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71 Applicant: TOYOTA JIDOSHA KABUSHIKI KAISHA
 1, Toyota-cho Toyota-shi
 Aichi-ken 471(JP)

72 Inventor: Kubo, Masahiro
 c/o TOYOTA JIDOSHA K.K. 1, Toyota-cho
 Toyota-shi Aichi-ken(JP)

72 Inventor: Tanaka, Atsuo
 c/o TOYOTA JIDOSHA K.K. 1, Toyota-cho
 Toyota-shi Aichi-ken(JP)

72 Inventor: Dohnomoto, Tadashi
 c/o TOYOTA JIDOSHA K.K. 1, Toyota-cho
 Toyota-shi Aichi-ken(JP)

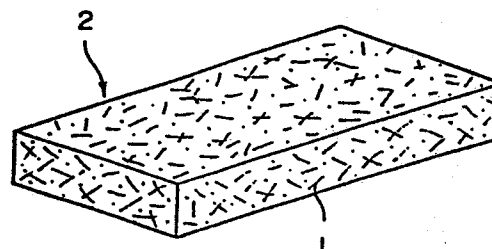
72 Inventor: Hirai, Hidetoshi c/o Toyoda Automatic Loom
 Works
 2-1 Toyoda-cho
 Kariya-shi Aichi-ken(JP)

74 Representative: Bühling, Gerhard, Dipl.-Chem. et al,
 Patentanwaltsbüro Tiedtke-Bühling-Kinne
 Grupe-Pellmann-Grams-Struif-Winter-Roth Bavariaring 4
 D-8000 München 2(DE)

54 Composite material including silicon nitride whisker type short fiber reinforcing material and aluminum alloy matrix metal with moderate copper and magnesium contents.

57 A composite material is made from silicon nitride whisker type short fiber material embedded in a matrix of metal. The matrix metal is an alloy consisting essentially of from approximately 2% to approximately 6% of copper, from approximately 0.5% to approximately 3% of magnesium, and remainder substantially aluminum. The fiber volume proportion of the silicon nitride type short fibers is between approximately 5% and approximately 50%, and may more desirably be between approximately 5% and approximately 40%. The magnesium content of the aluminum alloy matrix metal may desirably be between approximately 0.5% and approximately 2.5%. And, in the desirable case that the fiber volume proportion of the silicon nitride whisker type short fiber material is between approximately 30% and approximately 40%, then the copper content of the aluminum alloy matrix metal is desired to be between approximately 2% and approximately 5%.

FIG. 7



COMPOSITE MATERIAL INCLUDING
SILICON NITRIDE WHISKER TYPE SHORT
5 FIBER REINFORCING MATERIAL AND
ALUMINUM ALLOY MATRIX METAL WITH
10 MODERATE COPPER AND MAGNESIUM
CONTENTS

15 BACKGROUND OF THE INVENTION

20 The present invention relates to a composite material made up
from reinforcing fibers embedded in a matrix of metal, and more
particularly relates to such a composite material utilizing silicon nitride
whisker type material as the reinforcing fiber material, and aluminum
alloy as the matrix metal, i.e. to a silicon nitride whisker reinforced
aluminum alloy.

25 The present invention has been described in Japanese Patent
Application Serial No. ...Showa 61-024539 (1986), filed by an

applicant the same as the applicant or the entity assigned or owed duty of assignment of the present patent application; and the present patent application hereby incorporates into itself by reference the text of said Japanese Patent Application and the claims and the drawings thereof; a
5 copy is appended to the present application.

Further, the present inventors wish hereby to attract the attention of the examining authorities to copending Patent Applications Serial Nos., and
10, which may be considered to be material to the examination of the present patent application.

In the prior art, the following aluminum alloys of the cast type and of the wrought type have been utilized as matrix metal for a composite
15 material incorporating reinforcing fiber material:

Cast type aluminum alloys

JIS standard AC8A (from about 0.8% to about 1.3% Cu, from about 11.0%
20 to about 13.0% Si, from about 0.7% to about 1.3% Mg, from about 0.8% to about 1.5% Ni, remainder substantially Al)

JIS standard AC8B (from about 2.0% to about 4.0% Cu, from about 8.5%
25 to about 10.5% Si, from about 0.5% to about 1.5% Mg, from about 0.1% to about 1% Ni, remainder substantially Al)

JIS standard AC4C (Not more than about 0.25% Cu, from about 6.5% to about 7.5% Si, from about 0.25% to about 0.45% Mg, remainder substantially Al)

- 5 AA standard A201 (from about 4% to about 5% Cu, from about 0.2% to about 0.4% Mn, from about 0.15% to about 0.35% Mg, from about 0.15% to about 0.35% Ti, remainder substantially Al)

- 10 AA standard A356 (from about 6.5% to about 7.5% Si, from about 0.25% to about 0.45% Mg, not more than about 0.2% Fe, not more than about 0.2% Cu, remainder substantially Al)

Al - from about 2% to about 3% Li alloy (DuPont)

15 Wrought type aluminum alloys

JIS standard 6061 (from about 0.4% to about 0.8% Si, from about 0.15% to about 0.4% Cu, from about 0.8% to about 1.2% Mg, from about 0.04% to about 0.35% Cr, remainder substantially Al)

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JIS standard 5056 (not more than about 0.3% Si, not more than about 0.4% Fe, not more than about 0.1% Cu, from about 0.05% to about 0.2% Mn, from about 4.5% to about 5.6% Mg, from about 0.05% to about 0.2% Cr, not more than about 0.1% Zn, remainder substantially Al)

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JIS standard 2024 (about 0.5% Si, about 0.5% Fe, from about 3.8% to about 4.9% Cu, from about 0.3% to about 0.9% Mn, from about 1.2% to about 1.8% Mg, not more than about 0.1% Cr, not more than about 0.25% Zn, not more than about 0.15% Ti, remainder substantially Al)

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JIS standard 7075 (not more than about 0.4% Si, not more than about 0.5% Fe, from about 1.2% to about 2.0% Cu, not more than about 0.3% Mn, from about 2.1% to about 2.9% Mg, from about 0.18% to about 0.28% Cr, from about 5.1% to about 6.1% Zn, about 0.2% Ti, remainder substantially Al)

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Previous research relating to composite materials incorporating aluminum alloys as their matrix metals has generally been carried out from the point of view and with the object of improving the strength and so forth of existing aluminum alloys without changing their composition, and therefore these aluminum alloys conventionally used in the manufacture of such prior art composite materials have not necessarily been of the optimum composition in relation to the type of reinforcing fibers utilized therewith to form a composite material, and therefore, in the case of using one or the other of such conventional above mentioned aluminum alloys as the matrix metal for a composite material, the optimization of the mechanical characteristics, and particularly of the strength, of the composite material using such an aluminum alloy as matrix metal has not heretofore been satisfactorily attained.

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SUMMARY OF THE INVENTION

The inventors of the present application have considered the above mentioned problems in composite materials which use such conventional
5 aluminum alloys as matrix metal, and in particular have considered the particular case of a composite material which utilizes silicon nitride whisker type material as reinforcing fiber material, since such silicon nitride whiskers, among the various types of reinforcing fibers used conventionally in the manufacture of a fiber reinforced metal composite
10 material, have particularly high strength and are exceedingly effective in improving the high temperature stability and the strength of the composite material. And the present inventors, as a result of various experimental researches to determine what composition of the aluminum alloy to be used as the matrix metal for such a composite material is optimum, have
15 discovered that an aluminum alloy having a content of copper and a content of magnesium within certain limits, and containing substantially no silicon, nickel, zinc, and so forth is optimal as matrix metal, particularly in view of the bending strength characteristics of the resulting composite material. The present invention is based on the knowledge obtained from
20 the results of the various experimental researches carried out by the inventors of the present application, as will be detailed later in this specification.

Accordingly, it is the primary object of the present invention to
25 provide a composite material utilizing silicon nitride whiskers as

reinforcing material and aluminum alloy as matrix metal, which enjoys superior mechanical characteristics such as bending strength.

5 It is a further object of the present invention to provide such a composite material utilizing silicon nitride whiskers as reinforcing material and aluminum alloy as matrix metal, which, for similar values of mechanical characteristics such as bending strength, can incorporate a lower volume proportion of reinforcing fiber material than prior art such composite materials.

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It is a further object of the present invention to provide such a composite material utilizing silicon nitride whiskers as reinforcing material and aluminum alloy as matrix metal, which is improved as regards workability.

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It is a further object of the present invention to provide such a composite material utilizing silicon nitride whiskers as reinforcing material and aluminum alloy as matrix metal, which is improved as regards machinability.

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It is a further object of the present invention to provide such a composite material utilizing silicon nitride whiskers as reinforcing material and aluminum alloy as matrix metal, which has reduced cost.

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It is a further object of the present invention to provide such a composite material utilizing silicon nitride whiskers as reinforcing

material and aluminum alloy as matrix metal, which has improved characteristics with regard to wear upon a mating member.

