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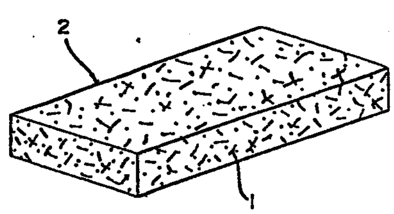
(54) **Composite material including silicon carbide short fibers as reinforcing material and aluminum alloy with copper and magnesium as matrix metal.**

(57) A composite material is made from silicon carbide short fibers embedded in a matrix of metal. The fiber volume proportion of the silicon carbide short fibers is between approximately 5% and approximately 50%. The metal is an alloy consisting essentially of between approximately 2% to approximately 6% of copper, between approximately 2% to approximately 4% of magnesium, and remainder substantially aluminum. The fiber volume proportion of the silicon carbide short fibers may more desirably be between approximately 5% and approximately 40%; the copper content of the aluminum alloy matrix metal may more desirably be between approximately 2% and approximately 5.5%; and the magnesium content of the aluminum alloy matrix metal may more desirably be between approximately 2% and approximately 3.5%.

FIG. 1



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COMPOSITE MATERIAL INCLUDING SILICON CARBIDE SHORT FIBERS AS REINFORCING MATERIAL AND ALUMINUM ALLOY WITH COPPER AND MAGNESIUM AS MATRIX METAL

BACKGROUND OF THE INVENTION

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 carbide short fiber material as the reinforcing fiber material and aluminum alloy as the matrix metal.

The present patent application has been at least partly prepared utilizing materials disclosed in Japanese Patent Application Serial No. .60-120786.................. (1985), laid open as Japanese Patent Laying Open Publication Serial No. .... (1986), and the present patent application hereby incorporates into itself by reference the disclosure of said Japanese Patent Application and of the claims and of the drawings thereof; a copy of said Japanese Patent Application is appended to this application.

In the prior art, the following aluminum alloys have been utilized as matrix metal for a composite material:

Cast type aluminum alloys:

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

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

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

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

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

Al - 2 to 3% Li alloy (DuPont)

Wrought type aluminum alloys:

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

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

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

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

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, 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 such conventional above mentioned aluminum alloys as the matrix metal for a composite material, it has not heretofore been attained to optimize the mechanical characteristics, and particularly the strength, of the composite materials using such aluminum alloys as matrix metal.

SUMMARY OF THE INVENTION

The inventors of the present application have considered the above mentioned problems in composite materials which use such conventional aluminum alloys as matrix metal, and in particular have considered the particular case of a composite material which utilizes silicon carbide short fibers as reinforcing fibers; since such silicon carbide short fibers, of the various reinforcing fibers used conventionally in the manufacture of a fiber reinforced metal composite material, have particularly high strength, and are exceedingly effective in improving the high temperature stability and strength. And the present inventors, as a result of various experimental research to determine what composition of the aluminum alloy to be used as the matrix metal for such a composite material is optimum, have discovered that an aluminum alloy having a content of copper and magnesium within certain limits, and containing substantially no silicon, nickel, zinc, and so forth is optimal as matrix metal. The present invention is based on the knowledge obtained from 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 provide a composite material utilizing silicon carbide short fibers as reinforcing material and aluminum alloy as matrix metal, which enjoys superior mechanical characteristics such as bending strength.

It is a further object of the present invention to provide such a composite material utilizing silicon carbide short fibers as reinforcing material and aluminum alloy as matrix metal, which is cheap.

It is a further object of the present invention to provide such a composite material utilizing silicon carbide short fibers 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.

It is a further object of the present invention to provide such a composite material utilizing silicon carbide short fibers as reinforcing material and aluminum alloy as matrix metal, which is improved over prior art such composite materials as regards machinability.

It is a further object of the present invention to provide such a composite material utilizing silicon carbide short fibers as reinforcing material and aluminum alloy as matrix metal, which is improved over prior art such composite materials as regards workability.

It is a further object of the present invention to provide such a composite material utilizing silicon carbide short fibers as reinforcing material and aluminum alloy as matrix metal, which has good characteristics with regard to amount of wear on a mating member.

It is a yet further object of the present invention to provide such a composite material utilizing silicon carbide short fibers as reinforcing material and aluminum alloy as matrix metal, which is not brittle.

It is a yet further object of the present invention to provide such a composite material utilizing silicon carbide short fibers as reinforcing material and aluminum alloy as matrix metal, which is durable.

It is a yet further object of the present invention to provide such a composite material utilizing silicon carbide short fibers as reinforcing material and aluminum alloy as matrix metal, which has good wear resistance.

It is a yet further object of the present invention to provide such a composite material utilizing silicon carbide short fibers as reinforcing material and aluminum alloy as matrix metal, which has good uniformity.

According to the most general aspect of the present invention, these and other objects are accomplished by a composite material, comprising silicon carbide short fibers embedded in a matrix of metal, the fiber volume proportion of said silicon carbide short fibers being between approximately 5% and approximately 50%, and said metal being an alloy consisting essentially of between approximately 2% to approximately 6% of copper, between approximately 2% to approximately 4% of magnesium, and remainder substantially aluminum; and more preferably the fiber volume proportion of said silicon carbide short fibers may be between approximately 5% and approximately 40%; more preferably the copper content of said aluminum alloy matrix metal may be between approximately 2% and approximately 5.5%; and more preferably the magnesium content of said aluminum alloy matrix metal may be between approximately 2% and approximately 3.5%.

According to the present invention as described above, as reinforcing fibers there are used silicon carbide short 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 2% to 6%, a magnesium content of 2% to 4%, and the remainder substantially aluminum, and the volume proportion of the silicon carbide short fibers is from 5% to 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 characteristics such as strength can be obtained.

Also according to the present invention, in cases where it is satisfactory if the same degree of strength as a conventional silicon carbide short fiber reinforced aluminum alloy is obtained, the volume proportion of silicon carbide short fibers in a composite material according to the present invention may be set to be lower than the value required for such a conventional composite material, and therefore, since it is possible to reduce the amount of silicon carbide short fibers 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 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 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 to rapidly disintegrate. Therefore the copper content of the aluminum 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 preferably is required to be in the range of from approximately 2% to approximately 5.5%.

Furthermore, oxides are normally present on the surface of such silicon carbide short fibers used as reinforcing fibers, before they are incorporated into the composite material, and if magnesium, which has a strong tendency to form oxides, is included in the molten matrix metal, then it is considered by the present inventors that the magnesium will react with the oxides on the surface of the silicon carbide short fibers during the process of infiltrating the molten matrix metal into the interstices of the reinforcing silicon carbide short fiber mass, and this magnesium will reduce the surface of the silicon carbide short fibers, as a result of which the affinity of the molten aluminum alloy matrix metal and the silicon carbide short fibers will be improved, and by this means the strength of the composite material will be improved. If, however, the magnesium content is less than 2%, as will become clear from the experimental researches given hereinafter, this effect is not sufficient, whereas if the magnesium content is more than 4% it is considered by the present inventors that an excessive oxidation-reduction reaction occurs, and as a result the silicon carbide short fibers deteriorate, or brittle interface reaction products are produced on the surface of the silicon carbide short fibers, and therefore the strength of the composite material is in the end reduced. Therefore the magnesium content of the aluminum 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 4%, and preferably is required to be in the range of from approximately 2% to approximately 3.5%.

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 carbide short fibers is less than 5%, a sufficient strength cannot be obtained, and if the volume proportion of silicon carbide short fibers exceeds 40% and particularly if it exceeds 50% even if the volume proportion of the silicon carbide short fibers is 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 carbide short fibers, but when the volume proportion of the silicon carbide 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 carbide short fibers, whereas when the volume proportion of the silicon carbide 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 the volume proportion of said silicon carbide short fibers. Therefore, according to one characteristic of the present invention, the volume proportion of the silicon carbide 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%.

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 within the aluminum alloy, the portions where the copper 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 approximately 2% and is less than approximately

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, and is 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, 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 approximately 3.5% and is less than approximately 6.5% is subjected to liquidizing processing for from about 2 hours to about 8 hours at a temperature of from about 460°C to about 510°C, and is 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.

Further the silicon carbide short fibers in the composite material of the present invention may be either silicon carbide whiskers or silicon carbide non continuous fibers, and the silicon carbide non continuous fibers may be silicon carbide continuous fibers cut to a predetermined length. Also, the fiber length of the silicon carbide 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 is preferably approximately 0.1 micron to approximately 25 microns, and particularly is from approximately 0.1 micron to approximately 20 microns.

It should be noted that in this specification all percentages, except in the expression 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 1%, and each of said elements individually is not present to more than 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 shown and described with regard to certain of the preferred embodiments thereof, and with reference to the illustrative drawings, which however should not be considered as limitative of the present invention in any way, since the scope of the present invention is to be considered as being delimited solely by the accompanying claims, rather than by any particular features of the disclosed embodiments or of the drawings. In these drawings:

Fig. 1 is a perspective view of a preform made of silicon carbide short whisker material, with said silicon carbide short whiskers being aligned substantially randomly in three dimensions, for incorporation into composite materials according to various preferred embodiments of the present invention;

Fig. 2 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 Fig. 1 silicon carbide short whisker material preform incorporated in a matrix of matrix metal;

Fig. 3 is a set of graphs in which copper 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 the first set of preferred embodiments of the material of the present invention, each said graph showing the relation between copper content and bending strength of certain composite material test pieces for a particular fixed percentage content of magnesium in the matrix metal of the composite material;

Fig. 4 is a set of graphs in which magnesium content in percent is shown along the horizontal axis and bending strength in kg/mm² is shown along the vertical axis, derived from data relating to bending strength tests for the first set of preferred embodiments of the material of the present invention, 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;

Fig. 5 is a set of graphs, similar to Fig. 3 for the first set of preferred embodiments, in which copper content in percent is shown along the horizontal axis and bending strength in kg/mm² is shown along the vertical axis, derived from data relating to bending strength tests for the second set of preferred embodiments of the material of the present invention, each said graph showing the relation between copper content and bending strength of certain composite material test pieces for a particular fixed percentage content of magnesium in the matrix metal of the composite material;

Fig. 6 is a set of graphs, similar to Fig. 4 for the 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 the second set of preferred embodiments of the material of the present invention, 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;

Fig. 7 is a set of graphs, similar to Figs. 3 and 5 for the first and second sets of preferred embodiments respectively, in which copper 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 the third set of preferred embodiments of the material of the present invention, each said graph showing the relation between copper content and bending strength of certain composite material test pieces for a particular fixed percentage content of magnesium in the matrix metal of the composite material;

Fig. 8 is a set of graphs, similar to Figs. 4 and 6 for the first and second sets of preferred embodiments respectively, in which magnesium content in percent is shown along the horizontal axis and bending strength in kg/mm² is shown along the vertical axis, derived from data relating to bending strength tests for the third set of preferred embodiments of the material of the present invention, 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;

Fig. 9 is a set of graphs, similar to Figs. 3, 5, and 7 for the first through the third sets of preferred embodiments respectively, in which copper content in percent is shown along the horizontal axis and bending strength in kg/mm² is shown along the vertical axis, derived from data relating to bending strength tests for the fourth set of preferred embodiments of the material of the present invention, each said graph showing the relation between copper content and bending strength of certain composite material test pieces for a particular fixed percentage content of magnesium in the matrix metal of the composite material;

Fig. 10 is a set of graphs, similar to Figs. 4, 6, and 8 for the first through the third sets of preferred embodiments respectively, 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 the fourth set of preferred embodiments of the material of the present invention, 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;

Fig. 11 is a set of graphs, similar to Figs. 3, 5, 7 and 9 for the first through the fourth sets of preferred embodiments respectively, in which copper 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 the fifth set of preferred embodiments of the material of the present invention, each said graph showing the relation between copper content and bending strength of certain composite material test pieces for a particular fixed percentage content of magnesium in the matrix metal of the composite material;

Fig. 12 is a set of graphs, similar to Figs. 4, 6, 8 and 10 for the first through the fourth sets of preferred embodiments respectively, 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 the fifth set of preferred embodiments of the material of the present invention, 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;

Fig. 13 is a set of graphs, similar to Figs. 3, 5, 7, 9 and 11 for the first through the fifth sets of preferred embodiments respectively, in which copper 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 the sixth set of preferred embodiments of the material of the present invention, each said graph showing the relation between copper content and bending strength of certain composite material test pieces for a particular fixed percentage content of magnesium in the matrix metal of the composite material;

Fig. 14 is a set of graphs, similar to Figs. 4, 6, 8, 10 and 12 for the first through the fifth sets of preferred embodiments respectively, in which magnesium content in percent is shown along the horizontal axis and bending strength in kg/mm² is shown along the vertical axis, derived from data relating to bending strength tests for the sixth set of preferred embodiments of the material of the present invention, 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; and

Fig. 15 is a graph in which the volume proportion of the reinforcing silicon carbide short fiber material in percent is shown along the horizontal axis and bending strength in kg/mm² is shown along the vertical axis, derived from data relating to bending strength tests for the seventh set of preferred embodiments of the material of the present invention, said graph showing the relation between volume proportion of the reinforcing silicon carbide short fiber material and bending strength of certain test pieces of the composite material.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described with reference to the various preferred embodiments thereof. It should be noted that all 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.

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 material of which is to be silicon carbide short fibers, the present inventors manufactured by using the high pressure casting method samples of various composite materials, utilizing as reinforcing material silicon carbide whisker material of type "Tokamax" (this is a trademark) made by Tokai Carbon K.K., which had fiber lengths 50 to 200 microns and fiber diameters 0.2

to 0.5 microns, 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 A44 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, introducing an appropriate quantity of substantially pure aluminum metal (purity at least 99%) and an appropriate quantity of substantially pure magnesium metal (purity at least 99%) into an alloy of approximately 50% aluminum and approximately 50% copper. And an appropriate number of silicon carbide whisker material preforms were made by, in each case, subjecting a quantity of the above specified silicon carbide whisker material to compression forming without using any binder. Each of these silicon carbide whisker material preforms was, as schematically illustrated in perspective view in Fig. 1 wherein an exemplary such preform is designated by the reference numeral 2 and the silicon carbide whiskers therein are generally designated as 1, about 38 x 100 x 16 mm in dimensions, and the individual silicon carbide whiskers 1 in said preform 2 were oriented substantially randomly in three dimensions. And the fiber volume proportion in each of said preforms 2 was approximately 30%.

