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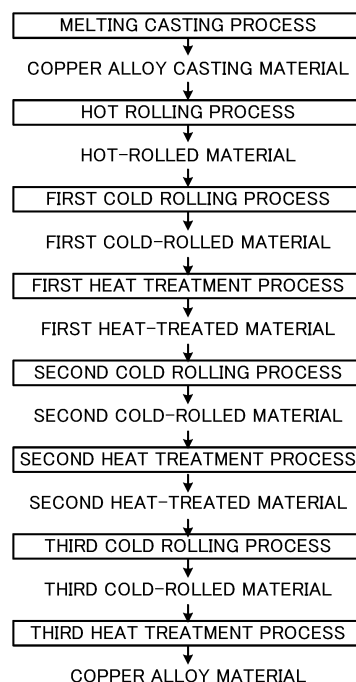
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Tokyo 135-0061 (JP)(54) **COPPER ALLOY MATERIAL AND METHOD FOR MANUFACTURING COPPER ALLOY MATERIAL**

(57) Provided are: a copper alloy material that does not have problems with residual smut, similar to C1940 and other Cu-Fe-Zn-P copper alloy materials, that has tensile strength and conductivity roughly comparable to those of C7025 and other Cu-Ni-Si copper alloy materials, and that preferably has good bending workability; and a method for manufacturing the copper alloy material. A copper alloy casting material is obtained by adding iron, phosphorous, zinc, and tin and performing melt casting. The manufacturing method proceeds through: hot rolling; cold rolling; heat treatment under sustained conditions of 500-600°C for up to four hours; cold rolling at 20-90% draft; heat treatment under sustained conditions of 380-480°C for one to twelve hours; cold rolling at 60-80% draft; and heat treatment under sustained conditions of 250-380°C for up to four hours. By said method, obtained is a copper alloy material that contains, by mass percentage, 1.6-2.6% iron, 0.01-0.35% phosphorus, 0.01-0.30% zinc, and 0.3-0.8% tin, the balance consisting of copper and impurity elements, that has tensile strength of at least 620 MPa, and that has conductivity of at least 40.0% IACS.

FIGURE**EP 4 488 396 A1**

Description

TECHNICAL FIELD

[0001] The present invention relates to a copper alloy material and a method for manufacturing the copper alloy material, and for example, relates to a copper alloy material and a method for manufacturing the copper alloy material used as a material for electric and electronic components such as a lead frame, a connector, and a terminal.

BACKGROUND ART

[0002] Conventionally, copper alloys have been commonly used as materials for lead frames and other electrical and electronic components because they have good strength and conductivity. Among copper alloys, for example, Cu-Fe-Zn-P copper alloys are considered to have a good balance of mechanical strength, electrical conductivity, and thermal conductivity. One of typical Cu-Fe-Zn-P copper alloys is, for example, C1940 specified in JIS-H3100:2018. C1940 is a precipitation-hardening copper alloy containing, by mass percent, about 2.2% of Fe, about 0.03% of P, and about 0.12% of Zn. C1940 has a conductivity of about 60% IACS and a tensile strength of about 400MPa to 550MPa, is internationally recognized as a standard copper alloy, and is used in many applications.

[0003] In recent years, as electric/electronic components have become highly functional and highly integrated, for example, in the field of lead frames, the thickness of the lead frame itself has reduced. The lead frame having a reduced thickness is easily deformed, and the mechanical strength of the C1940 is insufficient. In such a case, for example, Cu-Ni-Si copper alloys are often used. Cu-Ni-Si copper alloys are precipitation-hardening copper alloys in which high strength is obtained by precipitating particles of a compound containing Ni and Si in a matrix phase containing Cu of copper alloys as a main component. One of typical Cu-Ni-Si copper alloys is, for example, C7025 called Corson alloy, which is out of the specification of JIS but contains, by mass percent, about 3.0% of Ni, about 0.65% of Si, and about 0.15% of Mg. C7025 has a tensile strength of about 600MPa to 700MPa and a conductivity of about 45.0% IACS, and is inferior to C1940 in bending workability, but is also used for the above-described lead frame.