According to the most general aspect of the present invention, these
5 and other objects are attained by a composite material comprising a mass
of silicon nitride whiskers embedded in a matrix of metal; said matrix
metal being an alloy consisting essentially of from approximately 2% to
approximately 6% of copper, from approximately 0.5% to approximately 3%
of magnesium, and remainder substantially aluminum; and the volume
10 proportion of said silicon nitride whiskers being from about 5% to about
50%.

According to the present invention as described above, as
reinforcing fibers there are used silicon nitride whisker type short
15 fibers, which have high strength, and are exceedingly effective in
improving the high temperature stability and strength of the resulting
composite material, and as matrix metal there is used an aluminum alloy
with a copper content of from approximately 2% to approximately 6%, a
magnesium content of from approximately 0.5% to approximately 3%, and
20 the remainder substantially aluminum, and the volume proportion of the
silicon nitride whiskers is desirably from approximately 5% to
approximately 50%, whereby, as is clear from the results of experimental
research carried out by the inventors of the present application as will
be described below, a composite material with superior mechanical
25 characteristics such as strength can be obtained. As stated above, the
fiber volume proportion of said silicon nitride whisker type fibers should

be between approximately 5% and approximately 50%; but, more preferably, said fiber volume proportion of said silicon nitride whisker type fibers should be between approximately 5% and approximately 40%.

5 Also according to the present invention, in cases where it is satisfactory if the same degree of strength as a conventional silicon nitride whisker type short fiber reinforced aluminum alloy is obtained, the volume proportion of silicon nitride type short fibers in a composite material according to the present invention may be set to be lower than
10 the value required for such a conventional composite material, and therefore, since it is possible to reduce the amount of silicon nitride whiskers used, the machinability and workability of the composite material can be improved, and it is also possible to reduce the cost of the composite material. Further, the characteristics with regard to wear
15 on a mating member will be improved.

 As will become clear from the experimental results detailed hereinafter, when copper is added to aluminum to make the matrix metal of the composite material according to the present invention, the strength
20 of the aluminum alloy matrix metal is increased and thereby the strength of the composite material is improved, but that effect is not sufficient if the copper content is less than 2%, whereas if the copper content is more than 6% the composite material becomes very brittle, and has a tendency rapidly to disintegrate. Therefore the copper content of the aluminum
25 alloy used as matrix metal in the composite material of the present invention is required to be in the range of from approximately 2% to

approximately 6%, and more preferably is desired to be in the range of from approximately 2% to approximately 5%.

Furthermore, oxides or O radicals are inevitably always present on the surfaces of such silicon nitride whiskers used as reinforcing fibers, and if, as is contemplated in the above presented discussion, magnesium, which has a strong tendency to form oxides, is contained within the molten matrix metal, such magnesium will react with the oxides or O radicals on the surfaces of the silicon nitride whiskers, and will reduce the surfaces of the silicon nitride whiskers, as a result of which the affinity of the molten aluminum alloy matrix metal and the silicon nitride whiskers will be improved, and by this means the strength of the composite material will be improved along with an increase in the content of magnesium, as experimentally has been established as will be described in the following, up to a magnesium content of approximately 2%. If, however, the magnesium content is less than approximately 0.5%, then this effect is insufficient and is insignificant; while, on the other hand, if the magnesium content exceeds approximately 3%, as will also be described in the following, the strength of the composite material on the contrary decreases rapidly. Therefore the magnesium content of the aluminum alloy used as matrix metal in the composite material of the present invention is desired to be from approximately 0.5% to approximately 3%, and preferably from approximately 0.5% to approximately 2.5%, and even more preferably from approximately 0.5% to approximately 2%.

Furthermore, in a composite material with an aluminum alloy of the above composition as matrix metal, as also will become clear from the experimental researches given hereinafter, if the volume proportion of the silicon nitride whisker type short fibers is less than 5%, a sufficient strength cannot be obtained; while, if said volume proportion of the silicon nitride whisker type short fibers is between about 5% and about 40%, the strength of the composite material increases greatly and substantially linearly along with increase in said silicon nitride whisker volume proportion; and, if said volume proportion of the silicon nitride whisker type short fibers exceeds 40%, and particularly if it exceeds 50%, even if said volume proportion of the silicon nitride whisker type short fibers is further increased, the strength of the composite material is not very significantly improved. Also, the wear resistance of the composite material increases with the volume proportion of the silicon nitride whisker type short fiber material, but when the volume proportion of the silicon nitride whisker type short fibers is in the range from zero to approximately 5% said wear resistance increases rapidly with an increase in the volume proportion of the silicon nitride whisker type short fibers, whereas, on the other hand, when the volume proportion of the silicon nitride whisker type short fibers is in the range of at least approximately 5%, the wear resistance of the composite material does not very significantly increase with an increase in said volume proportion of said silicon nitride whisker type short fibers. Therefore, according to one characteristic of the present invention, the volume proportion of the silicon nitride whisker type short fibers is required to be in the range of from approximately 5% to approximately 50%, and preferably is

required to be in the range of from approximately 5% to approximately 40%.

As a result of other experimental research carried out by the inventors of the present application, when the volume proportion of the silicon nitride whiskers is in the relatively high portion of the above described desirable range, that is to say is from approximately 30% to approximately 40%, it is preferable that the copper content of the aluminum alloy should be from approximately 2% to approximately 5%.

Therefore, according to another detailed characteristic of the present invention, the volume proportion of the silicon nitride whiskers should be from approximately 30% to approximately 40%, and the copper content of the aluminum alloy should be from approximately 2% to approximately 5%.

If, furthermore, the copper content of the aluminum alloy used as matrix metal of the composite material of the present invention has a relatively high value, if there are unevennesses in the concentration of the copper or the magnesium within the aluminum alloy, the portions where the copper concentration or the magnesium concentration is high will be brittle, and it will not therefore be possible to obtain a uniform matrix metal or a composite material of good and uniform quality. Therefore, according to another detailed characteristic of the present invention, in order that the concentration of copper within the aluminum alloy matrix metal should be uniform, such a composite material of which the matrix metal is aluminum alloy of which the copper content is at least 0% and is less than 3.5% is subjected to liquidizing processing

for from about 2 hours to about 8 hours at a temperature of from about 480°C to about 520°C, while on the other hand such a composite material of which the matrix metal is aluminum alloy of which the copper content is at least 3.5% and is less than 6% is subjected to liquidizing processing
5 for from about 2 hours to about 8 hours at a temperature of from about 460°C to about 510°C. In either case, these materials are also, preferably, further subjected to aging processing for about 2 hours to about 8 hours at a temperature of from about 150°C to 200°C.

10 Further, the fiber length of the silicon nitride whisker type short fibers is preferably from approximately 10 microns to approximately 5 cm, and particularly is from approximately 50 microns to approximately 2 cm, and the fiber diameter of said silicon nitride whisker type fibers is further desired, preferably, to be from approximately 0.1 micron to
15 approximately 25 microns, and particularly is more preferably desired to be from approximately 0.1 micron to approximately 20 microns.

As fiber reinforced aluminum alloys which may be considered to be related to the present invention, there have been disclosed in the
20 following Japanese patent applications filed by an applicant the same as the applicant of the parent Japanese patent application of which Convention priority is being claimed for the present patent application - Japanese Patent Applications (1) Sho 60-120786 (1985), (2) Sho 60-120787 (1985), (3) Sho 60-120788 (1985), and (4) Sho 61-19793
25 (1986) - respectively: (1) a composite material including silicon carbide short fibers in a matrix of aluminum alloy having a copper content of

from approximately 2% to approximately 6%, a magnesium content of from approximately 2% to approximately 4%, and remainder substantially aluminum, with the volume proportion of said silicon carbide short fibers being from approximately 5% to approximately 50%; (2) a composite material including alumina short fibers in a matrix of aluminum alloy having a copper content of from approximately 2% to approximately 6%, a magnesium content of from approximately 0.5% to approximately 4%, and remainder substantially aluminum, with the volume proportion of said alumina short fibers being from approximately 5% to approximately 50%, (3) a composite material including silicon carbide short fibers in a matrix of aluminum alloy having a copper content of from approximately 2% to 6%, a magnesium content of from approximately 0% to approximately 4%, and remainder substantially aluminum, with the volume proportion of said silicon carbide short fibers being from approximately 5% to approximately 50%; and (4) a composite material including alumina-silica short fibers in a matrix of aluminum alloy having a copper content of from approximately 2% to 6%, a magnesium content of from approximately 0.5% to approximately 3.5%, and remainder substantially aluminum, with said alumina-silica short fibers having a composition of from about 35% to about 65% Al_2O_3 , from about 65% to about 35% SiO_2 , and from about 0% to about 10% of other constituents, and with the volume proportion of said alumina-silica short fibers being from approximately 5% to approximately 50%. However, it is not hereby intended to admit any of the above identified documents as prior art to the present patent application except to the extent in any case otherwise mandated by applicable law.