Next, each of these silicon carbide whisker material preforms 2 was subjected to high pressure casting together with an appropriate quantity of one of the aluminum alloys A1 through A44 described above, in the following manner. First, the preform 2 was heated up to a temperature of approximately 600°C, and then said preform 2 was 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 A44 described above, molten and at a temperature of approximately 710°C, was relatively rapidly poured into said mold cavity 4, so as to surround the preform 2 therein, and then as shown in schematic perspective view in Fig. 2 a pressure plunger 6, which itself had previously been preheated up to a temperature of approximately 200°C, 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 to a pressure of approximately 1000 kg/cm^2. Thereby, the molten aluminum alloy was caused to percolate into the interstices of the silicon carbide 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 preform 2 included therein was removed from the casting mold 3, and the peripheral portion of said solidified aluminum alloy mass was machined away, leaving only a sample piece of composite material which had silicon carbide fiber whisker material as reinforcing material and the appropriate one of the aluminum alloys A1 through A44 as matrix metal. The volume proportion of silicon carbide fibers in each of the resulting composite material sample pieces was approximately 30%.

Next, the following post processing steps were performed on the composite material samples. Irrespective of the magnesium content of the aluminum alloy matrix metal: those of said composite material samples whose matrix metal had a copper content of less than approximately 2% were subjected to liquidizing processing at a temperature of approximately 530°C for approximately 8 hours, and then were subjected to artificial aging processing at a temperature of approximately 160°C for approximately 8 hours; those of said composite material samples whose matrix metal had a copper content of at least approximately 2% and not more than approximately 3.5% were subjected to liquidizing processing at a temperature of 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; and those of said composite material samples whose matrix metal had a copper content of at least approximately 3.5% and not more than approximately 6.5% were subjected to 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.

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 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 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 piece 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).

The results of these bending strength tests were as shown in the appended Table 2, and as summarized in the graphs of Fig. 3 and Fig. 4. The numerical values in Table 2 indicate the bending strengths (in kg/mm^2) of the composite material bending strength test pieces having as matrix metals aluminum alloys having percentage contents of copper and magnesium as shown along the upper edge and down the left edge of the table, respectively. The graphs of Fig. 3 are based upon the data in Table 2, and show the relation between copper content and the bending strength (in kg/mm^2) of certain of the composite material test pieces, for percentage contents of magnesium fixed along the various lines thereof; and the graphs of Fig. 4 are also based upon the data in Table 2, and similarly but contrariwise show the relation between magnesium content and the bending strength (in kg/mm^2) of certain of the composite material test pieces, for percentage contents of copper fixed along the various lines thereof. In Table 2, Fig. 3, and Fig. 4, the values for magnesium content and for copper content are shown with their second decimal places rounded by rounding .04 downwards to .0 and .05 upwards to .1.

From Table 2, Fig. 3, and Fig. 4, it will be understood that, substantially irrespective of the magnesium content of the aluminum alloy matrix metal of the bending strength composite material test pieces: when the copper content was either at the low extreme of approximately 1.5% or at the high extreme of approximately 6.5% the bending strength of the composite material had a relatively low value; when the copper content was in the range of approximately 3% to approximately 4% the bending strength of the composite material reached a maximum value; and, when the copper content was in the range of not less than approximately 4% the bending strength of the composite material had a tendency to reduce along with an increase in the copper content. Also, it will be understood that, substantially irrespective of the copper content of the aluminum alloy matrix metal of the bending strength composite material test pieces: when the magnesium content was either below approximately 2% or above approximately 4% the bending strength of the composite material had a relatively low value; when the magnesium content was approximately 3% the bending strength of the composite material had a substantially maximum value; when the magnesium content either increased or decreased from said optimal bending strength value of approximately 3% the bending strength of the composite material decreased gradually; and, when the magnesium content was approximately 4.5%, the bending strength of the composite material was substantially the same as when the magnesium content was approximately 1%.

It will be further seen from the values in Table 2 that, for such a composite material having a volume proportion of approximately 30% of silicon carbide whisker material as reinforcing fiber material and using such an aluminum alloy as matrix metal, the bending strength values are generally very much higher than the typical bending strength of approximately 60 kg/mm² attained in the conventional art for a composite material using as matrix metal a conventionally so utilized aluminum alloy of JIS standard AC4C and using similar silicon carbide short fiber material as reinforcing material; and in particular it will be appreciated that the bending strength of such a composite material whose matrix metal aluminum alloy has a copper content of from approximately 2% to approximately 6% and a magnesium content of from approximately 2% to approximately 4% is approximately between 1.4 and 1.6 times as great as that of such an abovementioned conventional composite material.

From the results of these bending strength tests it will be seen that, in order to increase the strength of a composite material having as reinforcing fiber material silicon carbide whiskers in a volume proportion of 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 5.5%; and it is preferable that the magnesium content of said Al-Cu-Mg type aluminum alloy matrix metal should be in the range of from approximately 2% to approximately 4%, and particularly should be in the range of from approximately 2% to approximately 3.5%.

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 carbide whisker material, and utilizing as matrix metal various other Al-Cu-Mg type aluminum alloys, but this time employing a fiber volume proportion of only approximately 10%. Then the present inventors again conducted evaluations of the bending strength of the various resulting composite material sample pieces.

First, a set of aluminum alloys designated as B1 through B39 were produced in the same manner as before, again having as base material aluminum and having various quantities of magnesium and copper mixed therewith, as shown in the appended Table 3. And an appropriate number of silicon carbide whisker material preforms were as before made by, in each case, subjecting a quantity of the previously utilized type of silicon carbide whisker material to compression forming without using any binder, each of said silicon carbide whisker material preforms 2 now having a fiber volume proportion of approximately 10%, by contrast to the first set of preferred embodiments described above. These preforms 2 had substantially the same dimensions as the preforms 2 of the first set of preferred embodiments.

Next, substantially as before, each of these silicon carbide whisker material preforms 2 was subjected to high pressure casting together with an appropriate quantity of one of the aluminum alloys B1 through B39 described above, utilizing operational parameters substantially as before. The solidified aluminum alloy mass with the preform 2 included therein was then removed from the casting mold, and the peripheral portion of said solidified aluminum alloy mass was machined away, leaving only a sample piece of composite material which had silicon carbide fiber whisker material as reinforcing material and the appropriate one of the aluminum alloys B1 through B39 as matrix metal. The volume proportion of silicon carbide fibers in each of the resulting composite material sample pieces was thus now approximately 10%. 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 substantially as in the case of the first set 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.

The results of these bending strength tests were as shown in the appended Table 4, and as summarized in the graphs of Fig. 5 and Fig. 6. The numerical values in Table 4 indicate the bending strengths (in kg/mm^2) of the composite material bending strength test pieces having as matrix metals aluminum alloys having percentage contents of copper and magnesium as shown along the upper edge and down the left edge of the table, respectively. The graphs of Fig. 5 are based upon the data in Table 4, and show the relation between copper content and the bending strength (in kg/mm^2) of certain of the composite material test pieces, for percentage contents of magnesium fixed along the various lines thereof; and the graphs of Fig. 6 are also based upon the data in Table 4, and similarly but contrariwise show the relation between magnesium content and the bending strength (in kg/mm^2) of certain of the composite material test pieces, for percentage contents of copper fixed along the various lines thereof. In Table 4, Fig. 5, and Fig. 6, as before, the values for magnesium content and for copper content are shown with their second decimal places rounded by rounding .04 downwards to .0 and .05 upwards to .1.

From Table 4, Fig. 5, and Fig. 6, it will be understood that, substantially irrespective of the magnesium content of the aluminum alloy matrix metal of the bending strength composite material test pieces: when the copper content was either at the low extreme of approximately 1.5% or at the high extreme of approximately 6.5% the bending strength of the composite material had a relatively low value; when the copper content was in the range of up to and including approximately 3% the bending strength of the composite material increased along with an increase in the copper content; when the copper content was approximately 4% the bending strength reached a substantially maximum value; and, when the copper content was in the range of not less than approximately 4% the bending strength of the composite material had a tendency to reduce along with an increase in the copper content. Also, it will be understood that, substantially irrespective of the copper content of the aluminum alloy matrix metal of the bending strength composite material test pieces: when the magnesium content was either below approximately 2% or above approximately 4% the bending strength of the composite material had a relatively low value; when the magnesium content was approximately 3% the bending strength of the composite material had a substantially maximum value; when the magnesium content either increased or decreased from approximately 3%, the bending strength of the composite material decreased gradually; and, when the magnesium content was approximately 4.5%, the bending strength of the composite material was substantially the same as when the magnesium content was approximately 1%.

It will be further seen from the values in Table 4 that, for such a composite material having a volume proportion of approximately 10% of silicon carbide whisker material as reinforcing fiber material and using such an aluminum alloy as matrix metal, the bending strength values are generally very much higher than the typical bending strength of approximately 44 kg/mm^2 attained in the conventional art for a composite material using as matrix metal a conventionally so utilized aluminum alloy of JIS standard AC4C and using similar silicon carbide short fiber material as reinforcing material; and in particular it will be appreciated that the bending strength of such a composite material whose matrix metal aluminum alloy has a copper content of from approximately 2% to approximately 6% and a magnesium content of from approximately 2% to approximately 4% is approximately between 1.3 and 1.5 times as great as that of such an abovementioned conventional composite material.

From the results of these bending strength tests it will be seen that, also in this case when the volume proportion of the reinforcing silicon carbide fibers is approximately 10% as in the previous case when said volume proportion was approximately 30%, in order to increase the strength of such a composite material having such silicon carbide whisker reinforcing fiber material and having as matrix metal an Al-Cu-Mg type aluminum alloy, it is again 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 5.5%; and it is preferable that the magnesium content of said Al-Cu-Mg type aluminum alloy matrix metal should be in the range of from approximately 2% to approximately 4%, and particularly should be in the range of from approximately 2% to approximately 3.5%.

THE THIRD SET OF PREFERRED EMBODIMENTS

Next, the present inventors manufactured further samples of various composite materials, again utilizing as reinforcing material the same silicon carbide whisker material, and utilizing as matrix metal various Al-Cu-Mg type aluminum alloys, but this time employing a fiber volume proportion of only approximately 5%. Then the present inventors again conducted evaluations of the bending strength of the various resulting composite material sample pieces.

First, a set of aluminum alloys the same as those designated as B1 through B39 in the case of the second set of preferred embodiments were produced in the same manner as before, except that the alloys B7, B12, B18, B24, B33, and B38 were not produced, and said alloys thus again had as base material aluminum and had various quantities of magnesium and copper mixed therewith. No particular table of proportions of magnesium and copper relating to these alloys of this third set of preferred embodiments like Tables 1 and 3 for the alloys of the first and second sets of preferred embodiments is appended, since none is required. And an appropriate number of silicon carbide whisker material preforms were made as before by, in each case, subjecting a quantity of the previously utilized type of silicon carbide whisker material to compression forming without using any binder, each of said silicon carbide whisker material preforms 2 now having a fiber volume proportion of approximately 5%, by contrast to the first and second sets of preferred embodiments described above; these preforms 2 had substantially the same dimensions as the preforms 2 of the first and second sets of preferred embodiments. Next, substantially as before, each of these silicon carbide whisker material preforms 2 was subjected to high pressure casting together with an appropriate quantity of one of the aluminum alloys described above, utilizing operational parameters substantially as before, and, after machining away the peripheral portions of the resulting solidified aluminum alloy masses, sample pieces of composite material which had silicon carbide fiber whisker material as reinforcing material and the appropriate one of the above described aluminum alloys as matrix metal were obtained. And the volume proportion of silicon carbide fibers in each of the resulting composite material sample pieces was thus now approximately 5%. Post processing steps were performed on the composite material samples, substantially as before, and 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 substantially as in the case of the first and second 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. The results of these bending strength tests were as shown in the appended Table 5, and as summarized in the graphs of Fig. 7 and Fig. 8. Thus, Table 5, Fig. 7, and Fig. 8 correspond respectively to Table 4, Fig. 5, and Fig. 6 of the second set of preferred embodiments described above, and also respectively to Table 2, Fig. 3, and Fig. 4 of the first set of preferred embodiments. As before, the numerical values in Table 5 indicate the bending strengths (in kg/mm^2) of the composite material bending strength test pieces having as matrix metals aluminum alloys having percentage contents of copper and magnesium as shown along the upper edge and down the left edge of the table, respectively. The graphs of Fig. 7 are based upon the data in Table 5, and show the relation between copper content and the bending strength (in kg/mm²) of certain of the composite material test pieces, for percentage contents of magnesium fixed along the various lines thereof; and the graphs of Fig. 8 are also based upon the data in Table 5, and similarly but contrariwise show the relation between 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. In Table 5, Fig. 7, and Fig. 8, as before, the values for magnesium content and for copper content are shown with their second decimal places rounded by rounding .04 downwards to .0 and .05 upwards to .1.

From Table 5, Fig. 7, and Fig. 8, it will be understood that, substantially irrespective of the magnesium content of the aluminum alloy matrix metal of the bending strength composite material test pieces: when the copper content was either at the low extreme of approximately 1.5% or at the high extreme of approximately 6.5% the bending strength of the composite material had a relatively low value; when the copper content was in the range of up to and including approximately 3% the bending strength of the composite material increased along with an increase in the copper content; when the copper content was approximately 4%

the bending strength reached a substantially maximum value; and, when the copper content was in the range of not less than approximately 4% the bending strength of the composite material had a tendency to reduce along with an increase in the copper content. Also, it will be understood that, substantially irrespective of the copper content of the aluminum alloy matrix metal of the bending strength composite material test pieces: when the magnesium content was either below approximately 2% or above approximately 4% the bending strength of the composite material had a relatively low value; when the magnesium content was approximately 3% the bending strength of the composite material had a substantially maximum value; when the magnesium content either increased or decreased from approximately 3%, the bending strength of the composite material decreased gradually; and, when the magnesium content was approximately 4.5%, the bending strength of the composite material was substantially the same as when the magnesium content was approximately 1%.