CITATION LIST

Patent Literature

[0004]

PTL 1: Japanese Patent No. 6301618

PTL 2: Japanese Patent No. 6811136

SUMMARY

TECHNICAL PROBLEM

[0005] In electric and electronic components such as lead frames, solder plating layers and silver plating layers are generally provided on surfaces of copper-alloy materials made of copper alloys for the purpose of facilitating attachment of silicon chips and mounting on circuit boards. When a plating layer is provided on the surface of a copper alloy material, chemical polishing is generally performed as a pretreatment to chemically dissolve an oxidized layer or a damaged layer on the surface using an acidic solution. For example, in the case of a copper-alloy material made of a Cu-Fe-Zn-P copper-alloy such as C1940, chemical polishing using an acidic liquid (chemical polishing liquid) containing sulfuric acid and hydrogen peroxide is generally performed as a pre-treatment. A copper alloy material made of a Cu-Fe-Zn-P copper alloy such as C1940 does not have the problem of smut remaining on the surface of the copper alloy material (hereinafter referred to as residual smut), which will be described later.

[0006] However, in the case of a copper-alloy material made of a higher-strength copper-alloy, for example, a copper-alloy material made of a Cu-Ni-Si copper-alloy such as C7025, when a chemical polishing liquid of the same quality as C1940 is used, particles of a compound containing Ni and Si are not dissolved, and therefore, a large amount of particles of the compound containing Ni and Si remain as a residue (smut) on the surface of the copper-alloy material. Residual smut on the surface of copper alloy materials is not easily removed by general surface cleaning after chemical polishing. Therefore, smut may be present in the subsequent plating layer, which may have a significant effect on the appearance and properties of the copper alloy material.

[0007] In order to solve the problem of the residual smut on the surfaces of high-strength copper alloys such as C7025, for example, PTL 1 proposes a method of controlling the particle size and shape of a compound containing Ni and Si so that

the residual area ratio of the residual smut on the surfaces of the copper alloys is less than 3%, and discloses a copper alloy material containing, by mass percent, Ni: 2.0 to 6.0%, Si: 0.3 to 2.0%, Cr: 0 to 1.0%, Mg: 0 to 1.0%, Sn: 0 to 0.8%, and Zn: 0 to 0.8%, with the balance being Cu and impurities. Furthermore, PTL 2 proposes a method for improving adhesion with resin by leaving unevenness on the surface of a copper alloy material by controlling the amount of residual smut on the surface of the copper alloy material, and discloses a Cu-Ni-Si copper alloy strip containing, by mass percent, Ni: 1.5 to 4.5%, Si: 0.4 to 1.1%, with the balance being Cu and impurities, and has a tensile strength of 800 MPa or more and an electrical conductivity of 30% IACS or more. However, both proposals in PTLs 1 and 2 allow residual smut on the surface of the copper alloy material, and do not fundamentally solve the problem of residual smut occurring on the surface of the copper alloy material.

[0008] Therefore, the present invention provides a copper-alloy material and a method for manufacturing a copper-alloy material, which are free from the above-described problem of residual smut similarly to copper-alloy materials made of Cu-Fe-Zn-P copper alloys such as C1940, have tensile strength and conductivity substantially equal to those of copper-alloy materials made of higher-strength Cu-Ni-Si copper alloys such as C7025, and preferably have good bendability. Copper alloy materials containing a large amount of the above-mentioned additive elements (for example, Ni, Si, Cr, Mg, Sn, Zn, etc.) generally have poor rolling workability, and is particularly prone to cracking during hot rolling. Therefore, the present invention desirably provides a copper alloy material and a method for producing a copper alloy material that has good rolling workability and is particularly resistant to cracking during hot rolling.

SOLUTION TO PROBLEM

[0009] The inventors of the present invention have conducted extensive studies on a copper alloy material made of a Cu-Fe-Zn-P copper alloy free from the problem of residual smut and a copper alloy material made of a Cu-Ni-Si copper alloy having the problem of residual smut in terms of the form and properties of the structure, the mechanical and electrical properties, the production conditions, and the like, and as a result, have found that the above problems can be solved by further devising the alloy composition of the Cu-Fe-Zn-P copper alloy and further devising the production conditions of a copper alloy material made of the copper alloy, and have conceived the present invention.

[0010] That is, a copper-alloy material according to the present invention contains, as essential elements, 1.6% or more and 2.6% or less of Fe, 0.01% or more and 0.3% or less of P, 0.01% or more and 0.3% or less of Zn, and 0.3% or more and 0.8% or less of Sn, with the balance being Cu and impurity elements, and has a tensile strength of 620MPa or more and a conductivity of 40.0% IACS or more in a temperature environment of 20 °C.