It should be noted that in this specification all percentages, except in expressions of volume proportion of reinforcing fiber material, are percentages by weight, and in expressions of the composition of an aluminum alloy, "substantially aluminum" means that, apart from aluminum, copper and magnesium, the total of the inevitable metallic elements such as silicon, iron, zinc, manganese, nickel, titanium, and chromium included in the aluminum alloy used as matrix metal is not more than about 1%, and each of said impurity type elements individually is not present to more than about 0.5%. It should further be noted that, in this specification, in descriptions of ranges of compositions, temperatures and the like, the expressions "at least", "not less than", "at most", "no more than", and "from ... to ..." and so on are intended to include the boundary values of the respective ranges.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described with respect to the preferred embodiments thereof, and with reference to the illustrative drawings appended hereto, which however are provided for the purposes of explanation and exemplification only, and are not intended to be limitative of the scope of the present invention in any way, since this scope is to be delimited solely by the accompanying claims. With relation to the figures, spatial terms are to be understood as referring only to the orientation on the drawing paper of the illustrations of the relevant parts, unless otherwise specified; like reference numerals,

unless otherwise so specified, denote the same parts and gaps and spaces and so on in the various figures; and:

5 Fig. 1 is a set of graphs in which magnesium content in percent is shown along the horizontal axis and bending strength in kg/mm^2 is shown along the vertical axis, derived from data relating to bending strength tests for a first group of the first set of preferred embodiments of the material of the present invention (in which the volume proportion of reinforcing silicon nitride whisker material was approximately 20%),
10 each said graph showing the relation between magnesium content and bending strength of certain composite material test pieces for a particular fixed percentage content of copper in the matrix metal of the composite material;

15 Fig. 2 is a set of graphs, similar to Fig. 1 for the first group of said first set of preferred embodiments, in which magnesium content in percent is shown along the horizontal axis and bending strength in kg/mm^2 is shown along the vertical axis, derived from data relating to bending strength tests for a second group of said first set of preferred
20 embodiments of the material of the present invention (in which the volume proportion of reinforcing silicon nitride whisker material was now approximately 10%), each said graph again showing the relation between magnesium content and bending strength of certain composite material test pieces for a particular fixed percentage content of copper
25 in the matrix metal of the composite material;

Fig. 3 is a set of graphs, similar to Fig. 1 for the first group of said first set of preferred embodiments and to Fig. 2 for the second group of said first preferred embodiment set, in which magnesium content in percent is shown along the horizontal axis and bending strength in kg/mm^2 is shown along the vertical axis, derived from data relating to bending strength tests for a third group of said first set of preferred embodiments of the material of the present invention (in which the volume proportion of reinforcing silicon nitride whisker material was now approximately 5%), each said graph similarly showing the relation between magnesium content and bending strength of certain composite material test pieces for a particular fixed percentage content of copper in the matrix metal of the composite material;

Fig. 4 is a set of graphs, similar to Figs. 1, 2, and 3 for the first through the third groups of said first set of preferred embodiments respectively, in which again magnesium content in percent is shown along the horizontal axis and bending strength in kg/mm^2 is shown along the vertical axis, derived from data relating to bending strength tests for a first group of the second set of preferred embodiments of the material of the present invention (in which the volume proportion of reinforcing silicon nitride whisker material was now approximately 40%), each said graph similarly showing the relation between magnesium content and bending strength of certain composite material test pieces for a particular fixed percentage content of copper in the matrix metal of the composite material;

Fig. 5 is a set of graphs, similar to Figs. 1, 2, and 3 for the three groups of the first set of preferred embodiments and to Fig. 4 for the first group of the second set of preferred embodiments respectively, in which again magnesium content in percent is shown along the horizontal axis and bending strength in kg/mm^2 is shown along the vertical axis, derived from data relating to bending strength tests for a second group of said second set of preferred embodiments of the material of the present invention (in which the volume proportion of reinforcing silicon nitride whisker material was now approximately 30%), each said graph similarly showing the relation between magnesium content and bending strength of certain composite material test pieces for a particular fixed percentage content of copper in the matrix metal of the composite material;

Fig. 6 is a graph relating to a set of tests in which the fiber volume proportion of reinforcing silicon nitride whisker material was varied, in which said reinforcing fiber proportion in percent is shown along the horizontal axis and bending strength in kg/mm^2 is shown along the vertical axis, derived from data relating to bending strength tests for a third set of preferred embodiments of the material of the present invention, said graphs showing the relation between volume proportion of the reinforcing silicon nitride whisker material and bending strength of test pieces of composite material including it;

Fig. 7 is a perspective view of a preform made of silicon nitride type short fiber material, with said silicon nitride type short fibers being

aligned substantially randomly in three dimensions, for incorporation into composite materials according to various preferred embodiments of the present invention;

5 Fig. 8 is a perspective view, showing said preform made of silicon nitride whisker type material enclosed in a stainless steel case both ends of which are open, for incorporation into said composite materials; and:

10 Fig. 9 is a schematic sectional diagram showing a high pressure casting device in the process of performing high pressure casting for manufacturing a composite material with the silicon nitride whisker type material preform of Figs. 18 and 19 (enclosed in its stainless steel case) being incorporated in a matrix of matrix metal.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

20 The present invention will now be described with reference to the various preferred embodiments thereof. It should be noted that all of the tables referred to in this specification are to be found at the end of the specification and before the claims thereof: the present specification is arranged in such a manner in order to maximize ease of pagination. Further, the preferred embodiments of the present invention are
25 conveniently divided into three groupings of sets thereof, as will be seen in what follows.

THE FIRST SET OF PREFERRED EMBODIMENTS

In order to assess what might be the most suitable composition for an aluminum alloy to be utilized as matrix metal for a contemplated composite material of the type described in the preamble to this specification, the reinforcing fiber material of which was to be silicon nitride whiskers, the present inventors manufactured by using the high pressure casting method samples of various composite materials, utilizing as reinforcing material silicon nitride whisker material (manufactured by Tateho Kagaku K.K.) which had composition at least 99% Si_3N_4 and which had average fiber length about 150 microns and average fiber diameter about 1 micron, and utilizing as matrix metal Al-Cu-Mg type aluminum alloys of various compositions. Then the present inventors conducted evaluations of the bending strength of the various resulting composite material sample pieces.

First, a set of aluminum alloys designated as A1 through A42 were produced, having as base material aluminum and having various quantities of magnesium and copper mixed therewith, as shown in the appended Table 1; this was done by, in each case, combining an appropriate quantity of substantially pure aluminum metal (purity at least 99%), an appropriate quantity of substantially pure magnesium metal (purity at least 99%), and an appropriate quantity of a mother alloy of approximately 50% aluminum and approximately 50% copper. And three sets, each containing an appropriate number (actually, forty two), of silicon nitride whisker material preforms were made by, in each case,

subjecting a quantity of the above specified silicon nitride whisker material to compression forming without using any binder. Each of these silicon nitride whisker material preforms was, as schematically illustrated in perspective view in Fig. 7 wherein an exemplary such preform is designated by the reference numeral 2 and the silicon nitride whiskers therein are generally designated as 1, about 38 x 100 x 16 mm in dimensions, and the individual silicon nitride whiskers 1 in said preform 2 were oriented in a substantially three dimensionally random manner. And the fiber volume proportion in a first set of said preforms 2 was approximately 20%, in a second set of said preforms 2 was approximately 10%, and in a third set of said preforms 2 was approximately 5%; thus, in all, there were a hundred and twenty six such preforms.

Next, each of these silicon nitride whisker material preforms 2 was subjected to high pressure casting together with an appropriate quantity of one of the aluminum alloys A1 through A42 described above, in the following manner. First, the preform 2 was inserted into a stainless steel case 2a, as shown in perspective view in Fig. 8, which was about 38 x 100 x 16 mm in internal dimensions and had both of its ends open. After this, each of these stainless steel cases 2a with its preform 2 held inside it was heated up to a temperature of approximately 600°C, and then as shown in schematic sectional view in Fig. 9 said case 2a and said preform 2 were placed within a mold cavity 4 of a casting mold 3, which itself had previously been preheated up to a temperature of approximately 250°C. Next, a quantity 5 of the appropriate one of the

aluminum alloys A1 to A42 described above, molten and maintained at a temperature of approximately 700°C, was relatively rapidly poured into said mold cavity 4, so as to surround the case 2a and the preform 2 therein, and then a pressure plunger 6, which itself had previously been
5 preheated up to a temperature of approximately 200°C, and which closely cooperated with the upper portion of said mold cavity 4, was inserted into said upper mold cavity portion, and was pressed downwards by a means not shown in the figure so as to pressurize said molten aluminum alloy quantity 5 and said preform 2 to a pressure of approximately
10 1000 kg/cm². Thereby, the molten aluminum alloy was caused to percolate into the interstices of the silicon nitride whisker material preform 2. This pressurized state was maintained until the quantity 5 of molten aluminum alloy had completely solidified, and then the pressure plunger 6 was removed and the solidified aluminum alloy mass with the
15 stainless steel case 2a and the preform 2 included therein was removed from the casting mold 3, and the peripheral portion of said solidified aluminum alloy mass and also the stainless steel case 2a were machined away, leaving only a sample piece of composite material which had silicon nitride whisker material as reinforcing material and the
20 appropriate one of the aluminum alloys A1 through A42 as matrix metal. The volume proportion of silicon nitride whisker material in each of the resulting composite material sample pieces thus produced from the first set (forty two in number) of said preforms 2 was approximately 20%, in each of the resulting composite material sample pieces thus produced
25 from the second set (also forty two in number) of said preforms 2 was approximately 10%, and in each of the resulting composite material

sample pieces thus produced from the third set (likewise forty two in number) of said preforms 2 was approximately 5%.