It will be further seen from the values in Table 5 that, for such a composite material having a volume proportion of approximately 5% of silicon carbide whisker material as reinforcing fiber material and using such an aluminum alloy as matrix metal, the bending strength values are generally very much higher than the typical bending strength of approximately 39 kg/mm^2 attained in the conventional art for a composite material using as matrix metal a conventionally so utilized aluminum alloy of JIS standard AC4C and using similar silicon carbide short fiber material as reinforcing material; and in particular it will be appreciated that the bending strength of such a composite material whose matrix metal aluminum alloy has a copper content of from approximately 2% to approximately 6% and a magnesium content of from approximately 2% to approximately 4% is approximately between 1.4 and 1.6 times as great as that of such an abovementioned conventional composite material.

From the results of these bending strength tests it will be seen that, also in this case when the volume proportion of the reinforcing silicon carbide fibers is approximately 5% as in the previous cases when said volume proportion was approximately 30% or 20%, in order to increase the strength of such a composite material having such silicon carbide whisker reinforcing fiber material and having as matrix metal an Al-Cu-Mg type aluminum alloy, it is again 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 5.5%; and it is preferable that the magnesium content of said Al-Cu-Mg type aluminum alloy matrix metal should be in the range of from approximately 2% to approximately 4%, and particularly should be in the range of from approximately 2% to approximately 3.5%.

THE FOURTH SET OF PREFERRED EMBODIMENTS

For the fourth set of preferred embodiments of the present invention, a different type of reinforcing fiber was chosen. The present inventors manufactured by using the high pressure casting method samples of various composite materials, utilizing as reinforcing material silicon carbide whisker material of type "Nikaron" (this is a trademark) made by Nihon Carbon K.K., which was a continuous fiber material with fiber diameters 10 to 15 microns and was cut at intervals of approximately 5 mm to produce a silicon carbide short fiber material, 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.

In detail, first, a set of aluminum alloys designated as B1 through B39 were produced in the same manner as in the second set of preferred embodiments described above, and thus the previously described Table 3 is applicable to this fourth set of preferred embodiments also. And an appropriate number of silicon carbide whisker material preforms were now made by, in each case, first adding polyvinyl alcohol to function as an organic binder to a quantity of the above described type of silicon carbide whisker material, then applying compression forming to the resulting fiber mass, and then drying the compressed form in the atmosphere at a temperature of approximately 600°C for approximately 1 hour so as to evaporate the polyvinyl alcohol organic binder. Each of the resulting silicon carbide whisker material preforms 2 now had a silicon carbide short fiber volume proportion of approximately 15%, by contrast to the first through the third sets of preferred embodiments described above. These preforms 2 had substantially the same dimensions of about 38 x 100 x 16 mm as the preforms 2 of the first through the third sets of preferred embodiments described above, and in this case the silicon carbide short fibers incorporated therein were oriented substantially randomly in planes parallel to their 38 mm x 100 mm faces, and had randomly overlapping orientation in the thickness direction orthogonal to these planes.

Next, substantially as before, each of these silicon carbide whisker material preforms was subjected to high pressure casting together with an appropriate quantity of one of the aluminum alloys B1 through B39 described above, utilizing operational parameters substantially as before. 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 was machined away, leaving only a sample piece of composite material which had silicon carbide fiber whisker material as reinforcing material and the appropriate one of the aluminum alloys B1 through B39 as matrix metal. The volume proportion of silicon carbide fibers in each of the resulting composite material sample pieces was thus now approximately 15%. And post processing steps of liquidizing processing and artificial aging processing 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 length approximately 50 mm, width approximately 10 mm, and thickness approximately 2 mm, substantially as before, with its 50 mm x 10 mm faces parallel to the planes of random two dimensional fiber orientation of the silicon carbide short fiber material included therein, and for each of these composite material bending strength test pieces a bending strength test was carried out, again substantially as before.

The results of these bending strength tests were as shown in the appended Table 6, and as summarized in the graphs of Fig. 9 and Fig. 10. The numerical values in Table 6 indicate the bending strengths (in kg/mm^2) of the composite material bending strength test pieces having as matrix metals aluminum alloys having percentage contents of copper and magnesium as shown along the upper edge and down the left edge of the table, respectively. The graphs of Fig. 9 are based upon the data in Table 6, and show the relation between copper content and the bending strength (in kg/mm^2) of certain of the composite material test pieces, for percentage contents of magnesium fixed along the various lines thereof; and the graphs of Fig. 10 are also based upon the data in Table 6, and similarly but contrariwise show the relation between magnesium content and the bending strength (in kg/mm^2) of certain of the composite material test pieces, for percentage contents of copper fixed along the various lines thereof. In Table 6, Fig. 9, and Fig. 10, as before, the values for magnesium content and for copper content are shown with their second decimal places rounded by rounding .04 downwards to .0 and .05 upwards to .1.

From Table 6, Fig. 9, and Fig. 10, it will be understood that, substantially irrespective of the magnesium content of the aluminum alloy matrix metal of the bending strength composite material test pieces: when the copper content was either at the low extreme of approximately 1.5% or at the high extreme of approximately 6.5% the bending strength of the composite material had a relatively low value; when the copper content was in the range of up to and including approximately 3% the bending strength of the composite material increased along with an increase in the copper content; when the copper content was approximately 4% the bending strength reached a substantially maximum value; and, when the copper content was in the range of not less than approximately 4% the bending strength of the composite material had a tendency to reduce along with an increase in the copper content. Also, it will be understood that, substantially irrespective of the copper content of the aluminum alloy matrix metal of the bending strength composite material test pieces: when the magnesium content was either below approximately 2% or above approximately 4% the bending strength of the composite material had a relatively low value; when the magnesium content was approximately 3% the bending strength of the composite material had a substantially maximum value; when the magnesium content either increased or decreased from approximately 3%, the bending strength of the composite material decreased gradually; and, when the magnesium content was approximately 4.5%, the bending strength of the composite material was substantially the same as when the magnesium content was approximately 1%.

From the results of these bending strength tests it will be seen that, also in this case when the volume proportion of this type of reinforcing silicon carbide fibers is approximately 15% as in the previous cases relating to the first type of reinforcing silicon carbide fibers, in order to increase the strength of such a composite material having such silicon carbide whisker reinforcing fiber material and having as matrix metal an Al-Cu-Mg type aluminum alloy, it is again 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 5.5%; and it is preferable that the magnesium content of said Al-Cu-Mg type aluminum alloy matrix metal should be in the range of from approximately 2% to approximately 4%, and particularly should be in the range of from approximately 2% to approximately 3.5%.

THE FIFTH SET OF PREFERRED EMBODIMENTS

Next, the present inventors manufactured further samples of various composite materials, again utilizing as reinforcing material the same silicon carbide whisker material as in the fourth set of preferred embodiments described above, and utilizing as matrix metal various Al-Cu-Mg type aluminum alloys, but this time employing a fiber volume proportion of approximately 20%. Then the present inventors again conducted evaluations of the bending strength of the various resulting composite material sample pieces.

First, a set of aluminum alloys the same as those designated as B1 through B39 in the case of the second and the fourth sets of preferred embodiments were produced in the same manner as before, except that (as in the case of the third set of preferred embodiments) the alloys B7, B12, B18, B24, B33, and B38 were not produced, and said alloys thus again had as base material aluminum and had various quantities of magnesium and copper mixed therewith. No particular table of proportions of magnesium and copper relating to these alloys of this third set of preferred embodiments like Tables 1 and 3 for the alloys of the first and second sets of preferred embodiments is appended, since none is required. And an appropriate number of silicon carbide whisker material preforms were made as before by, in each case, subjecting a quantity of the type of silicon carbide whisker material utilized in the fourth set of preferred embodiments to compression forming as described above, each of said silicon carbide whisker material preforms 2 now having a fiber volume proportion of approximately 20%, by contrast to the fourth set of preferred embodiments described above; these preforms 2 had substantially the same dimensions as the preforms 2 of the fourth set of preferred embodiments, and the same type of fiber orientation. Next, substantially as before, each of these silicon carbide whisker material preforms 2 was subjected to high pressure casting together with an appropriate quantity of one of the aluminum alloys described above, utilizing operational parameters substantially as before, and, after machining away the peripheral portions of the resulting solidified aluminum alloy masses, sample pieces of composite material which had silicon carbide fiber whisker material as reinforcing material and the appropriate one of the above described aluminum alloys as matrix metal were obtained. And the volume proportion of silicon carbide fibers in each of the resulting composite material sample pieces was thus now approximately 20%. Post processing steps were performed on the composite material samples, substantially as before, and from each of the composite material sample pieces manufactured as described above, to which heat treatment had again been applied, there was cut a bending strength test piece of dimensions substantially as in the case of the fourth set of preferred embodiments and with fiber orientation substantially as described above, and for each of these composite material bending strength test pieces a bending strength test was carried out, again substantially as before. The results of these bending strength tests were as shown in the appended Table 7, and as summarized in the graphs of Fig. 11 and Fig. 12. Thus, Table 7, Fig. 11, and Fig. 12 correspond respectively to Table 6, Fig. 9, and Fig. 10 of the fourth set of preferred embodiments described above. As before, the numerical values in Table 7 indicate the bending strengths (in kg/mm^2) of the composite material bending strength test pieces having as matrix metals aluminum alloys having percentage contents of copper and magnesium as shown along the upper edge and down the left edge of the table, respectively. The graphs of Fig. 11 are based upon the data in Table 7, and show the relation between copper content and the bending strength (in kg/mm^2) of certain of the composite material test pieces, for percentage contents of magnesium fixed along the various lines thereof; and the graphs of Fig. 12 are also based upon the data in Table 7, and similarly but contrariwise show the relation between magnesium content and the bending strength (in kg/mm^2) of certain of the composite material test pieces, for percentage contents of copper fixed along the various lines thereof. In Table 7, Fig. 11, and Fig. 12, as before, the values for magnesium content and for copper content are shown with their second decimal places rounded by rounding .04 downwards to .0 and .05 upwards to .1.

From Table 7, Fig. 11, and Fig. 12, it will be understood that, substantially irrespective of the magnesium content of the aluminum alloy matrix metal of the bending strength composite material test pieces: when the copper content was either at the low extreme of approximately 1.5% or at the high extreme of approximately 6.5% the bending strength of the composite material had a relatively low value; when the copper content was in the range of up to and including approximately 3% the bending strength of the composite material increased along with an increase in the copper content; when the copper content was approximately 4% the bending strength reached a substantially maximum value; and, when the copper content was in the range of not less than approximately 4% the bending strength of the composite material had a tendency to reduce along with an increase in the copper content. Also, it will be understood that, substantially irrespective of the copper content of the aluminum alloy matrix metal of the bending strength composite material test pieces: when the magnesium content was either below approximately 2% or above approximately 4% the bending strength of the composite material had a relatively low value; when the magnesium content was approximately 3% the bending strength of the composite material had a substantially maximum value; when the magnesium content either increased or decreased from approximately 3%, the bending strength of the composite material decreased gradually; and, when the magnesium content was approximately 4.5%, the bending strength of the composite material was substantially the same as when the magnesium content was approximately 1%.

It will be further seen from the values in Table 7 that, for such a composite material having a volume proportion of approximately 20% of silicon carbide whisker material as reinforcing fiber material and using such an aluminum alloy as matrix metal, the bending strength values are generally very much higher than the typical bending strength of approximately 51 kg/mm^2 attained in the conventional art for a composite material using as matrix metal a conventionally so utilized aluminum alloy of JIS standard AC4C and using similar silicon carbide short fiber material as reinforcing material; and in particular it will be appreciated that the bending strength of such a composite material whose matrix metal aluminum alloy has a copper content of from approximately 2% to approximately 6% and a magnesium content of from approximately 2% to approximately 4% is approximately between 1.2 and 1.5 times as great as that of such an abovementioned conventional composite material.

From the results of these bending strength tests it will be seen that, also in this case when the volume proportion of the reinforcing silicon carbide fibers is approximately 20% as in the previous cases, in order to increase the strength of such a composite material having such silicon carbide whisker reinforcing fiber material and having as matrix metal an Al-Cu-Mg type aluminum alloy, it is again 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 5.5%; and it is preferable that the magnesium content of said Al-Cu-Mg type aluminum alloy matrix metal should be in the range of from approximately 2% to approximately 4%, and particularly should be in the range of from approximately 2% to approximately 3.5%.

THE SIXTH SET OF PREFERRED EMBODIMENTS

Next, the present inventors manufactured further samples of various composite materials, again utilizing as reinforcing material the same silicon carbide whisker material as in the fourth set of preferred embodiments described above, and utilizing as matrix metal various Al-Cu-Mg type aluminum alloys, but this time employing a fiber volume proportion of approximately 40%. Then the present inventors again conducted evaluations of the bending strength of the various resulting composite material sample pieces.