[0011] The copper alloy material according to the present invention is preferably a copper alloy material containing, by mass%, 0.01% or more and 0.20% or less of P.

[0012] The copper alloy material according to the present invention preferably contains, by mass%, Fe, P, Zn, and Sn, 0.002% or more and 0.025% or less of Mn as essential elements, and the balance being Cu and impurity elements, and has an elongation at break of more than 20% in a temperature environment of 950 °C.

[0013] The copper alloy material according to the present invention is preferably a copper alloy material in which a value obtained by $(\text{Mn content} + \text{total content of impurity elements}) / (\text{Fe content} + \text{P content} + \text{Sn content}) \times 100$ is 1.1 or less in terms of content expressed in mass%.

[0014] Moreover, the method according to the present invention having the following processes: melting and casting process for producing copper alloy casting material containing, by mass%, 1.6% or more and 2.6% or less of Fe, 0.01% or more and 0.3% or less of P, 0.01% or more and 0.3% or less of Zn, and 0.3% or more % and 0.8% or less of Sn as essential elements, with the balance consisting of Cu and impurity elements; a hot rolling process in which hot rolling is performed using the copper alloy casting material to produce a hot-rolled material; a first cold rolling process of performing cold rolling using the hot-rolled material to produce a first cold-rolled material; a first heat treatment process of producing a first heat-treated material by heat-retaining of the first cold-rolled material at a temperature of 500 °C or more and 600 °C or less for 4 hours or less; a second cold rolling process of producing a second cold-rolled material by cold rolling the first heat treated material at a rolling degree of 20% or more and 90% or less; a second heat treatment process of producing a second heat-treated material by heat-retaining of the second cold-rolled material at a temperature of 380 °C or more and 480 °C or less for 1 hour or more and 12 hours or less; a third cold rolling process of producing a third cold-rolled material by performing cold rolling using the second heat treated material at a rolling degree of 60% or more and 80% or less; and a third heat treatment process of producing a copper alloy material by heat-retaining of the third cold-rolled material at a temperature of 250 °C or more and 380 °C or more for 4 hours or less, in which the melting and casting process, the hot rolling process, the first cold rolling process, the first heat treatment process, the second cold rolling process, the second heat treatment process, the third cold rolling process, and the third heat treatment process are performed in this order in order to manufacture a copper alloy material that has a tensile strength of 620 MPa or more and a conductivity of 40.0% IACS or more in a temperature environment of 20°C.

[0015] The method for manufacturing a copper alloy material according to the present invention is preferably a method for manufacturing a copper alloy material containing 0.01% or more and 0.20% or less of P by mass%.

[0016] The method for manufacturing a copper alloy material according to the present invention is preferably a method for manufacturing a copper alloy material having a breaking elongation of more than 20% in a temperature environment of 950 °C, by

performing a melting and casting process of manufacturing copper alloy casting material containing, by mass%, Fe, P, Zn, Sn, and 0.002% or more and 0.025% or less of Mn as essential elements, with the balance being Cu and impurities, and after the melting process, and performing the hot rolling process, the first cold rolling process, the first heat treatment process, the second cold rolling process, the second heat treatment process, the third cold rolling process, and the third heat treatment process in this order after the melting and casting process.

[0017] The method for manufacturing a copper alloy material according to the present invention is preferably a method for manufacturing a copper alloy material comprising a melting and casting process of manufacturing a copper alloy cast material in which a value obtained by (Mn content + total content of impurity elements) / (Fe content + P content + Sn content) $\times$ 100 is 1.1 or less in terms of content expressed in mass%.

ADVANTAGEOUS EFFECTS OF INVENTION

[0018] According to the present invention, it is possible to provide a copper-alloy material and a method for manufacturing a copper-alloy material, which are free from the above-described problem of residual smut similarly to copper-alloy materials made of Cu-Fe-Zn-P copper alloys such as C1940, and have tensile strength and conductivity substantially equivalent to those of copper-alloy materials made of higher-strength Cu-Ni-Si copper alloys such as C7025. Further, according to the present invention, by appropriately selecting the structure, a copper alloy material and a method for producing copper alloy material with good bending workability, and a copper alloy material and a method for producing copper alloy material with good rolling workability and particularly resistant to cracking during hot rolling, can be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. 1 is a view showing a flow of main processes in a method for manufacturing a copper alloy material according to the present invention.

