of said porous preform, wherein in said first process fine pieces of a third material having good affinity to the molten matrix metal are mixed in said porous preform, and in said second process at least a part of said preform is contacted with a molten mass of the matrix metal so that the molten matrix metal infiltrates into the interstices of said porous preform with no substantial pressure being applied thereto.

2. A method according to claim 1, wherein said third material for said fine pieces is a metal or metals selected from a group consisting of Ni, Fe, Co, Cr, Mn, Cu, Ag, Si, Mg, Al, Zn, Sn, Ti and an alloy or alloys including any one of these metals as a principal component when the matrix metal is Al or an Al alloy.

3. A method according to claim 1, wherein said third material for said fine pieces is a metal or metals selected from a group consisting of Ni, Cr, Ag, Al, Zn, Sn, Pb and an alloy or alloys including any one of these metals as a principal component when the matrix metal is Mg or a Mg alloy.

4. A method according to claim 1, wherein when said reinforcing material is particularly selected from a group consisting of short fibers, whisker, particles and mixtures thereof made of an inorganic material other than metal, and the matrix metal is a metal selected from a group consisting of Al, Mg, Al alloy and Mg alloy, the material for said fine pieces is an oxide or oxides of a metal or metals selected from a group consisting of W, Mo, Pb, Bi, V, Cu, Ni, Co, Sn, Mn, B, Cr, Mg and Al and mixtures thereof.

5. A method according to claim 2, wherein said fine pieces of a determinate metal or metals are incorporated into the preform at a ratio more than 150% by weight relative to the amount of the reinforcing material.

6. A method according to claim 4, wherein said fine pieces of a determinate metal oxide or metal oxides are incorporated into the preform at a ratio more than 7.5% by weight.

7. A method according to claim 4, wherein said fine pieces of a determinate metal oxide or metal oxides are incorporated into the preform at a ratio more than 10% by weight.

8. A method according to claim 4, wherein said fine pieces of a determinate metal oxide or metal oxides are incorporated into the preform at a ratio more than 15% by weight.

9. A method according to claim 2, wherein the metal to form said fine pieces is selected more particularly from a group consisting of Hi, Fe, Co, Cu, Si, Zn, Sn, Ti and an alloy including one of these metals as a principal component.

10. A method according to claim 4, wherein the metal to form said fine pieces is selected more particularly from a group consisting of W, Mo, Pb, Bi, Cu, Ni, Co, Sn, Mn, Cr or an alloy including one of these metals as a principal component.

11. A method according to claim 4, wherein the metal to form said fine pieces is selected more particularly from a group consisting of W, Mo, Pb, Co, Mn or an alloy including one of these metals as a principal component.

12. A method according to claim 1, wherein the matrix metal is an Al alloy including at least one of Mg, Zr and Ca by an amount more than 0.5%.

13. A method according to claim 3, wherein said fine pieces of a certain determinate metal or metals is incorporated into the preform by an amount of more than 130% by weight relative to the reinforcing material in the preform.

14. A method according to claim 2, wherein the total volumetric ratio of said reinforcing material and said fine pieces of a determinate metal or metals is set to 5-90%.

15. A method according to claim 3, wherein the total volumetric ratio of said reinforcing material and said fine pieces of a determinate metal or metals is set to 5-90%.

16. A method according to claim 2, wherein the total volumetric ratio of said reinforcing material and said fine pieces of a determinate metal or metals is set to 7.5-85%.

17. A method according to claim 3, wherein the total volumetric ratio of said reinforcing material and said fine pieces of a determinate metal or metals is set to 7.5-85%.

18. A method according to claim 4, wherein the total volumetric ratio of said reinforcing material and said fine pieces of a determinate metal oxide or metal oxides is set to 4-85%.

19. A method according to claim 4, wherein the total volumetric ratio of said reinforcing material and said fine pieces of a determinate metal oxide or metal oxides is set to 5-80%.

20. A method according to claim claim 2, wherein the volumetric ratio of said fine pieces of a determinate metal or metals in the preform is set to be less than 85%.

21. A method according to claim claim 3, wherein the volumetric ratio of said fine pieces of a determinate metal or metals in the preform is set to be less than 85%.

22. A method according to claim 4, wherein the volumetric ratio of said fine pieces of a determinate metal oxide or metal oxides in the preform is set to be less than 45%.

23. A method according to claim 4, wherein the volumetric ratio of said fine pieces of a determinate metal oxide or metal oxides in the preform is set to be less than 40%.

24. A method according to claim 1, wherein the preform has a predetermined shape and dimensions, and only a part thereof is dipped into a bath of molten matrix metal.

FIG. 1

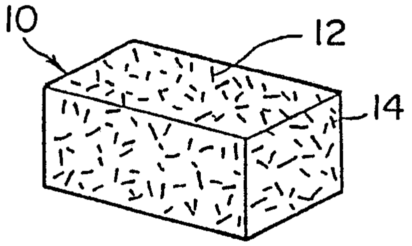


FIG. 2

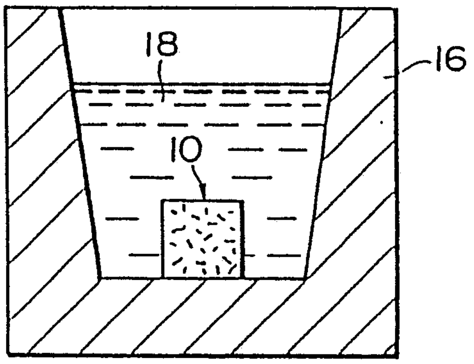


FIG. 3

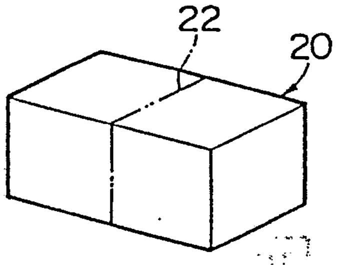


FIG. 4

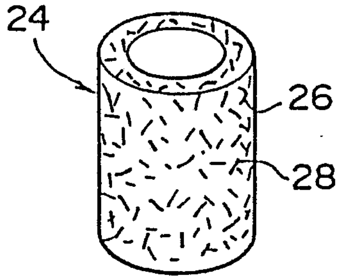


FIG. 5

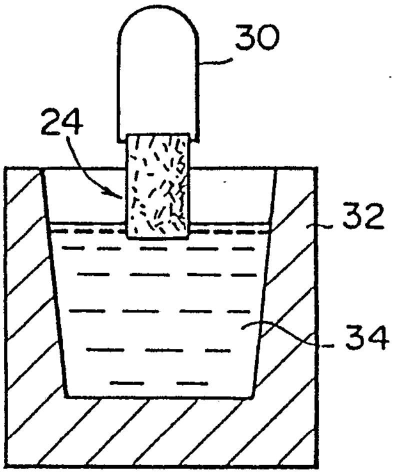


FIG. 6