5 Next the following post processing steps were performed on the composite material samples. First, irrespective of the value for the magnesium content: those of said composite material samples which incorporated an aluminum alloy matrix metal which had copper content less than about 2% were subjected to liquidizing processing at a temperature of approximately 530°C for approximately 8 hours, and then
10 were subjected to artificial aging processing at a temperature of approximately 160°C for approximately 8 hours; and those of said composite material samples which incorporated an aluminum alloy matrix metal which had copper content of at least about 2% and less than about 3.5% were subjected to liquidizing processing at a temperature of
15 approximately 500°C for approximately 8 hours, and then were subjected to artificial aging processing at a temperature of approximately 160°C for approximately 8 hours; while those of said composite material samples which incorporated an aluminum alloy matrix metal which had copper content more than about 3.5% and less than about 6.5% were subjected to
20 liquidizing processing at a temperature of approximately 480°C for approximately 8 hours, and then were subjected to artificial aging processing at a temperature of approximately 160°C for approximately 8 hours. Then, in each set of cases, from each of the composite material sample pieces manufactured as described above, to which heat treatment
25 had been applied, there was cut a bending strength test piece of length approximately 50 mm, width approximately 10 mm, and thickness

approximately 2 mm, and for each of these composite material bending strength test pieces a three point bending strength test was carried out, with a gap between supports of approximately 40 mm. In these bending strength tests, the bending strength of the composite material bending strength test pieces was measured as the surface stress at breaking point M/Z (M is the bending moment at the breaking point, while Z is the cross section coefficient of the composite material bending strength test piece).

10 The results of these bending strength tests were as shown in the first three columns of the appended Table 2, and as summarized in the line graphs of Figs. 1 through 3, which relate to the cases of fiber volume proportion being equal to 20%, 10%, and 5% respectively. The first through the third columns of Table 2 show, for the respective cases of 5%, 10%, and 20% volume proportion of the reinforcing silicon nitride fiber material, the values of the bending strength (in kg/mm^2) for each of the test sample pieces made from the aluminum alloys designated as A1 through A42. And each of the line graphs of Fig. 1 shows the relation between magnesium content (in percent) and the bending strength (in kg/mm^2) shown along the vertical axis of those of said composite material test pieces having as matrix metals aluminum alloys with percentage content of magnesium as shown along the horizontal axis and with percentage content of copper fixed along said line graph, and having as reinforcing material the above specified silicon nitride fibers in volume proportion of 20%; each of the line graphs of Fig. 2 likewise shows the relation between magnesium content (in

percent) and the bending strength (in kg/mm²) shown along the vertical axis of those of said composite material test pieces having as matrix metals aluminum alloys with percentage content of magnesium as shown along the horizontal axis and with percentage content of copper fixed along said line graph, and having as reinforcing material the above specified silicon nitride fibers in volume proportion of 10%; and each of the line graphs of Fig. 3 similarly shows the relation between magnesium content (in percent) and the bending strength (in kg/mm²) shown along the vertical axis of those of said composite material test pieces having as matrix metals aluminum alloys with percentage content of magnesium as shown along the horizontal axis and with percentage content of copper fixed along said line graph, and having as reinforcing material the above specified silicon nitride fibers in volume proportion of 5%.

From Table 2 and from Figs. 1 through 3 it will be understood that for all of these composite materials, when as in these cases the volume proportion of the reinforcing silicon nitride whisker material of these composite material bending strength test sample pieces was approximately 20%, was approximately 10%, or was approximately 5%, substantially irrespective of the magnesium content of the aluminum alloy matrix metal, when the copper content was either at the low extreme of approximately 1.5% or was at the high extreme of approximately 6.5%, the bending strength of the composite material test sample pieces had a relatively low value; and, substantially irrespective of the copper content of the aluminum alloy matrix metal, when the magnesium content was either at the lower value of approximately 0% or at the higher value of

approximately 4%, the bending strength of the composite material test sample pieces had a relatively low value. Further, it will be seen that, when the magnesium content was in the range of from approximately 1% to approximately 2%, the bending strength of the composite material test sample pieces attained a substantially maximum value; and, when the magnesium content increased above or decreased below this range, then the bending strength of the composite material test sample pieces decreased gradually; while, when the magnesium content was either in the low range below approximately 0.5% or was in the high range above approximately 3%, the bending strength of the composite material test sample pieces reduced relatively suddenly with decrease or increase respectively of the magnesium content; and, when the magnesium content was approximately 4%, the bending strength of the composite material test sample pieces had substantially the same value as, or at any rate a not greater value than, when the magnesium content was approximately 0%.

From the results of these bending strength tests it will be seen that, in order to provide for a good and appropriate bending strength for a composite material having as reinforcing fiber material such silicon nitride whiskers in volume proportions of approximately 20%, approximately 10%, and approximately 5%, and having as matrix metal an Al-Cu-Mg type aluminum alloy, it is preferable that the copper content of said Al-Cu-Mg type aluminum alloy matrix metal should be in the range of from approximately 2% to approximately 6%; while the magnesium content of said Al-Cu-Mg type aluminum alloy matrix metal should be in the range of from approximately 0.5% to approximately 3%, more

preferably should be in the range of from approximately 0.5% to approximately 2.5%, and even more preferably should be in the range of from approximately 0.5% to approximately 2%.

5 THE SECOND SET OF PREFERRED EMBODIMENTS

Next, the present inventors manufactured further samples of various composite materials, again utilizing as reinforcing material the same silicon nitride short type fiber material, and utilizing as matrix
10 metal substantially the same forty two Al-Cu-Mg type aluminum alloys, but this time employing, for the one set, fiber volume proportions of approximately 40%, and, for another set, fiber volume proportions of approximately 30%. Then the present inventors again conducted evaluations of the bending strength of the various resulting composite
15 material sample pieces.

First, a set of forty two quantities of aluminum alloy material the same as those utilized in the first set of preferred embodiments were produced in the same manner as before, again having as base material
20 aluminum and having various quantities of magnesium and copper mixed therewith. And an appropriate number (actually eighty six) of silicon nitride whisker type fiber material preforms were as before made by the method disclosed above with respect to the first set of preferred embodiments, one group of said silicon nitride short whisker type fiber
25 material preforms now having a fiber volume proportion of approximately 40%, and another set of said silicon nitride short whisker type fiber

material preforms now having a fiber volume proportion of approximately 30%, by contrast to the first set of preferred embodiments described above. These preforms had substantially the same dimensions as the preforms of the first set of preferred embodiments.

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Next, substantially as before, each of these silicon nitride whisker type material preforms was subjected to high pressure casting together with an appropriate quantity of one of the aluminum alloys A1 through A42 described above, utilizing operational parameters substantially as before. In each case, the solidified aluminum alloy mass with the preform included therein was then removed from the casting mold, and the peripheral portion of said solidified aluminum alloy mass and the stainless steel case were machined away, leaving only a sample piece of composite material which had silicon nitride short whisker type fiber material as reinforcing material and the appropriate one of the aluminum alloys A1 through A42 as matrix metal. The volume proportion of silicon nitride short whisker type fibers in each of the one group of the resulting composite material sample pieces was thus now approximately 40%, and in each of the other group of the resulting composite material sample pieces was thus now approximately 30%. And post processing steps were performed on the composite material samples, substantially as before. From each of the composite material sample pieces manufactured as described above, to which heat treatment had been applied, there was cut a bending strength test piece of dimensions and parameters substantially as in the case of the first set of preferred embodiments, and for each of these composite material bending strength

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test pieces a bending strength test was carried out, again substantially as before.

5 The results of these bending strength tests were as shown in the last two columns of Table 2 and as summarized in the graphs of Figs. 4 and 5, which relate to the cases of fiber volume proportion being equal to 40% and 30% respectively; thus, Figs. 4 and 5 correspond to Figs. 1 through 3 relating to the first set of preferred embodiments. In the graphs of Figs. 4 and 5, there are again shown relations between
10 magnesium content and the bending strength (in kg/mm²) of certain of the composite material test pieces, for percentage contents of copper fixed along the various lines thereof.