First, a set of aluminum alloys the same as those designated as B1 through B39 in the case of the second and the fourth sets of preferred embodiments were produced in the same manner as before, and further an additional alloy B40 was produced having a copper content of approximately 5.49%, a magnesium content of approximately 2.98%, remainder substantially aluminum, and said alloys B1 through B40 thus again had as base material aluminum and had various quantities of magnesium and copper mixed therewith. No particular table of proportions of magnesium and copper relating to these alloys of this third set of preferred embodiments like Tables 1 and 3 for the alloys of the first and second sets of preferred embodiments is appended, since again none is required. And an appropriate number of silicon carbide whisker material preforms were made as before by, in each case, subjecting a quantity of the same type of silicon carbide whisker material as utilized in the fourth set of preferred embodiments to compression forming as described with regard to said fourth set of preferred embodiments, each of said silicon carbide whisker material preforms 2 now having a fiber volume proportion of approximately 40% by contrast to said fourth set of preferred embodiments; these preforms 2 had substantially the same dimensions as the preforms 2 of the fourth set of preferred embodiments, and the same type of fiber orientation. Next, substantially as before, each of these silicon carbide whisker material preforms 2 was subjected to high pressure casting together with an appropriate quantity of one of the aluminum alloys described above, utilizing operational parameters substantially as before, and, after machining away the peripheral portions of the resulting solidified aluminum alloy masses, sample pieces of composite material which had silicon carbide fiber whisker material as reinforcing material and the appropriate one of the above described aluminum alloys as matrix metal were obtained. And the volume proportion of silicon carbide fibers in each of the resulting composite material sample pieces was thus now approximately 40%. Post processing steps were performed on the composite material samples, substantially as before, and from each of the composite material sample pieces manufactured as described above, to which heat treatment had again been applied, there was cut a bending strength test piece of dimensions substantially as in the case of the fourth set of preferred embodiments and with fiber orientation substantially as described above, and for each of these composite material bending strength test pieces a bending strength test was carried out, again substantially as before. The results of these bending strength tests were as shown in the appended Table 8, and as summarized in the graphs of Fig. 13 and Fig. 14. Thus, Table 8, Fig. 13, and Fig. 14 correspond respectively to Table 6, Fig. 9, and Fig. 10 of the fourth set of preferred embodiments described above. As before, the numerical values in Table 8 indicate the bending strengths (in kg/mm^2) of the composite material bending strength test pieces having as matrix metals aluminum alloys having percentage contents of copper and magnesium as shown along the upper edge and down the left edge of the table, respectively. The graphs of Fig. 13 are based upon the data in Table 8, and show the relation between copper content and the bending strength (in kg/mm^2) of certain of the composite material test pieces, for percentage contents of magnesium fixed along the various lines thereof; and the graphs of Fig. 14 are also based upon the data in Table 8, and similarly but contrariwise show the relation between magnesium content and the bending strength (in kg/mm^2) of certain of the composite material test pieces, for percentage contents of copper fixed along the various lines thereof. In Table 8, Fig. 13, and Fig. 14, as before, the values for magnesium content and for copper content are shown with their second decimal places rounded by rounding .04 downwards to .0 and .05 upwards to .1.

From Table 8, Fig. 13, and Fig. 14, it will yet again be understood that, substantially irrespective of the magnesium content of the aluminum alloy matrix metal of the bending strength composite material test pieces: when the copper content was either at the low extreme of approximately 1.5% or at the high extreme of approximately 6.5% the bending strength of the composite material had a relatively low value; when the copper content was in the range of up to and including approximately 3% the bending strength of the composite material increased along with an increase in the copper content; when the copper content was approximately 4% the bending strength reached a substantially maximum value; and, when the copper content was in the range of not less than approximately 4% the bending strength of the composite material had a tendency to reduce along with an increase in the copper content. Also, it will be yet again understood that, substantially irrespective of the copper content of the aluminum alloy matrix metal of the bending strength composite material test pieces: when the magnesium content was either below approximately 2% or above approximately 4% the bending strength of the composite material had a relatively low value; when the magnesium content was approximately 3% the bending strength of the composite material had a substantially maximum value; when the magnesium content either increased or decreased from approximately 3%, the bending strength of the composite material decreased gradually; and, when the magnesium content was approximately 4.5%, the bending strength of the composite material was substantially the same as when the magnesium content was approximately 1%.

It will be further seen from the values in Table 8 that, for such a composite material having a volume proportion of approximately 40% of such silicon carbide whisker material as reinforcing fiber material and using such an aluminum alloy as matrix metal, the bending strength values are generally very much higher than the typical bending strength of approximately 75 kg/mm^2 attained in the conventional art for a composite material using as matrix metal a conventionally so utilized aluminum alloy of JIS standard AC4C and using similar silicon carbide short fiber material as reinforcing material; and in particular it will be appreciated that the bending strength of such a composite material whose matrix metal aluminum alloy has a copper content of from approximately 2% to approximately 6% and a magnesium content of from approximately 2% to approximately 4% is approximately between 1.3 and 1.5 times as great as that of such an abovementioned conventional composite material.

From the results of these bending strength tests it will be seen that, also in this case when the volume proportion of the reinforcing silicon carbide fibers is approximately 40% as in the previous cases, in order to increase the strength of such a composite material having such silicon carbide whisker reinforcing fiber material and having as matrix metal an Al-Cu-Mg type aluminum alloy, it is again 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 5.5%; and it is preferable that the magnesium content of said Al-Cu-Mg type aluminum alloy matrix metal should be in the range of from approximately 2% to approximately 4%, and particularly should be in the range of from approximately 2% to approximately 3.5%.

OTHER EMBODIMENTS

Although no particular details thereof are given in the interests of brevity of description, in fact other sets of preferred embodiments similar to the fourth through the sixth sets of preferred embodiments described above were produced, in similar manners to those described above, but differing in the the silicon carbide short fibers which constituted the reinforcing material were in these cases cut to a length of approximately 1 cm; and bending strength tests of the same types as conducted in the fourth through the sixth sets of preferred embodiments described above were carried out on bending test samples which as before had their

50 mm x 10 mm faces extending parallel to the planes of random two dimensional fiber orientation of the silicon carbide short fiber material included in said test samples. The results of these bending strength tests were similar to those described above for said fourth through sixth sets of preferred embodiments, and the conclusions drawn therefrom were accordingly similar.

THE SEVENTH SET OF PREFERRED EMBODIMENTS

Since from the above described first through the sixth sets of preferred 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 particularly to be in the range of from approximately 2% to approximately 5.5%, and that it is preferable that the magnesium content of said Al-Cu-Mg type aluminum alloy matrix metal to be in the range of from approximately 2% to approximately 4%, and particularly to be in the range of from approximately 2% to approximately 3.5%, it is now germane to provide a set of tests to establish what fiber volume proportion of the reinforcing silicon carbide short fibers is most appropriate. This was done, in the seventh set of preferred embodiments now described, by varying said fiber volume proportion of the reinforcing silicon carbide whisker 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 3% and also magnesium content of approximately 3% and remainder substantially aluminum. In other words, an appropriate number of silicon carbide whisker material preforms were as before made by, in each case, subjecting a quantity of the type of silicon carbide whisker material utilized in the case of the first set of preferred embodiments described above to compression forming without using any binder, the various ones of said silicon carbide whisker material preforms having fiber volume proportions of approximately 0%, 5%, 10%, 25%, 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 first set of preferred embodiments. And, substantially as before, each of these silicon carbide whisker material preforms was subjected to high pressure casting together with an appropriate quantity of one of the aluminum alloy matrix metal described above, utilizing operational parameters substantially as before. 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, leaving only a sample piece of composite material which had silicon carbide fiber whisker material as reinforcing material in the appropriate fiber volume proportion and the described aluminum alloy as matrix metal. And post processing steps were performed on the composite material samples, similarly to what was done before: the composite material samples were subjected to liquidizing processing at a temperature of 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. From each of the composite material sample pieces manufactured as described above, to which heat treatment had been applied, there were then cut two bending strength test pieces, each of dimensions substantially as in the case of the first set 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. The results of these bending strength tests were as shown in the graph of Fig. 15, which shows the relation between the volume proportion of the silicon carbide short reinforcing fibers and the bending strength (in kg/mm^2) of the composite material test pieces.

From Fig. 15, it will be understood that: when the volume proportion of the silicon carbide 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 admixtured therewith; when the volume proportion of the silicon carbide short reinforcing fibers was in the range of 5% to 40% the bending strength of the composite material increased greatly, and substantially linearly along with increasing fiber volume proportion; and, when the volume proportion of the silicon carbide short reinforcing fibers increased above 40%, the bending strength of the composite material hardly increased along with any further increase in the fiber volume proportion, but remained substantially constant.

OTHER EMBODIMENTS

Although no particular details thereof are given in the interests of brevity of description, in fact two other sets of preferred embodiments similar to the seventh set of preferred embodiments described above were produced, in a similar manner to that described above, but differing in that in one of them the Al-Cu-Mg type aluminum alloy matrix metal utilized therein had copper content of approximately 2% and magnesium content of approximately 4% and remainder substantially aluminum, and in the other one of them said Al-Cu-Mg type aluminum alloy matrix metal utilized therein had copper content of approximately 6% and magnesium content of approximately 2% and remainder substantially aluminum; and bending strength tests of the same types as conducted in the seventh set of preferred embodiments described above were carried out on similar bending test samples. The results of these bending strength tests were similar to those described above for said seventh set of preferred embodiments and shown in Fig. 15, and the conclusions drawn therefrom were accordingly similar.

Further, although again no particular details thereof are given in the interests of brevity of description, another set of preferred embodiments similar to the seventh set of preferred embodiments described above was produced, in a similar manner to that described above, with the Al-Cu-Mg type aluminum alloy matrix metal utilized therein similarly having copper content of approximately 3% and also magnesium content of approximately 3% and remainder substantially aluminum, but now utilizing a type of silicon carbide short fiber reinforcing material the same as that used in the fourth set of preferred embodiments described above; and bending strength tests of the same type as conducted in the seventh set of preferred embodiments described above were carried out on similar bending test samples. The results of these bending strength tests were analogous to those described above for said seventh set of preferred embodiments and shown in Fig. 15, and exhibited the same trends; the conclusions drawn therefrom were accordingly again similar.

From these results described above, it is seen that in a composite material having silicon carbide short fiber reinforcing material and having as matrix metal an Al-Cu-Mg type aluminum alloy, said Al-Cu-Mg type aluminum alloy matrix metal having a copper content in the range of from approximately 2% to approximately 6%, a magnesium content in the range of from approximately 2% to approximately 4%, and remainder substantially aluminum, it is preferable that the fiber volume proportion of the silicon carbide 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%.

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Although the present invention has been shown and described in terms of certain sets of preferred embodiments thereof, and with reference to the appended drawings, it should not be considered as being particularly limited thereby. 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 legitimate and properly interpreted scope of the accompanying claims, which follow after the Tables.

TABLE 1

ALLOY NO.	COPPER CONTENT (WT %)	MAGNESIUM CONTENT (WT %)
A1	1.50	1.02
A2	1.48	2.00
A3	1.45	4.02
A4	2.04	0.04
A5	2.04	1.02
A6	2.03	1.98
A7	2.00	2.95
A8	1.96	3.45
A9	1.96	3.95
A10	3.03	0.03
A11	2.97	1.04
A12	2.95	2.02
A13	2.96	3.03
A14	2.95	3.49
A15	2.97	3.97
A16	2.95	4.45
A17	4.04	1.02
A18	4.02	1.96
A19	3.98	3.00

A20	3.95	3.47
A21	3.96	3.97
A22	3.97	4.45
A23	4.54	0.05
A24	5.03	1.00
A25	4.96	2.04
A26	4.97	3.00
A27	4.96	3.47
A28	4.97	3.96
A29	4.95	4.46
A30	5.52	1.02
A31	5.51	2.01
A32	5.49	2.98
A33	5.45	3.97
A34	5.54	0.04
A35	5.95	0.95
A36	5.97	2.01
A37	5.98	2.95
A38	5.97	3.46
A39	5.96	3.99
A40	5.97	4.47
A41	6.49	1.01
A42	6.47	1.98
A43	6.48	3.46
A44	6.45	3.99

TABLE 2

Mg % \ Copper %	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5
0	--	69	--	71	--	--	73	--	--	75	--
0.5	--	--	--	--	--	--	--	--	--	--	--
1	70	75	--	80	--	80	--	81	82	82	71
1.5	--	--	--	--	--	--	--	--	--	--	--
2	76	83	--	85	--	87	--	85	84	84	72
2.5	--	--	--	--	--	--	--	--	--	--	--
3	--	88	--	93	--	92	--	88	86	83	--
3.5	--	86	--	89	--	88	--	86	--	84	71
4	79	84	--	86	--	87	--	85	84	84	70
4.5	--	--	--	81	--	81	--	79	--	77	--

TABLE 3

ALLOY NO.	COPPER CONTENT (WT %)	MAGNESIUM CONTENT (WT %)
B1	1.50	1.02
B2	1.48	2.00
B3	1.45	4.02
B4	2.04	1.02
B5	2.03	1.98
B6	2.00	2.95
B7	1.96	3.45
B8	1.96	3.95
B9	2.97	1.04
B10	2.95	2.02
B11	2.96	3.03
B12	2.95	3.49
B13	2.97	3.97
B14	2.95	4.45
B15	4.04	1.02
B16	4.02	1.96
B17	3.98	3.00
B18	3.95	3.47
B19	3.96	3.97
B20	3.97	4.45
B21	5.03	1.00

B22	4.96	2.04
B23	4.97	3.00
B24	4.96	3.47
B25	4.97	3.96
B26	4.95	4.46
B27	5.52	1.02
B28	5.51	2.01
B29	5.45	3.97
B30	5.95	0.95
B31	5.97	2.01
B32	5.98	2.95
B33	5.97	3.46
B34	5.96	3.99
B35	5.97	4.47
B36	6.49	1.01
B37	6.47	1.98
B38	6.48	3.46
B39	6.45	3.99

TABLE 4

Mg %	Copper % 1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5
0	--	--	--	--	--	--	--	--	--	--	--
0.5	--	--	--	--	--	--	--	--	--	--	--
1	47	50	--	50	--	59	--	54	54	53	46
1.5	--	--	--	--	--	--	--	--	--	--	--
2	48	64	--	65	--	62	--	60	59	57	48
2.5	--	--	--	--	--	--	--	--	--	--	--
3	--	60	--	63	--	65	--	64	--	63	--
3.5	--	60	--	62	--	63	--	62	--	60	54
4	53	58	--	60	--	61	--	60	59	58	53
4.5	--	--	--	52	--	53	--	54	--	53	--

TABLE 5

Mg %	Copper % 1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5
0	--	--	--	--	--	--	--	--	--	--	--
0.5	--	--	--	--	--	--	--	--	--	--	--
1	44	49	--	50	--	55	--	52	51	50	44
1.5	--	--	--	--	--	--	--	--	--	--	--
2	45	55	--	62	--	60	--	56	55	54	47
2.5	--	--	--	--	--	--	--	--	--	--	--
3	--	58	--	60	--	61	--	60	--	57	--
3.5	--	--	--	--	--	--	--	--	--	--	--
4	46	56	--	57	--	58	--	57	56	55	46
4.5	--	--	--	49	--	50	--	48	--	47	--

TABLE 6

	Copper %										
Mg %	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5
0	--	--	--	--	--	--	--	--	--	--	--
0.5	--	--	--	--	--	--	--	--	--	--	--
1	51	55	--	57	--	65	--	61	59	57	52
1.5	--	--	--	--	--	--	--	--	--	--	--
2	53	65	--	67	--	69	--	68	66	65	55
2.5	--	--	--	--	--	--	--	--	--	--	--
3	--	68	--	70	--	71	--	70	--	68	--
3.5	--	65	--	69	--	70	--	68	--	66	59
4	57	63	--	68	--	67	--	65	63	64	57
4.5	--	--	--	59	--	57	--	54	--	54	--

TABLE 7

Mg %	Copper % 1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5
0	--	--	--	--	--	--	--	--	--	--	--
0.5	--	--	--	--	--	--	--	--	--	--	--
1	53	59	--	63	--	65	--	66	65	62	55
1.5	--	--	--	--	--	--	--	--	--	--	--
2	55	62	--	71	--	73	--	70	69	67	57
2.5	--	--	--	--	--	--	--	--	--	--	--
3	--	70	--	74	--	75	--	73	--	70	--
3.5	--	--	--	--	--	--	--	--	--	--	--
4	54	68	--	69	--	70	--	68	67	65	56
4.5	--	--	--	60	--	61	--	59	--	57	--

TABLE 8

Mg % \ Copper %	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5
0	--	--	--	--	--	--	--	--	--	--	--
0.5	--	--	--	--	--	--	--	--	--	--	--
1	88	91	--	93	--	96	--	92	91	90	84
1.5	--	--	--	--	--	--	--	--	--	--	--
2	90	99	--	102	--	104	--	102	101	100	89
2.5	--	--	--	--	--	--	--	--	--	--	--
3	--	102	--	108	--	109	--	106	104	103	--
3.5	--	100	--	105	--	106	--	102	--	100	91
4	91	98	--	101	--	104	--	100	99	99	89
4.5	--	--	--	90	--	91	--	88	--	87	--

WHAT IS CLAIMED IS:

1. A composite material, comprising silicon carbide short fibers embedded in a matrix of metal, the fiber volume proportion of said silicon carbide short fibers being between approximately 5% and approximately 50%, and said metal being an alloy consisting essentially of between approximately 2% to approximately 6% of copper, between approximately 2% to approximately 4% of magnesium, and remainder substantially aluminum.