DESCRIPTION OF EMBODIMENTS

[0020] Hereinafter, a configuration of the copper alloy material according to the present invention and a method for manufacturing the copper alloy material will be described along the flow of the main processes shown in FIG. 1. It should be understood that the copper alloy material and the method for manufacturing the copper alloy material according to the present invention are defined by the claims and include all modifications within the meaning and scope equivalent to the scope of the claims. The content (numerical value) of an element and the chemical composition (numerical value) of a material are expressed by mass% unless otherwise specified.

[0021] The copper-alloy material according to the present invention contains 1.6% or more and 2.6% or less of Fe (iron), 0.01% or more and 0.3% or less of P (phosphorus), 0.01% or more and 0.3% or less of Zn (zinc), and 0.3% or more and 0.8% or less of Sn (tin) (preferably more than 0.3% and 0.8% or less of Sn) as essential elements, with the balance being Cu (copper) and impurity elements, and has a tensile strength of 620MPa or more (preferably 625MPa or more, more preferably 630MPa or more) and a conductivity of 40.0% IACS or more (preferably 45.0% IACS or more) in a temperature environment of 20 °C. The copper alloy constituting the copper-alloy material according to the present invention is a Cu-Fe-P-Zn-Sn-based copper-alloy in terms of alloy composition.

[0022] The copper alloy material according to the present invention preferably contains 0.01% or more and 0.20% or less of P.

[0023] The copper alloy material according to the present invention preferably contains Fe (1.6% or more and 2.6% or less), P (0.01% or more and 0.3% or less, preferably 0.01% or more and 0.20% or less), Zn (0.01% or more and 0.3% or less), Sn (0.3% or more and 0.8% or less, preferably more than 0.3% and 0.8% or less), and 0.002% or more and 0.025% or less of Mn, as essential elements, with the balance being Cu and impurity elements, and has an elongation at break of more than 20% in a temperature environment of 950 °C.

[0024] In the copper alloy material according to the present invention, a value obtained by (Mn content + total content of impurity elements) / (Fe content + P content + Sn content) $\times$ 100 (hereinafter referred to as "MI value") is preferably 1.1 or less.

[0025] The reasons for limiting the elements contained in the copper alloy constituting the copper alloy material according to the present invention are as follows.

<Fe (Iron)>

[0026] The copper alloy material according to the present invention contains, as an essential element, 1.6% or more and 2.6% or less of Fe. In the copper alloy material, Fe forms a solid solution in a matrix phase mainly containing Cu of the copper alloy, and a part of Fe is dispersed and precipitated in the matrix phase as Fe or a compound containing Fe and P. These effects of Fe contribute to improving the mechanical strength and heat resistance of the copper alloy material. Therefore, the copper alloy material containing an appropriate amount of Fe can have higher mechanical strength and heat resistance while maintaining appropriate electrical conductivity.

[0027] When the amount of Fe contained in the copper-alloy material is excessively small (less than 1.6%), the above-described action and effect of Fe are not sufficiently exhibited, and when the amount of Fe contained in the copper-alloy material is excessively large (more than 2.6%), an excessively large crystallized product of Fe is formed in a copper-alloy cast material to be described later, which may cause deterioration in surface cleanliness or processing cracking. From this viewpoint, the copper-alloy material according to the present invention contains 1.6% or more and 2.6% or less of Fe, and preferably contains 2.1% or more and 2.4% or less of Fe in order to obtain more well-balanced characteristics. In addition, the copper-alloy material according to the present invention contains 1.6% or more and 2.6% or less (preferably 2.1% or more and 2.4% or less) of Fe, and has a preferable balance between tensile strength and conductivity in consideration of the Sn content as described later. In this case, for example, the copper-alloy material has a tensile strength of 630MPa or more and a conductivity of 45.0% IACS or more.