From Table 2 and from Figs. 4 and 5 it will be understood that
15 for all of these composite materials, when as in these cases the volume proportion of the reinforcing silicon nitride whisker material of these bending strength composite material test sample pieces was approximately 40% or was approximately 30%, substantially irrespective of the magnesium content of the aluminum alloy matrix metal, when the copper
20 content was either at the low extreme of approximately 1.5% or was at the high extreme of approximately 6.5%, the bending strength of the composite material test sample pieces had a relatively low value; and, substantially irrespective of the copper content of the aluminum alloy matrix metal, when the magnesium content was either at the lower value
25 of approximately 0% or at the higher value of approximately 4%, the bending strength of the composite material test sample pieces had a

relatively low value. Further, it will be seen that, when the magnesium content was in the range of from approximately 0.5% to approximately 2%, the bending strength of the composite material test sample pieces attained a substantially maximum value; and, when the magnesium content increased above or decreased below this range, then the bending strength of the composite material test sample pieces decreased gradually; while, when the magnesium content was either in the low range below approximately 0.5% or was in the high range above approximately 3%, the bending strength of the composite material test sample pieces reduced relatively suddenly with decrease or increase respectively of the magnesium content; and, when the magnesium content was approximately 4%, the bending strength of the composite material test sample pieces had substantially the same value as, or at least a value not greater than, when the magnesium content was approximately 0%.

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From the results of these bending strength tests it will be seen that, in order to provide for a good and appropriate bending strength for a composite material having as reinforcing fiber material such silicon nitride whiskers in volume proportion of approximately 40% and approximately 30% and having as matrix metal an Al-Cu-Mg type aluminum alloy, it is preferable that the copper content of said Al-Cu-Mg type aluminum alloy matrix metal should be in the range of from approximately 2% to approximately 6%, and particularly should be in the range of from approximately 2% to approximately 5%, while the magnesium content of said Al-Cu-Mg type aluminum alloy matrix metal should be in the range of from approximately 0.5% to approximately 3%,

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and particularly should be in the range of from approximately 0.5% to approximately 2.5%, and even more particularly should be in the range of from approximately 0.5% to approximately 2%.

5 THE THIRD SET OF PREFERRED EMBODIMENTS

Variation of fiber volume proportion

Since from the above described first and second sets of preferred
10 embodiments the fact has been amply established and demonstrated that it is preferable for the copper content of the Al-Cu-Mg type aluminum alloy matrix metal to be in the range of from approximately 2% to approximately 6%, and that it is preferable for the magnesium content of said Al-Cu-Mg type aluminum alloy matrix metal to be in the range of
15 from approximately 0.5% to approximately 3%, it next was deemed germane to provide a set of tests to establish what fiber volume proportion of the reinforcing silicon nitride whisker type short fibers is most appropriate. This was done, in the third set of preferred embodiments now to be described, by varying said fiber volume
20 proportion of the reinforcing silicon nitride whisker type short fiber material while using an Al-Cu-Mg type aluminum alloy matrix metal which had the proportions of copper and magnesium which had as described above been established as being quite good, i.e. which had copper content of approximately 4% and magnesium content of
25 approximately 1%, and whose remainder content was substantially aluminum. In other words, an appropriate number (in fact six) of

preforms made of the whisker type silicon nitride material used in the preferred embodiments detailed above, hereinafter denoted respectively as B1 through B6, were made by subjecting quantities of said short fiber material to compression forming without using any binder, in the same manner as in the above described two sets of preferred embodiments, the six ones in said set of silicon nitride whisker type short fiber material preforms having fiber volume proportions of approximately 5%, 10%, 20%, 30%, 40%, and 50%. These preforms had substantially the same dimensions and the same type of three dimensional random fiber orientation as the preforms of the above described sets of preferred embodiments. And, substantially as before, each of these silicon nitride whisker type short fiber material preforms was subjected to high pressure casting together with an appropriate quantity of the aluminum alloy matrix metal described above, utilizing operational parameters substantially as before. In each case, the solidified aluminum alloy mass with the preform included therein was then removed from the casting mold, and as before the peripheral portion of said solidified aluminum alloy mass was machined away along with the stainless steel case which had been utilized, leaving only a sample piece of composite material which had silicon nitride whisker type short fiber material as reinforcing material in the appropriate fiber volume proportion and had the described aluminum alloy as matrix metal. And post processing and artificial aging processing steps were performed on the composite material samples, similarly to what was done before. From each of the composite material sample pieces manufactured as described above, to which heat treatment had been applied, there was then cut a bending

strength test piece, each of dimensions substantially as in the case of the above described sets of preferred embodiments, and for each of these composite material bending strength test pieces a bending strength test was carried out, again substantially as before. Also, for reference purposes, a similar test sample was cut from a piece of a cast aluminum alloy material which included no reinforcing fiber material at all, said aluminum alloy material having copper content of about 4%, magnesium content of about 1%, and balance substantially aluminum, and having been subjected to post processing and artificial aging processing steps, similarly to what was done before. And for this comparison sample, referred to as B0, a bending strength test was carried out, again substantially as before. The results of these bending strength tests were as shown in the graph of Fig. 6; the zero point of said graph corresponds to the test sample B0 with no reinforcing silicon nitride whisker type fiber material at all. This graph shows the relation between the volume proportion of the silicon nitride whisker type short reinforcing fibers and the bending strength (in kg/mm²) of the composite material test pieces.

From Fig. 6, it will be understood that: when the volume proportion of the silicon nitride whisker type short reinforcing fibers was in the range of up to and including approximately 5% the bending strength of the composite material hardly increased along with an increase in the fiber volume proportion, and its value was close to the bending strength of the aluminum alloy matrix metal by itself with no reinforcing fiber material admixed therewith; when the volume

proportion of the silicon nitride whisker type short reinforcing fibers was in the range of 5% to 40% the bending strength of the composite material increased relatively greatly and substantially linearly along with increase in the fiber volume proportion; and, when the volume proportion of the silicon nitride whisker type short reinforcing fibers increased above 40%, and particularly when said volume proportion of said silicon nitride whisker type short reinforcing fibers increased above 50%, the bending strength of the composite material did not increase very much even with further increase in the fiber volume proportion. From these results described above, it is seen that in a composite material having silicon nitride whisker type short fiber reinforcing material and having as matrix metal an Al-Cu-Mg type aluminum alloy, it is preferable that the fiber volume proportion of said silicon nitride type short fiber reinforcing material should be in the range of from approximately 5% to approximately 50%, and more preferably should be in the range of from approximately 5% to approximately 40%.

CONCLUSION

Although the present invention has been shown and described in terms of the preferred embodiments thereof, and with reference to the appended drawings, it should not be considered as being particularly limited thereby, since the details of any particular embodiment, or of the drawings, could be varied without, in many cases, departing from the ambit of the present invention. Accordingly, the scope of the present invention is to be considered as being delimited, not by any particular

perhaps entirely fortuitous details of the disclosed preferred embodiments, or of the drawings, but solely by the scope of the accompanying claims, which follow after the Tables.

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TABLE 1

5	ALLOY NO.	COPPER CONTENT (WT%)	MAGNESIUM CONTENT (WT%)
	A1	1.52	0.03
10	A2	1.52	0.47
	A3	1.51	1.01
	A4	1.49	1.99
	A5	1.47	2.98
	A6	1.46	4.02
15	A7	1.99	0.04
	A8	1.99	0.52
	A9	1.97	1.03
	A10	1.96	2.00
	A11	1.96	2.96
20	A12	1.95	3.95
	A13	3.04	0.03
	A14	3.02	0.51
	A15	3.02	0.99
	A16	3.00	1.96
25	A17	2.98	2.98
	A18	2.97	4.01

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	A19	4.03	0.02
	A20	4.02	0.52
	A21	4.01	1.01
	A22	3.98	2.03
5	A23	3.96	3.00
	A24	3.95	3.97
	A25	5.03	0.03
	A26	5.02	0.52
	A27	5.02	1.04
10	A28	5.00	2.01
	A29	4.99	2.99
	A30	4.96	3.96
	A31	6.03	0.03
	A32	6.02	0.49
15	A33	6.00	0.98
	A34	5.98	2.02
	A35	5.96	3.01
	A36	5.95	4.04
	A37	6.51	0.03
20	A38	6.50	0.51
	A39	6.50	1.02
	A40	6.49	1.99

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TABLE 2

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SILICON NITRIDE FIBER VOLUME PROPORTION

	ALLOY NO.	5%	10%	20%	30%	40%
10	A1	41	48	60	63	73
	A2	44	53	64	67	78
	A3	46	55	67	69	80
	A4	48	55	68	70	81
	A5	47	53	65	68	79
15	A6	40	47	59	61	74
	A7	42	50	61	65	75
	A8	51	59	70	76	92
	A9	53	62	73	79	94
	A10	54	63	74	80	95
20	A11	50	58	69	75	88
	A12	43	49	60	65	77
	A13	44	51	62	67	76
	A14	53	61	72	78	94
	A15	56	63	75	81	96
25	A16	57	64	76	81	96
	A17	51	58	70	74	88
	A18	43	48	60	64	76

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	A19	45	53	63	68	78
	A20	55	63	74	81	96
	A21	59	65	77	85	97
	A22	59	65	77	82	96
5	A23	51	59	71	73	87
	A24	42	48	61	63	75
	A25	46	54	65	70	80
	A26	57	65	76	85	98
	A27	60	67	78	83	98
10	A28	59	65	77	79	97
	A29	50	57	70	73	87
	A30	41	47	59	63	75
	A31	48	55	67	71	82
	A32	60	67	77	74	89
15	A33	61	68	78	74	88
	A34	59	64	76	73	86
	A35	49	57	68	72	83
	A36	40	46	58	62	73
	A37	43	52	62	66	79
20	A38	49	57	67	71	83
	A39	49	56	66	70	82
	A40	48	54	64	68	80

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A41	46	51	62	66	77
A42	39	46	58	62	70

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WHAT IS CLAIMED IS:

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1. A composite material comprising a mass of silicon nitride whiskers embedded in a matrix of metal; said matrix metal being an alloy consisting essentially of from approximately 2% to approximately 6% of copper, from approximately 0.5% to approximately 3% of magnesium, and remainder substantially aluminum; and the volume proportion of said silicon nitride whiskers being from about 5% to about 50%.