2. A composite material according to claim 1, wherein the fiber volume proportion of said silicon carbide short fibers is between approximately 5% and approximately 40%.

3. A composite material according to claim 1 or claim 2, wherein the copper content of said aluminum alloy matrix metal is between approximately 2% and approximately 5.5%.

4. A composite material according to claim 1 or claim 2, wherein the magnesium content of said aluminum alloy matrix metal is between approximately 2% and approximately 3.5%.

5. A composite material according to claim 3, wherein the magnesium content of said aluminum alloy matrix metal is between approximately 2% and approximately 3.5%.

FIG. 1

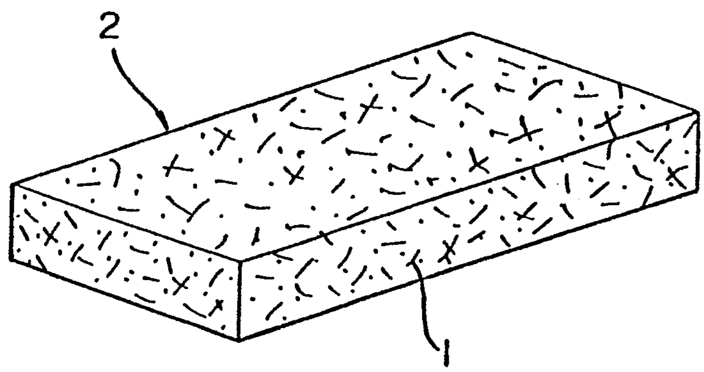


FIG. 2

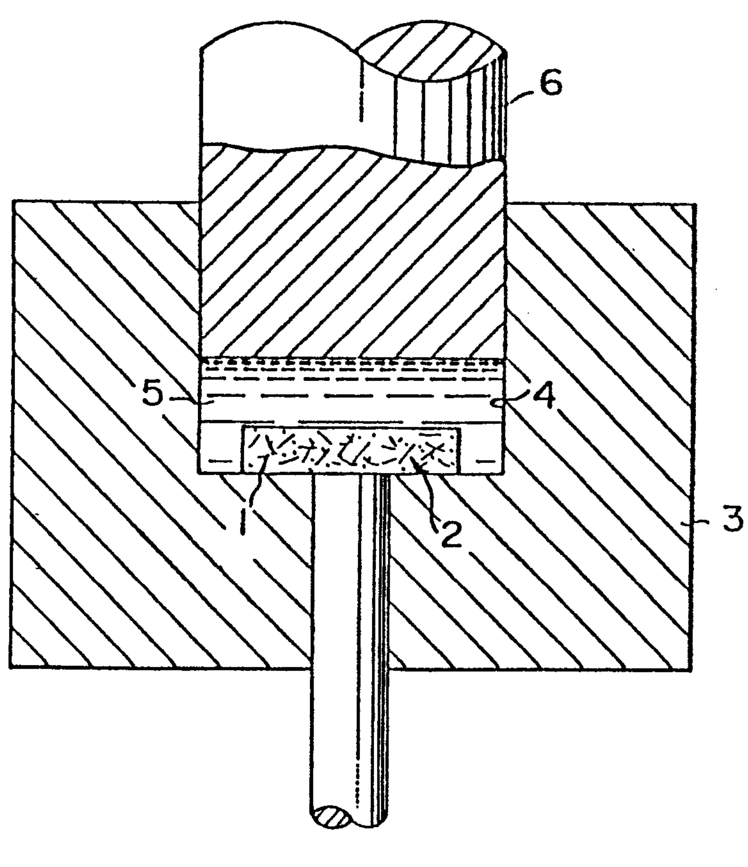
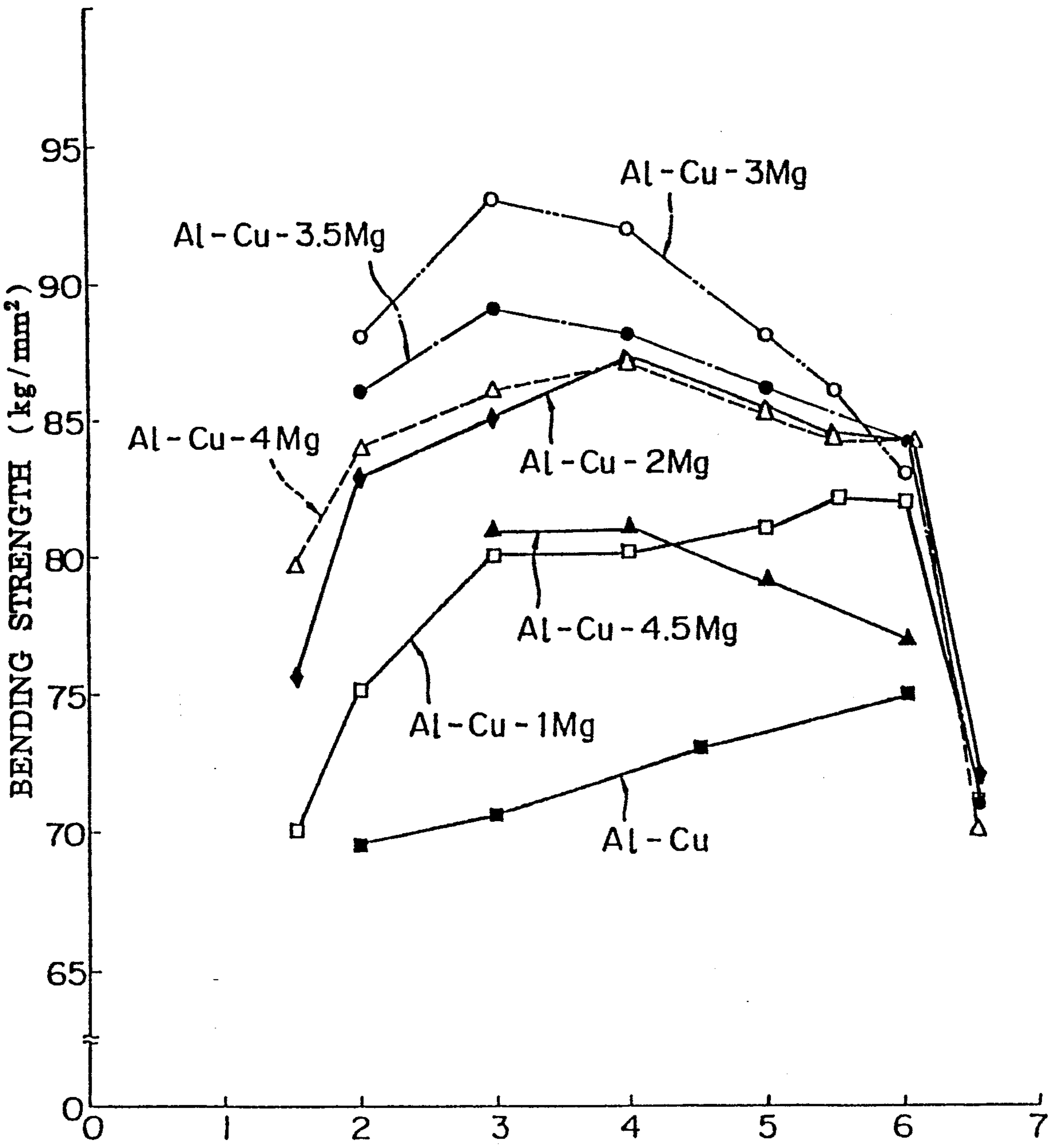


FIG. 3

EMBODIMENT 1



Cu CONTENT (%)

FIG. 4

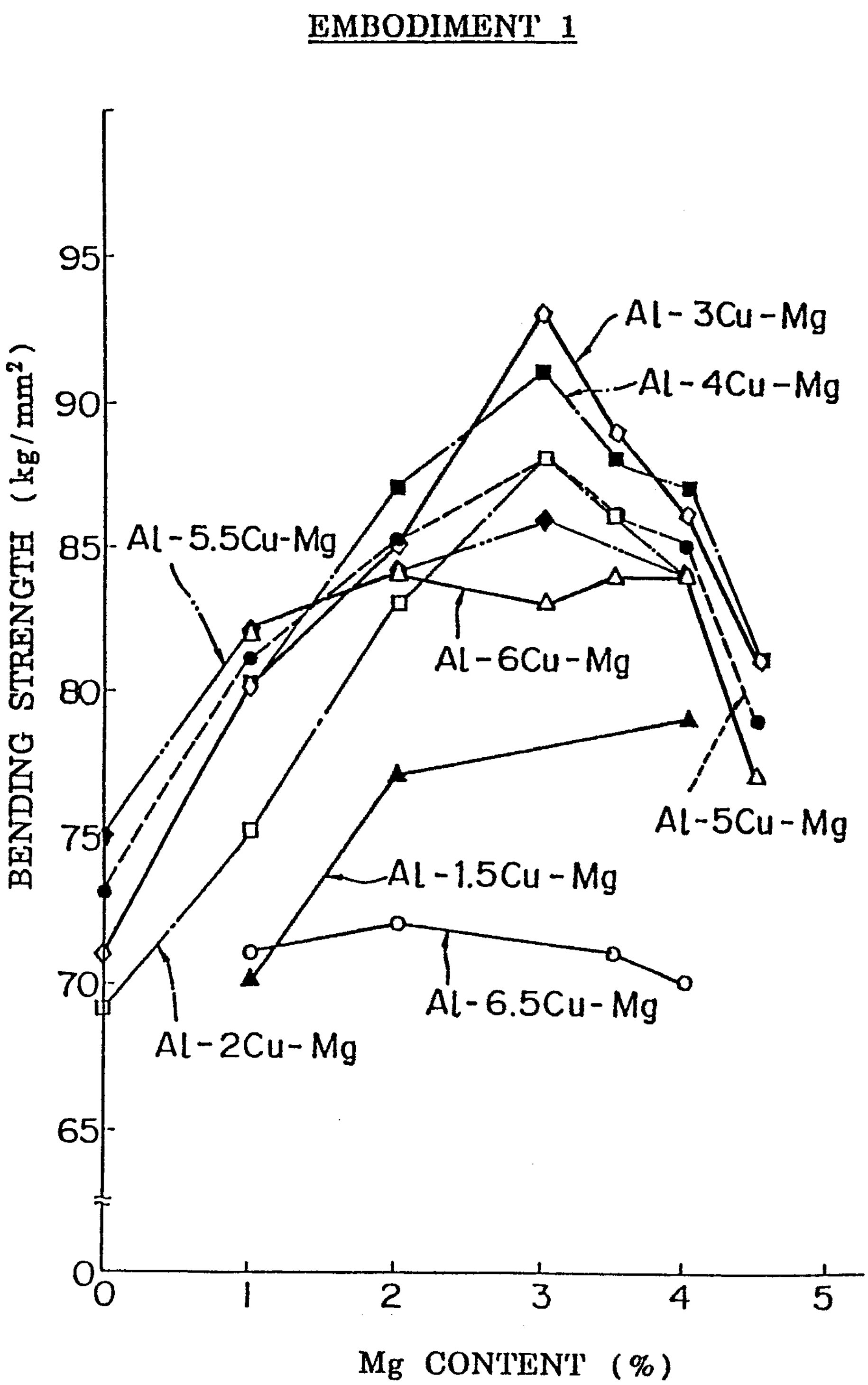

EMBODIMENT 1
BENDING STRENGTH (kg/mm²)
95
90
85
80
75
70
65
0
Al-3Cu-Mg
Al-4Cu-Mg
Al-5.5Cu-Mg
Al-6Cu-Mg
Al-5Cu-Mg
Al-1.5Cu-Mg
Al-6.5Cu-Mg
Al-2Cu-Mg
0
1
2
3
4
5
Mg CONTENT (%)