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2. A composite material according to claim 1, wherein the volume proportion of said silicon nitride whiskers is from about 5% to about 40%.

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3. A composite material according to claim 1, wherein the magnesium content of said aluminum alloy matrix metal is between approximately 0.5% and approximately 2.5%.

4. A composite material according to claim 2, wherein the magnesium content of said aluminum alloy matrix metal is between approximately 0.5% and approximately 2.5%.

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5. A composite material according to claim 1, wherein the magnesium content of said aluminum alloy matrix metal is between approximately 0.5% and approximately 2%.

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6. A composite material according to claim 2, wherein the magnesium content of said aluminum alloy matrix metal is between approximately 0.5% and approximately 2%.

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7. A composite material according to any one of claims 1 through 6, wherein the fiber volume proportion of said silicon nitride whiskers is between approximately 30% and approximately 40%, and the copper content of said aluminum alloy matrix metal is between approximately 2% and approximately 5%.

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FIG. 1
SILICON NITRIDE WHISKERS
AT VOLUME PROPORTION 20%

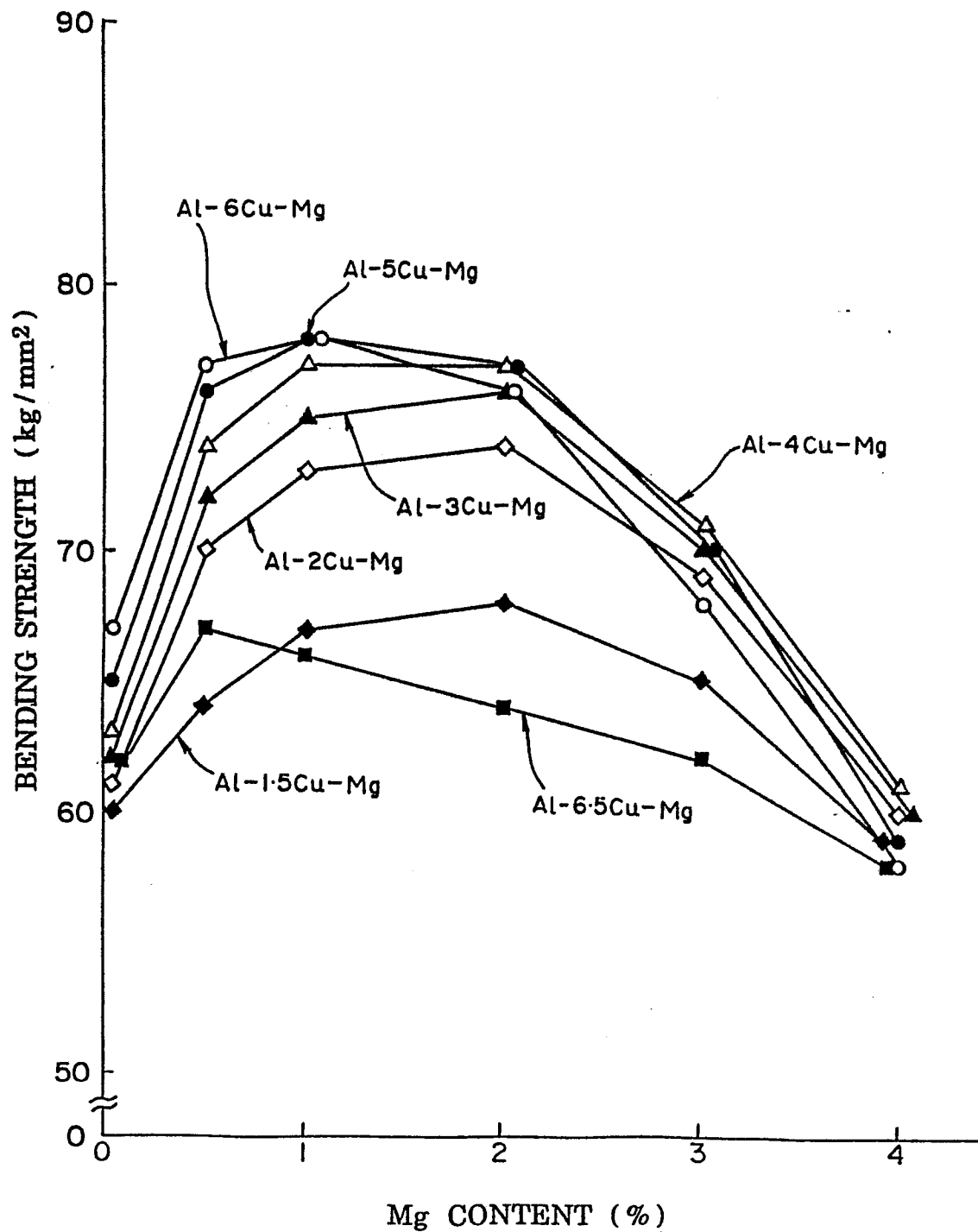


FIG. 2
SILICON NITRIDE WHISKERS
AT VOLUME PROPORTION 10%

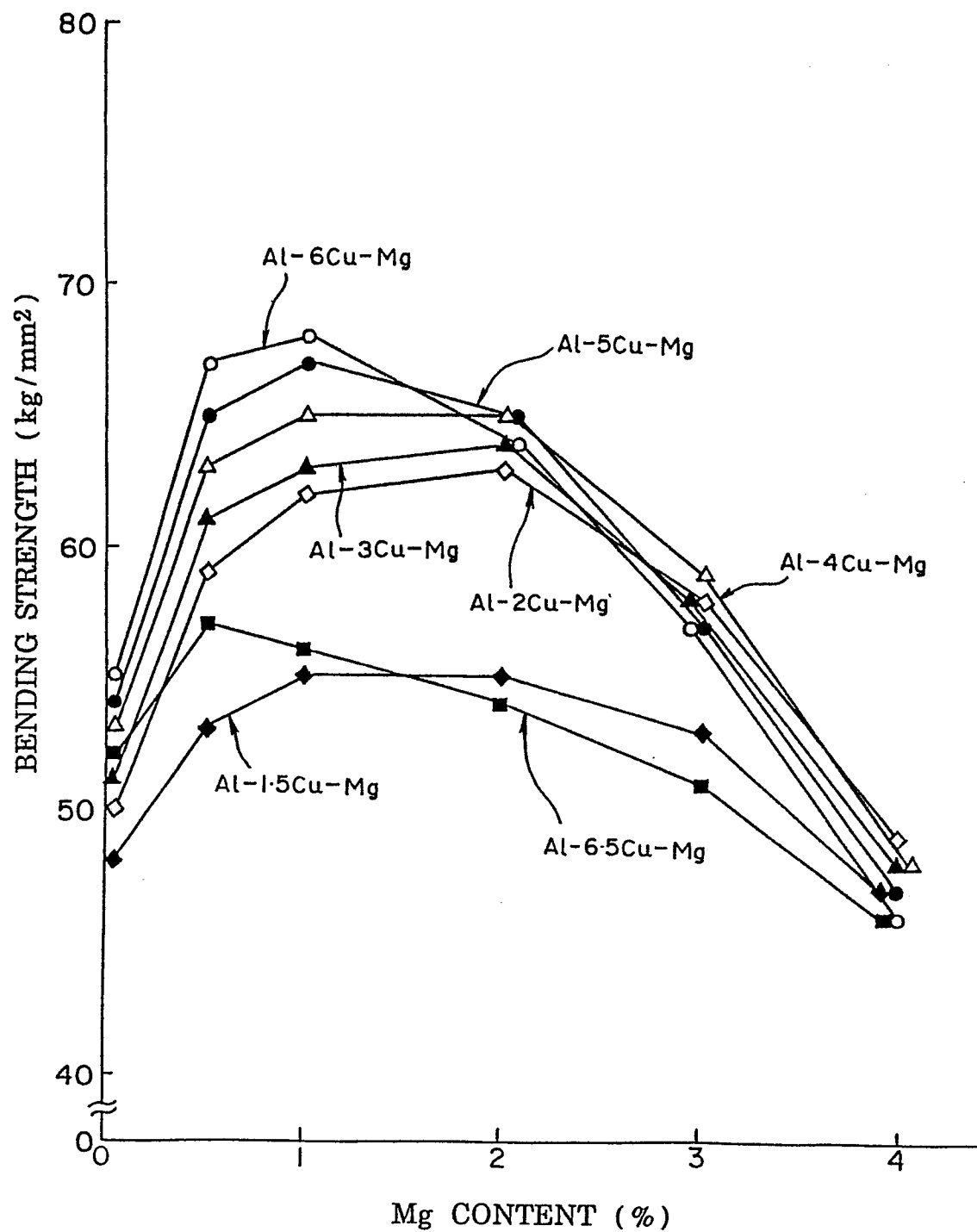


FIG. 3
SILICON NITRIDE WHISKERS
AT VOLUME PROPORTION 5%

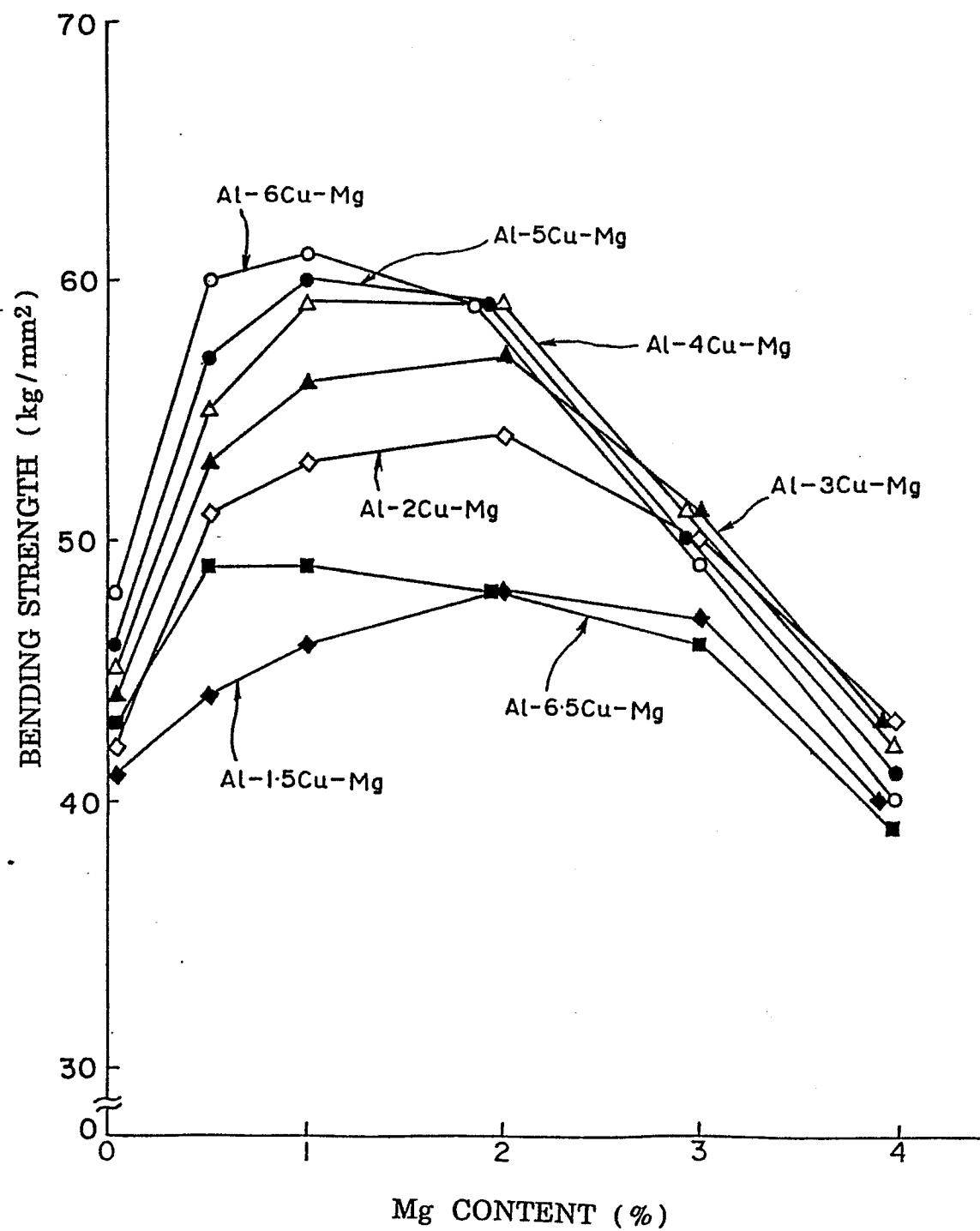


FIG. 4
SILICON NITRIDE WHISKERS
AT VOLUME PROPORTION 40%

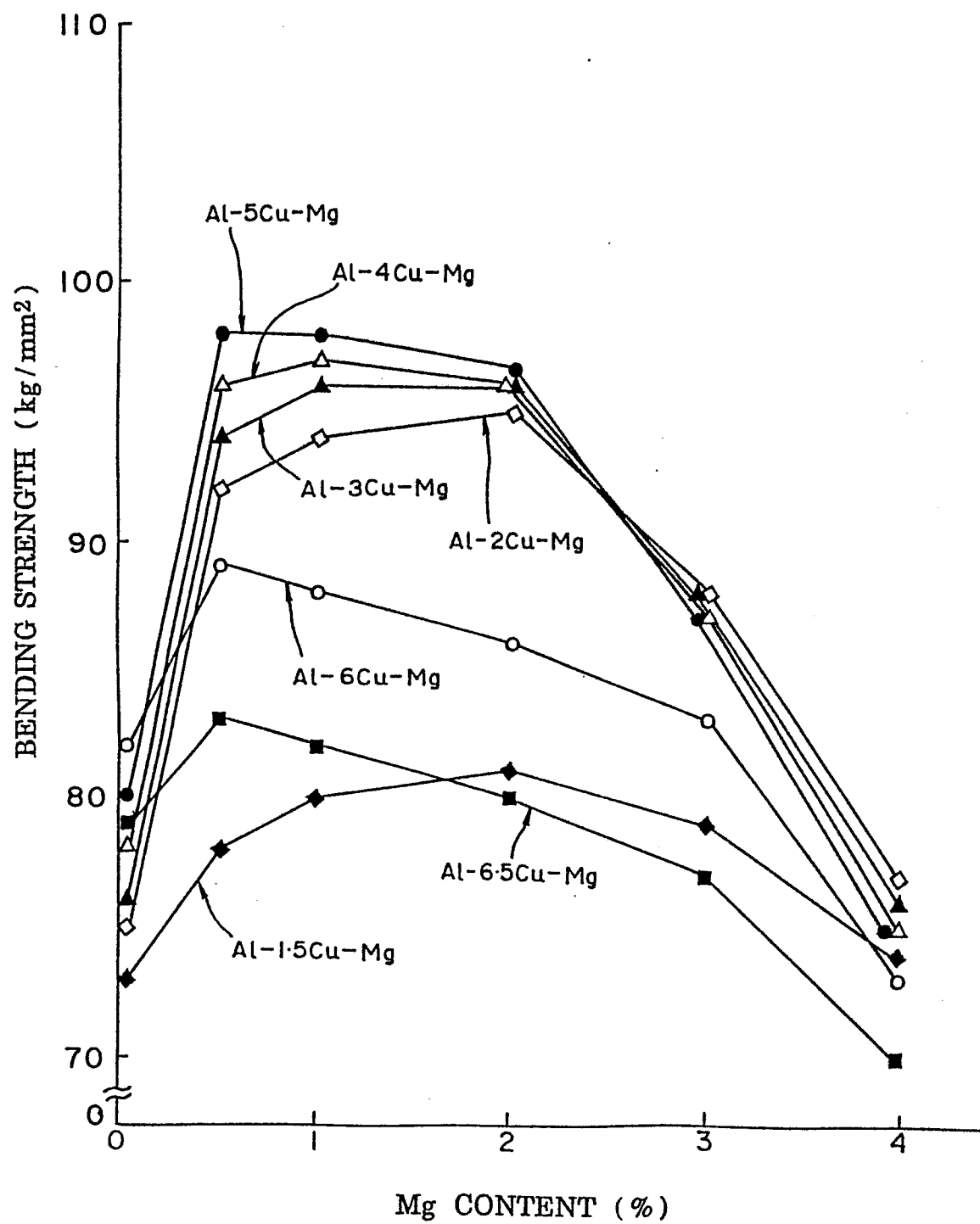


FIG. 5
SILICON NITRIDE WHISKERS
AT VOLUME PROPORTION 30%

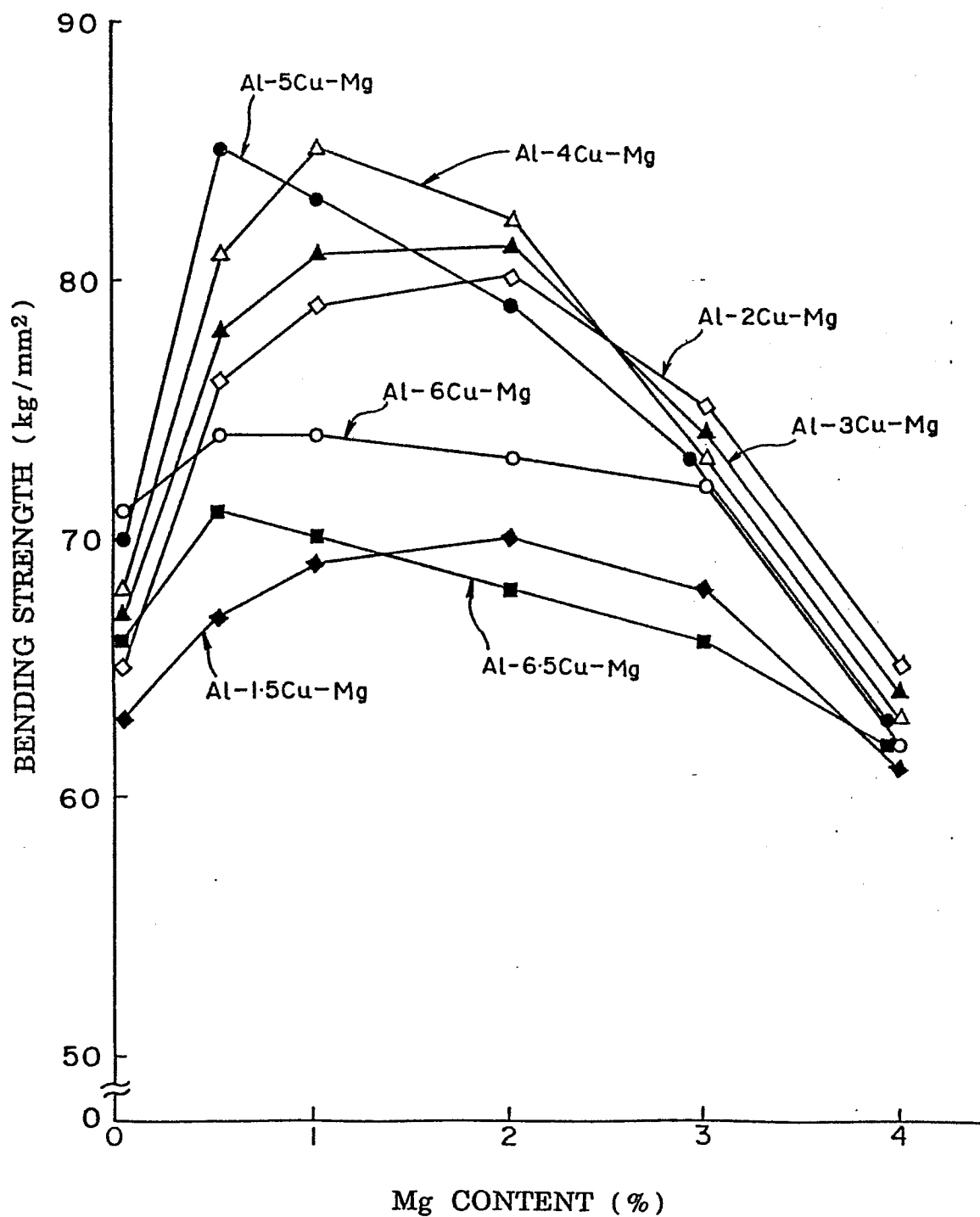


FIG. 6

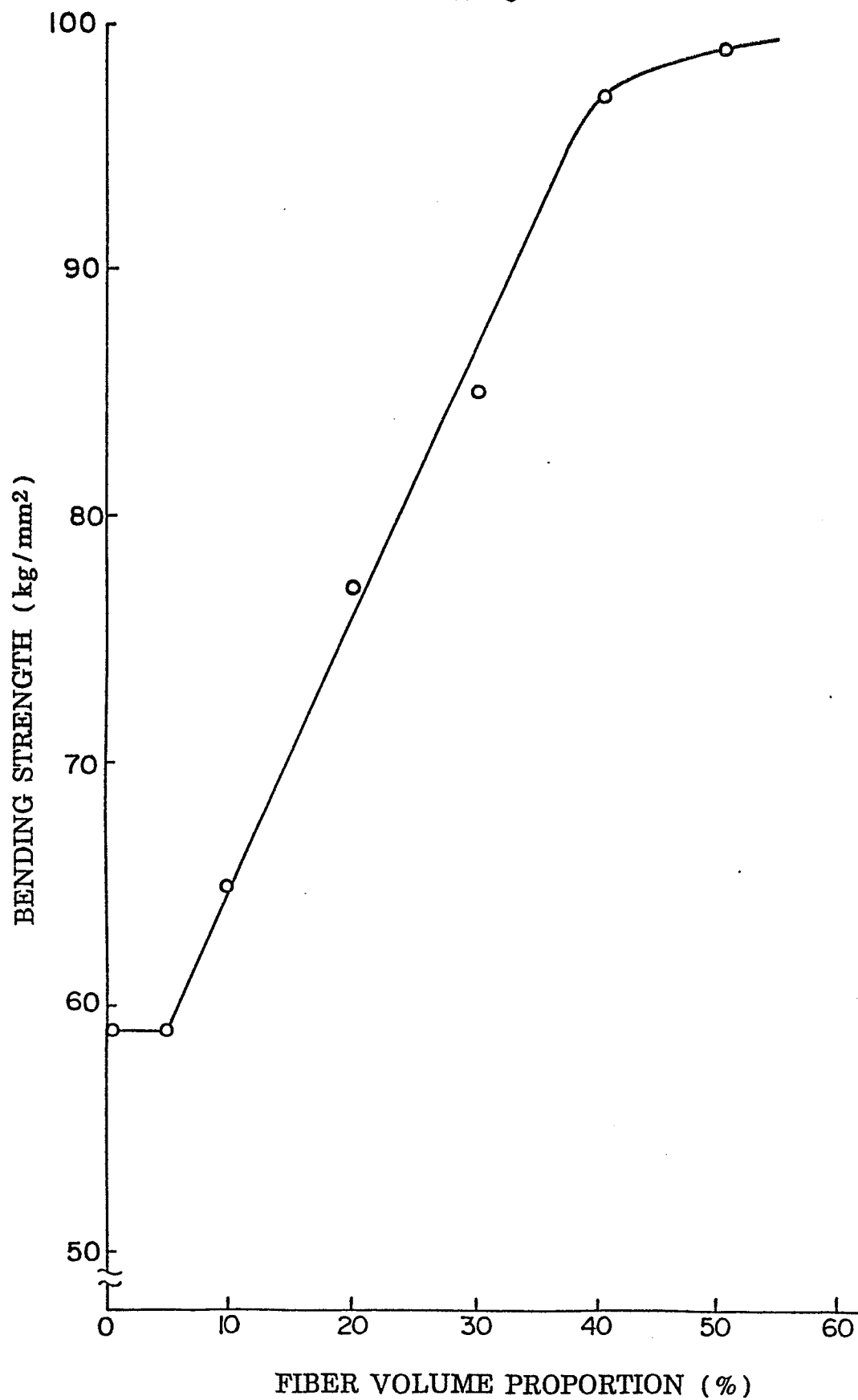


FIG. 7

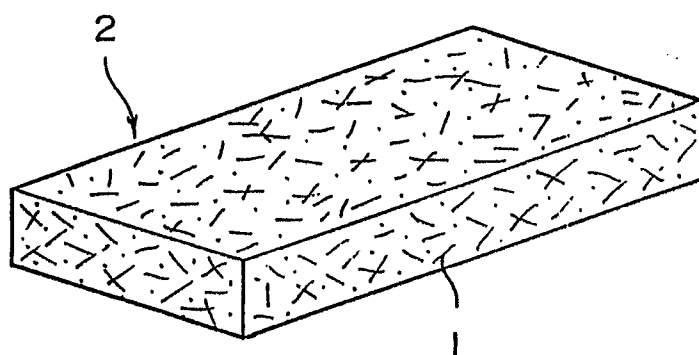


FIG. 8

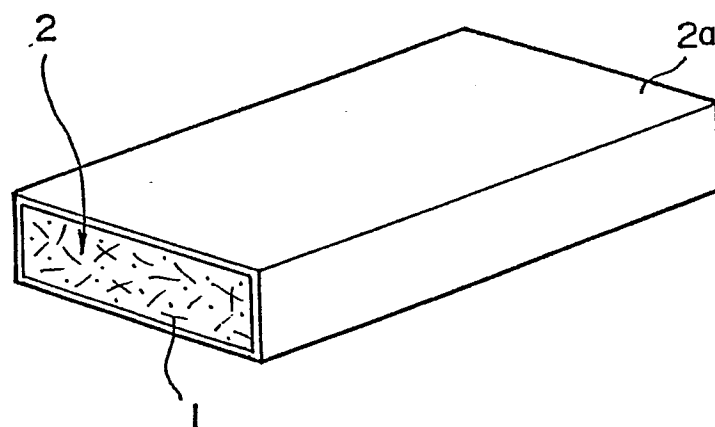


FIG. 9