FIG. 5

EMBODIMENT 2

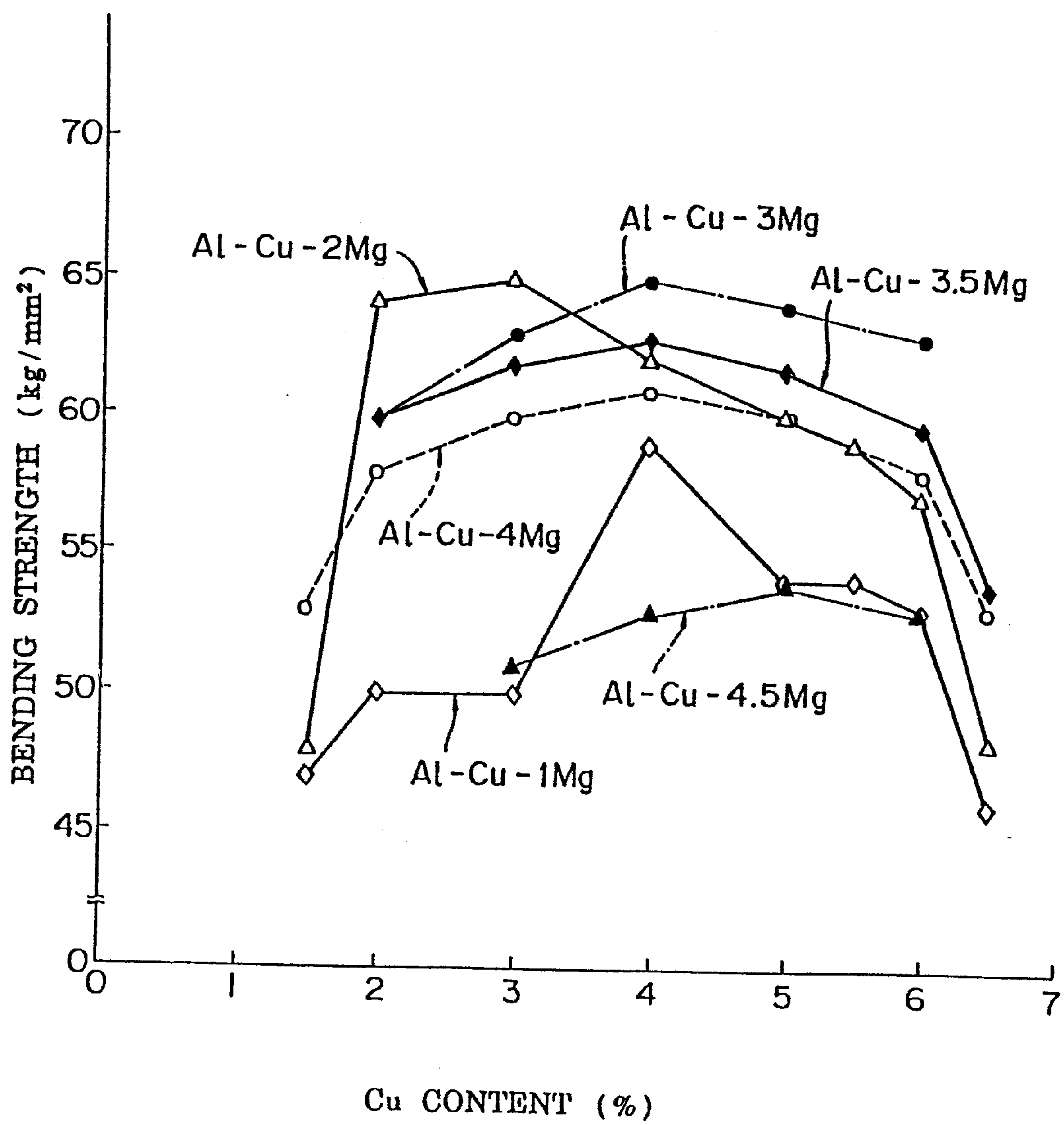


FIG. 6

EMBODIMENT 2

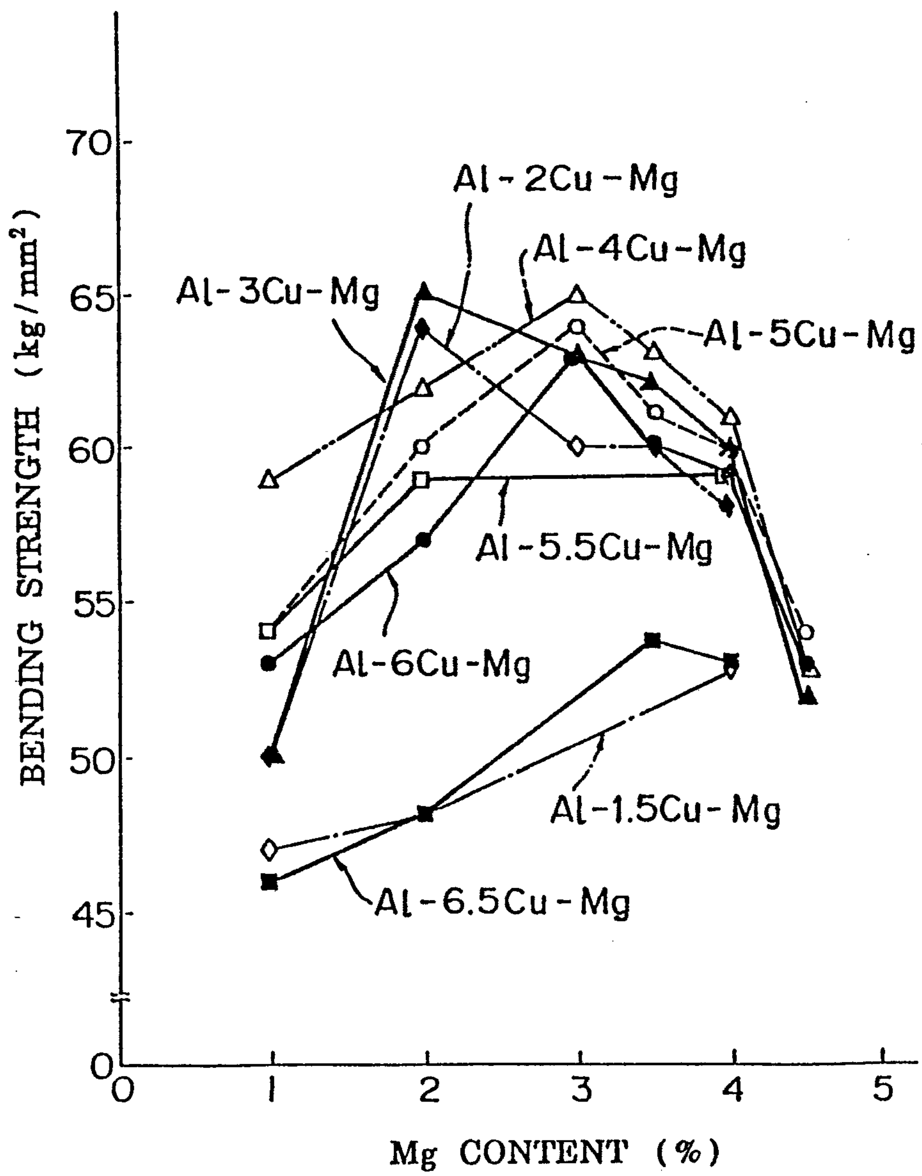


FIG. 7

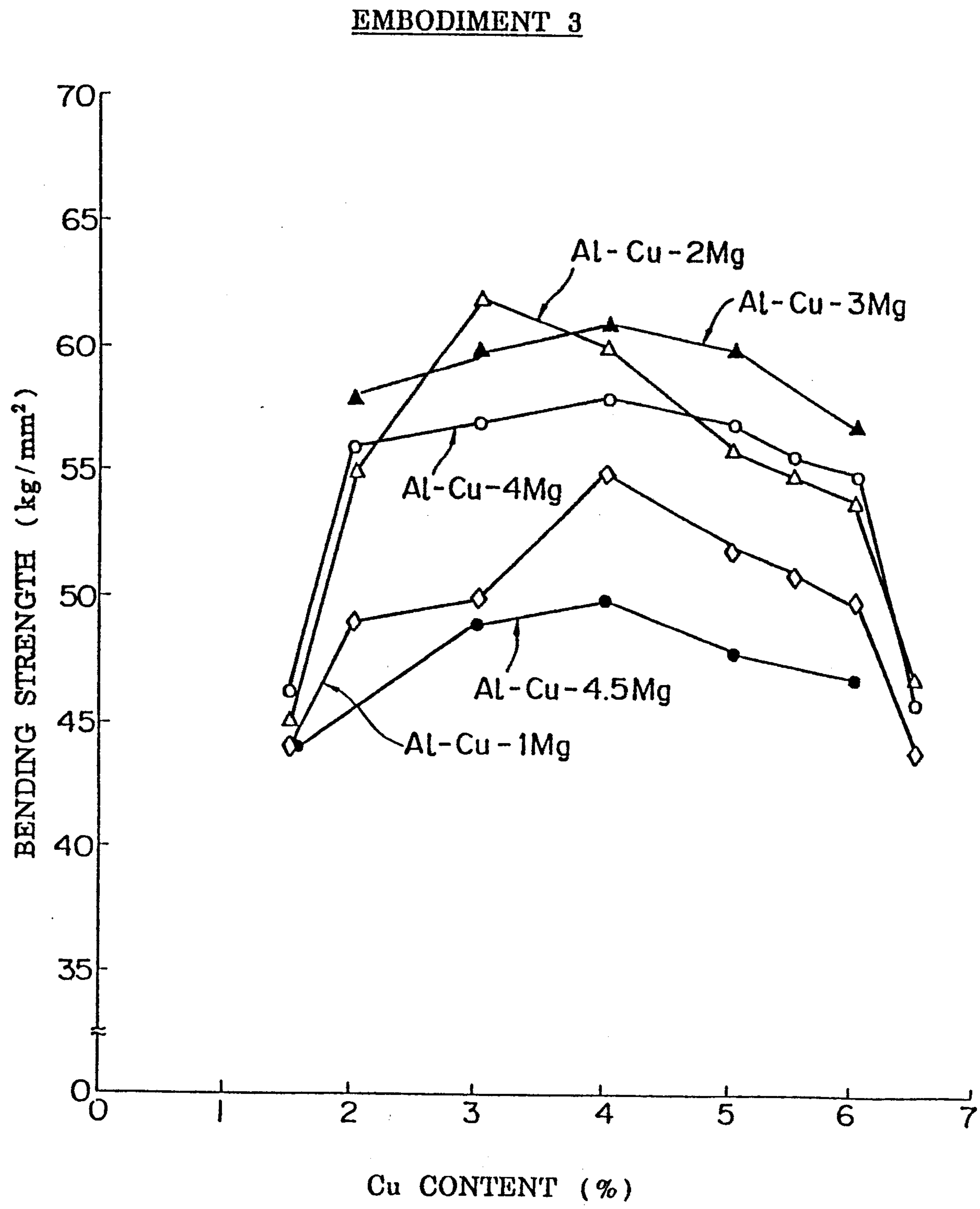

EMBODIMENT 3
BENDING STRENGTH (kg/mm²)
70
65
60
55
50
45
40
35
0
Al-Cu-2Mg
Al-Cu-3Mg
Al-Cu-4Mg
Al-Cu-4.5Mg
Al-Cu-1Mg
0
1
2
3
4
5
6
7
Cu CONTENT (%)

FIG. 8

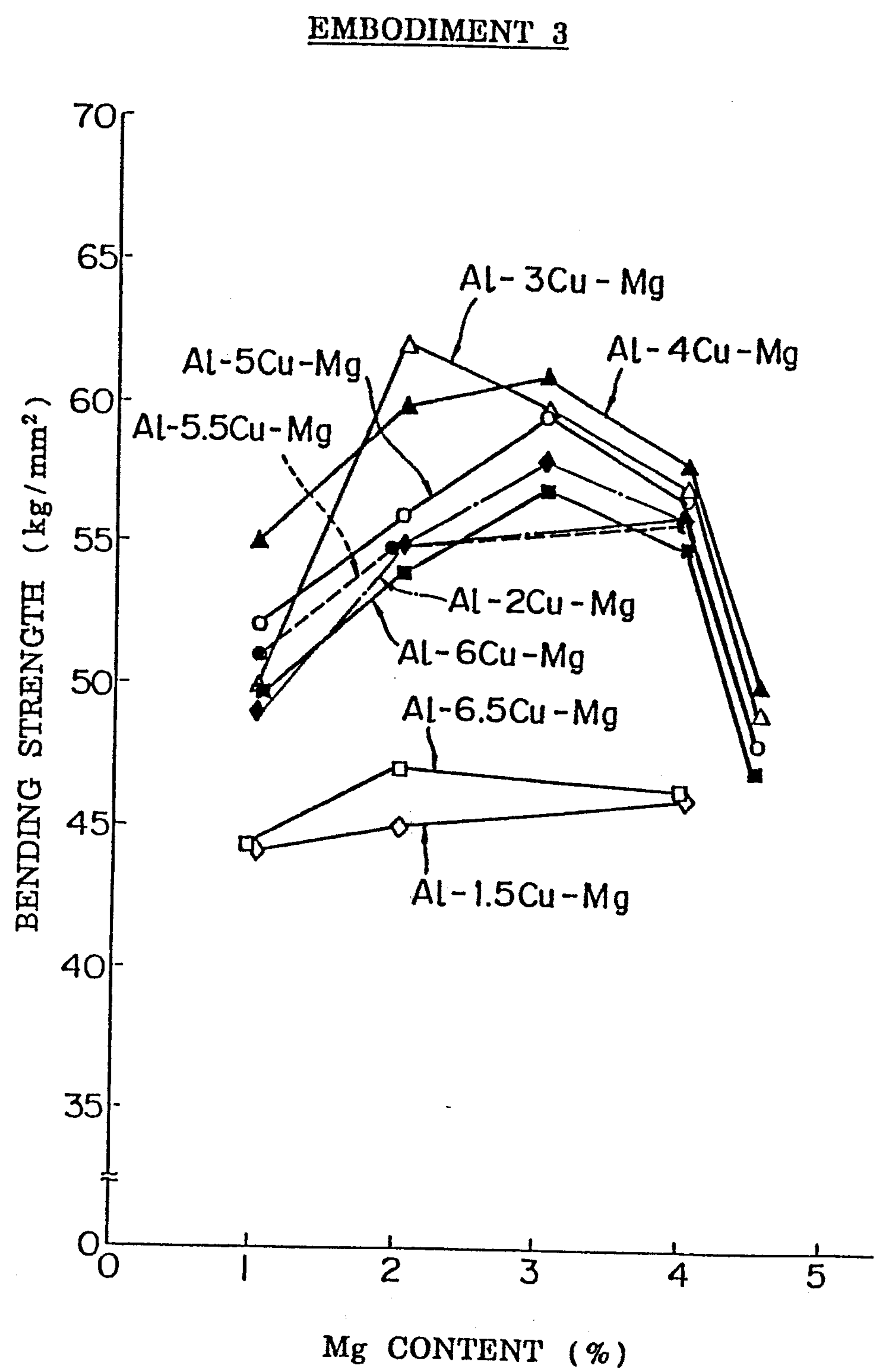

EMBODIMENT 3
70
65
60
55
50
45
40
35
0
BENDING STRENGTH (kg / mm²)
Al-3Cu-Mg
Al-4Cu-Mg
Al-5Cu-Mg
Al-5.5Cu-Mg
Al-2Cu-Mg
Al-6Cu-Mg
Al-6.5Cu-Mg
Al-1.5Cu-Mg
0
1
2
3
4
5
Mg CONTENT (%)

FIG. 9

EMBODIMENT 4

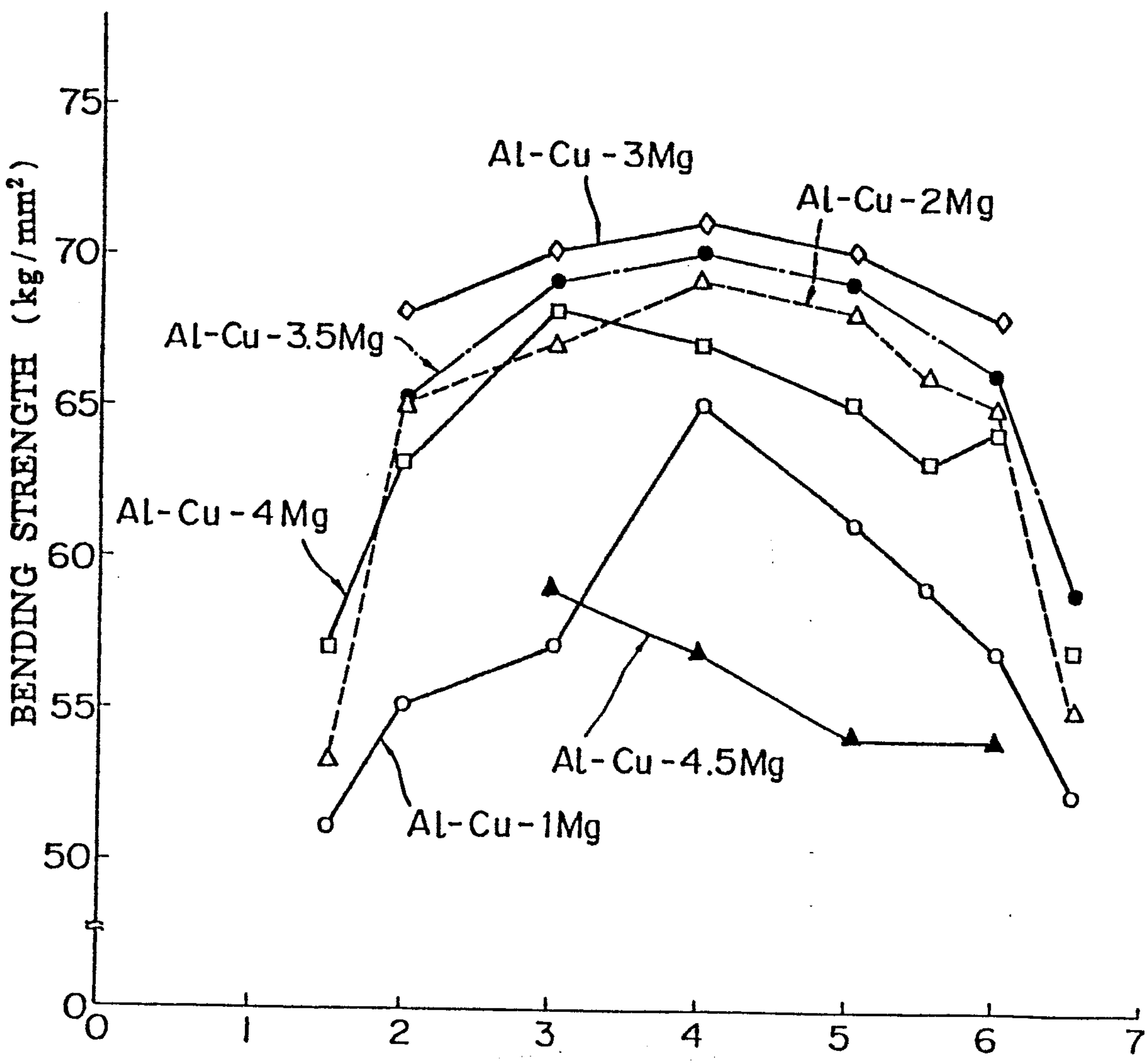


FIG. 10

EMBODIMENT 4

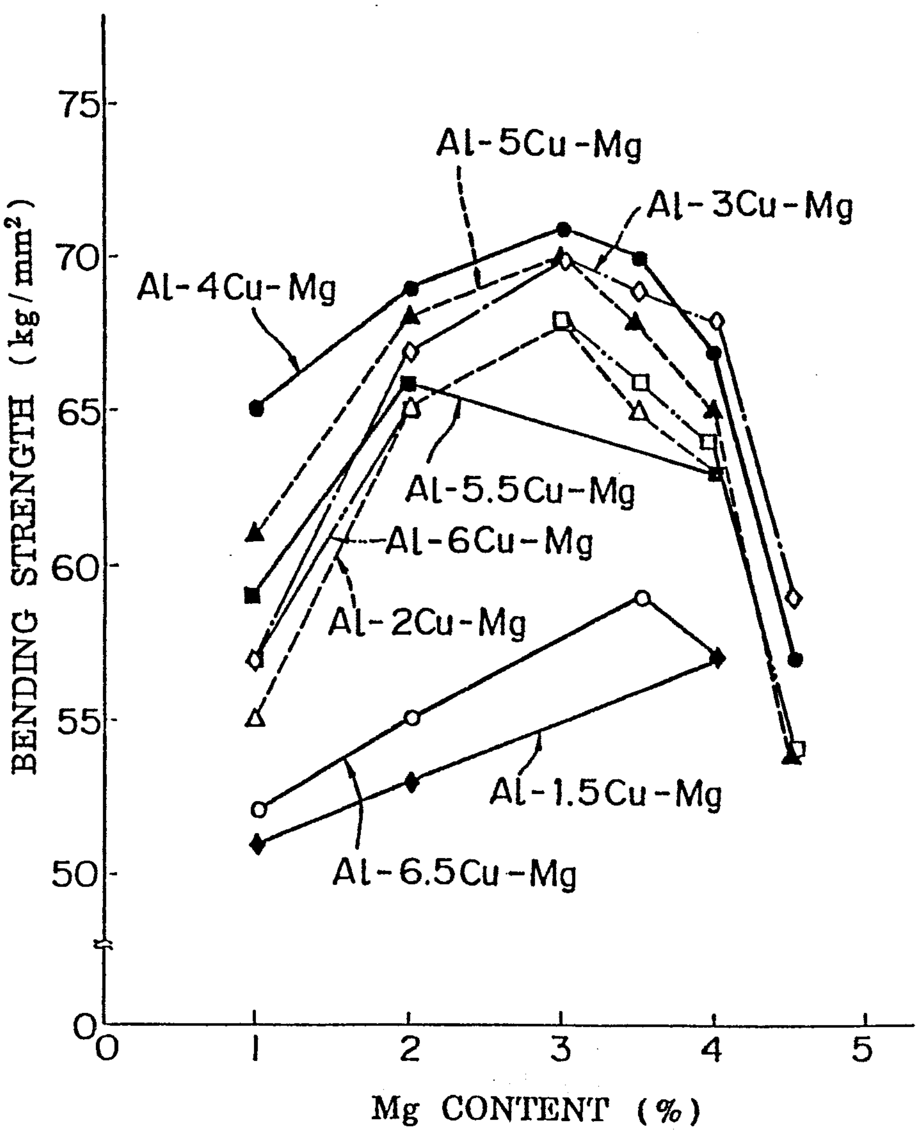


FIG. 11

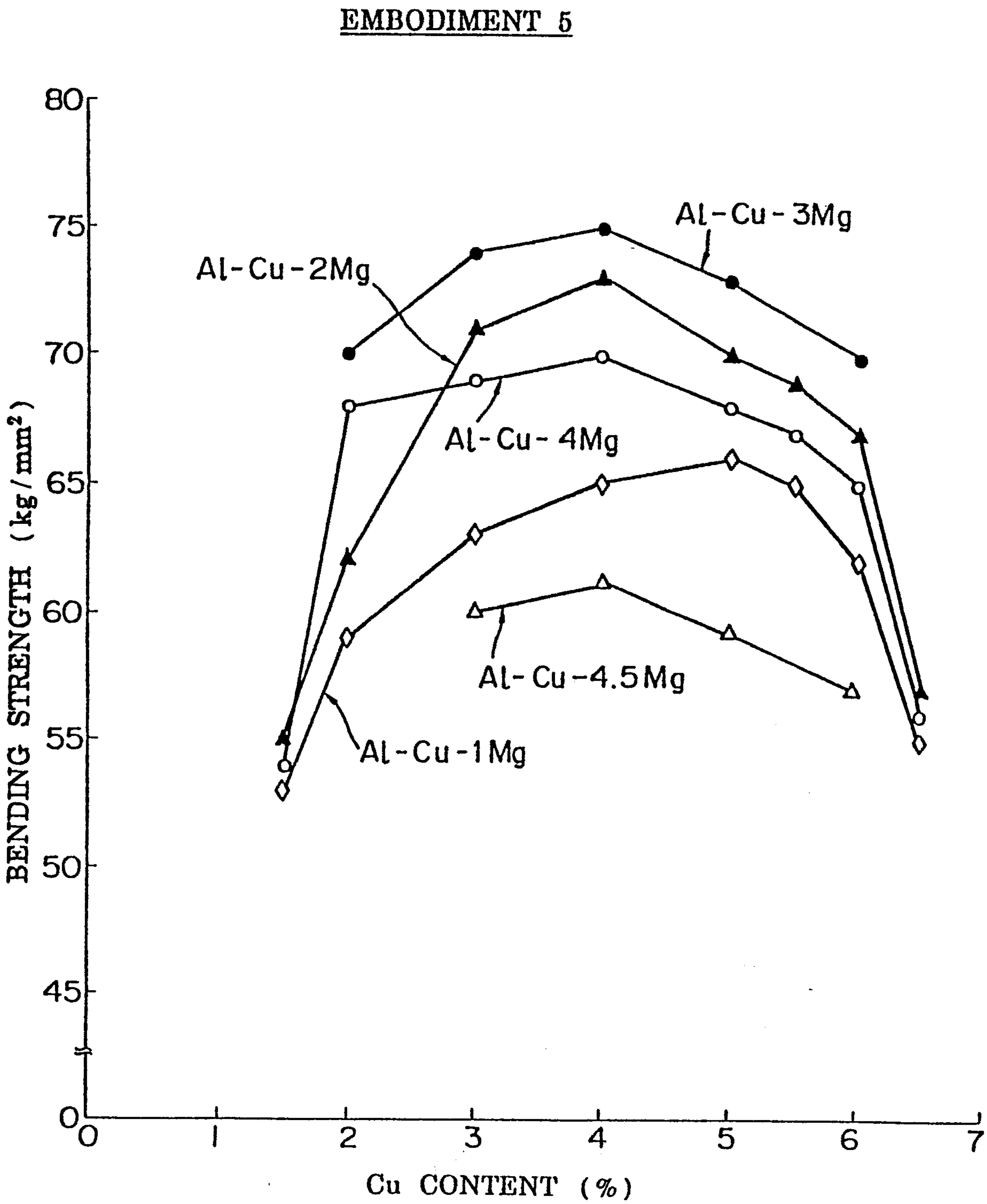

EMBODIMENT 5
BENDING STRENGTH (kg/mm²)
80
75
70
65
60
55
50
45
0
0
1
2
3
4
5
6
7
Cu CONTENT (%)
Al-Cu-3Mg
Al-Cu-2Mg
Al-Cu-4Mg
Al-Cu-4.5Mg
Al-Cu-1Mg

FIG. 12

EMBODIMENT 5

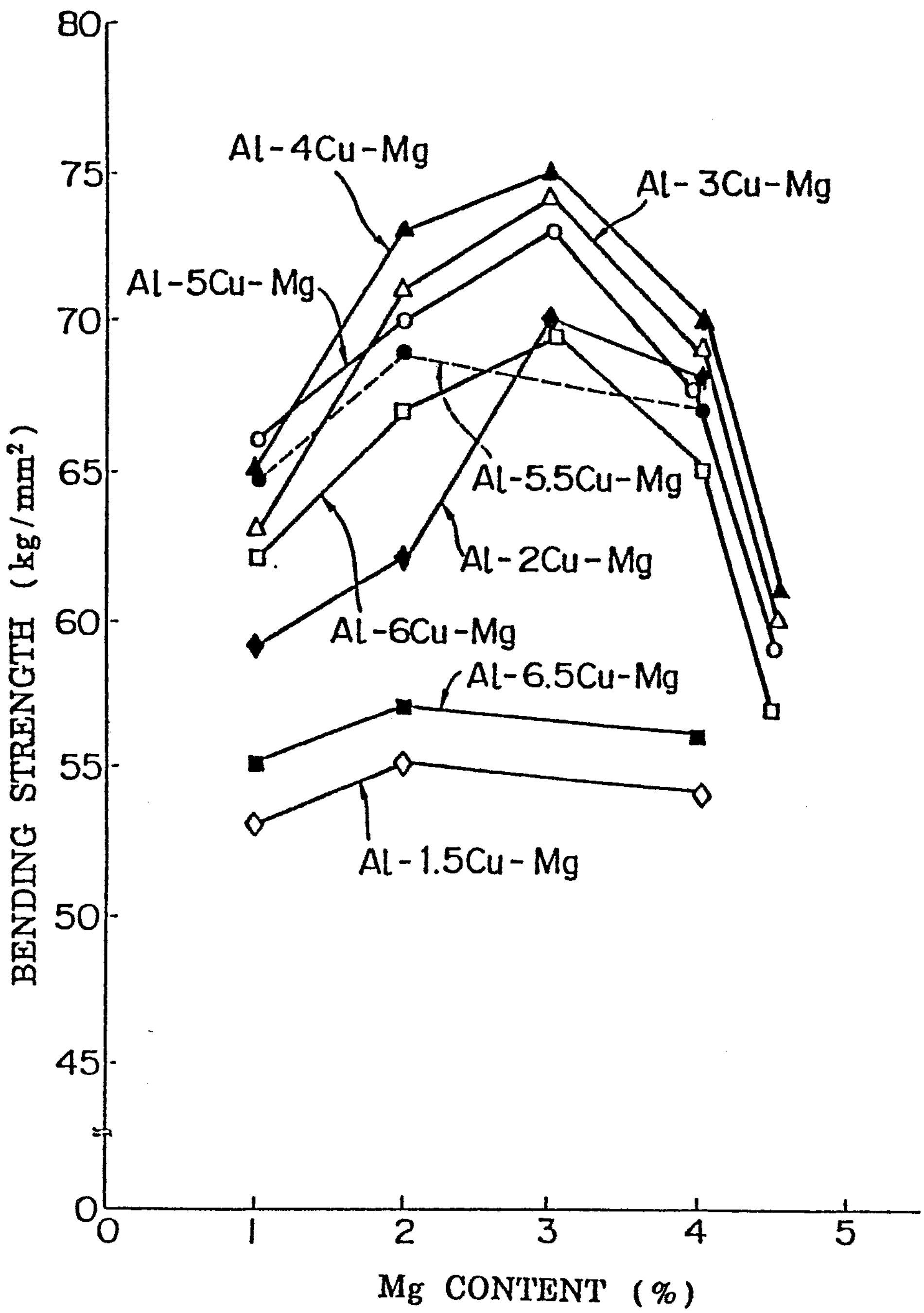


FIG. 13

EMBODIMENT 6

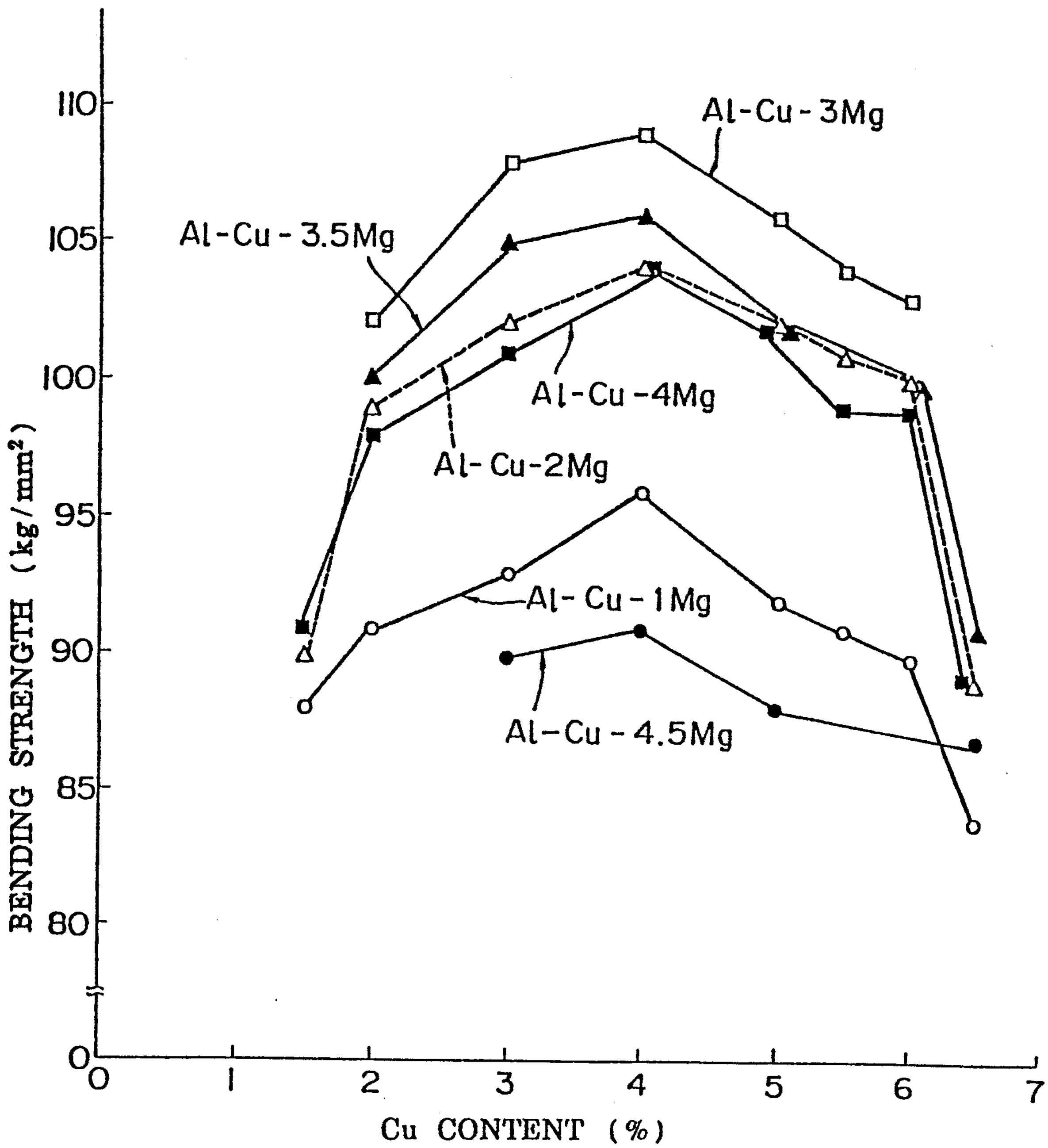


FIG. 14

EMBODIMENT 6

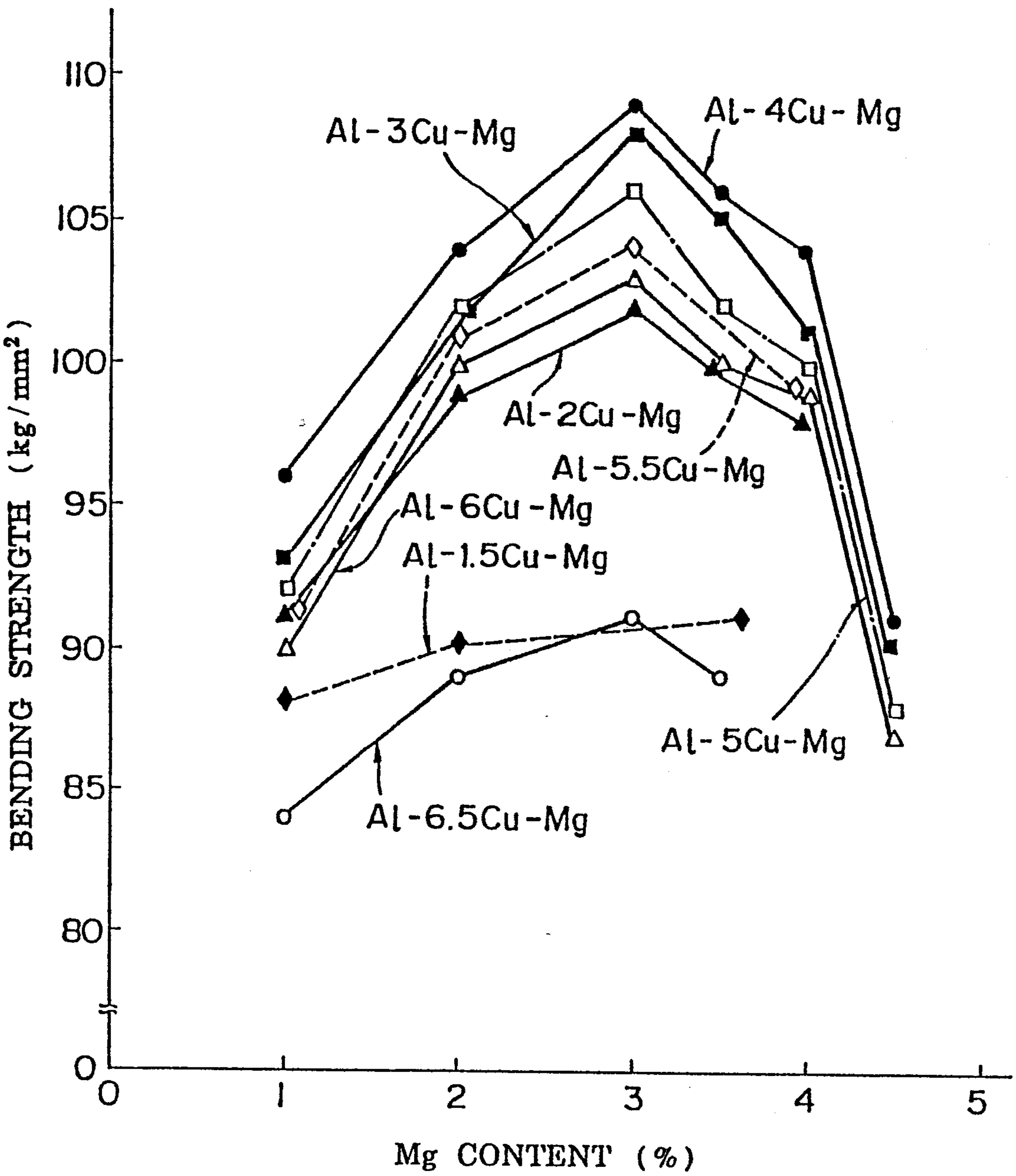
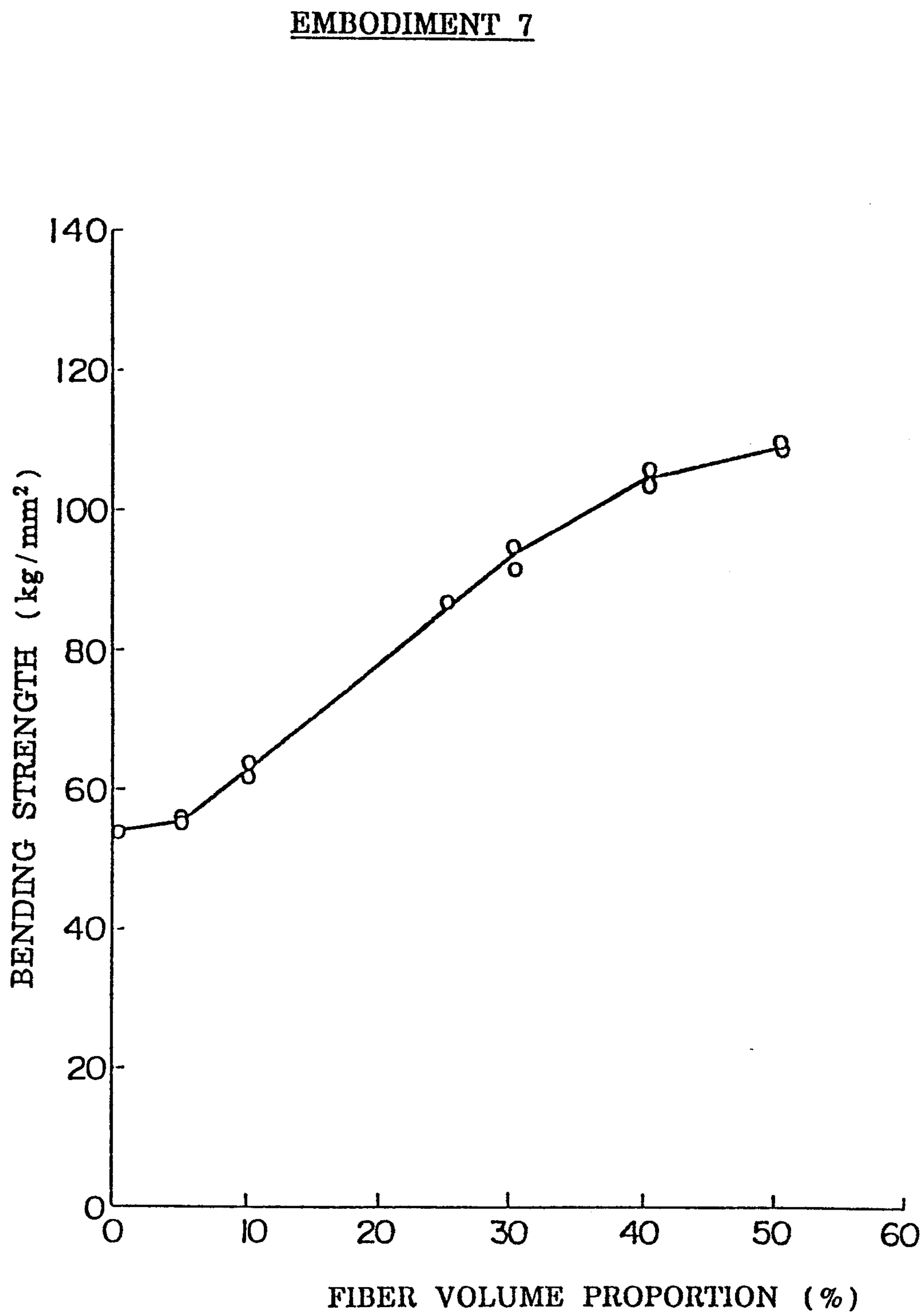


FIG. 15


EMBODIMENT 7
BENDING STRENGTH (kg / mm²)
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
FIBER VOLUME PROPORTION (%)

0207314

European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 86 10 7542

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A	ALUMINIUM, vol. 50, no. 12, 1974, pages 765-770, Dusseldorf, DE; K.F. SAHM: "Herstellung und Eigenschaften kurzfaserverstärkter Aluminiumlegierungen" * Whole article * ---	1	C 22 C 1/09
A	FR-A-2 030 043 (UNITED AIRCRAFT CORP.) * Claims 1,8,11 * -----	1	

TECHNICAL FIELDS SEARCHED (Int. Cl.4)

C 22 C 1/09

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	02-10-1986	LIPPENS M.H.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document