<P (Phosphorus)>

[0028] The copper alloy material according to the present invention contains 0.01% or more and 0.3% or less of P as an essential element. In the copper alloy material, P acts as a deoxidizer for removing excess oxygen present in a molten metal in a melting and casting process to be described later, and a part of P forms a compound containing Fe and P and is dispersed and precipitated in a matrix phase mainly containing Cu of the copper alloy. Such action of P contributes to improving the mechanical strength and heat resistance of the copper alloy material. Therefore, a copper alloy material containing an appropriate amount of P can have higher mechanical strength and heat resistance while maintaining appropriate electrical conductivity.

[0029] When the amount of P contained in the copper alloy material is excessively small (less than 0.01%), the above-described action and effect of P are not sufficiently exhibited, and when the amount of P contained in the copper alloy material is excessively large (more than 0.3%), a decrease in hot workability in a hot rolling process to be described later or a decrease in electrical conductivity of the copper alloy material may be caused. From this viewpoint, in the copper alloy material according to the present invention, the amount of P is set to 0.01% or more and 0.3% or less, and more preferably 0.01% or more and 0.20% or less in order to improve bending workability.

<Zn (Zinc)>

[0030] The copper-alloy material according to the present invention contains, as an essential element, 0.01% or more and 0.3% or less of Zn. In the copper-alloy material, Zn improves the wettability of the surfaces of the copper-alloy material with respect to solder, and also improves the weather resistance of the solder plating layers provided on the surfaces of the copper-alloy material. Such an effect of Zn is particularly required when a solder plating layer is provided on the surface of a copper alloy material, such as in the above-mentioned lead frame. Therefore, the copper-alloy material containing an appropriate amount of Zn is practically high in availability.

[0031] In the case where the amount of Zn contained in the copper alloy material is excessively small (less than 0.01%), the above-described action and effect of Zn are not sufficiently exhibited, and in the case where the amount of Zn contained in the copper alloy material is excessively large (more than 0.3%), the above-described action and effect of Zn are saturated, which may cause a decrease in the electrical conductivity of the copper alloy material. From this point of view, the copper alloy material according to the present invention has a Zn content of 0.01% or more and 0.3% or less, preferably 0.05% or more and 0.2% or less in order to obtain better balanced properties.

<Sn (Tin)>

[0032] The copper-alloy material according to the present invention contains, as an essential element, 0.3% or more and 0.8% or less (preferably, more than 0.3% and 0.8% or less) of Sn. In the copper alloy material, Sn is dissolved in the matrix phase of the copper alloy, which is mainly composed of Cu, and contributes to further improving the mechanical strength and heat resistance of the copper alloy material. Therefore, a copper-alloy material containing an appropriate amount of Sn can have higher mechanical strength and heat resistance while maintaining appropriate electrical conductivity, as compared with a copper-alloy material not containing the appropriate amount of Sn. Note that this Sn is not added to the

above-described Cu-Fe-Zn-P copper alloys and Cu-Ni-Si copper alloys. By utilizing this effect of Sn, the mechanical strength of copper alloy material made of Cu-Fe-Zn-P copper alloy can be pulled up to almost the same level as that of copper alloy material made of Cu-Ni-Si copper alloy. Note that Sn is not added to the above-described C1940 and C7025. Further, even if a copper alloy material made of Cu-Fe-Zn-P copper alloy further contains an appropriate amount of Sn, the above-mentioned problem of residual smut does not occur. In this regard, please refer to Table 1 and the like described later.

[0033] If the Sn contained in the copper alloy material is excessively small (less than 0.3%), the effect of the action of Sn is not sufficiently exhibited. Also, if the Sn contained in the copper alloy material is excessively large (more than 0.8%), although the mechanical strength of the copper alloy material is further improved, it may cause a large decrease in the conductivity of the copper alloy material. From this viewpoint, the copper alloy material according to this invention contains Sn in the range of 0.3% or more and 0.8% or less, and preferably in the range of more than 0.3% and 0.8% or less in order to stably obtain a tensile strength of 625 MPa or more. This point should also be referred to the section on the influence of Sn described later. Also, the copper alloy material according to this invention contains Sn in the range of 0.5% or more and 0.7% or less, and the balance of tensile strength and conductivity is preferable considering the Fe content as described above. In this case, for example, a copper alloy material having a tensile strength of 630 MPa or more and a conductivity of 45.0% IACS or more is obtained.

<Mn (Manganese)>

[0034] The copper alloy material according to this invention contains, as essential elements, Fe, P, Zn, and Sn in the above-mentioned range, and preferably, further contains 0.002% or more and 0.025% or less of Mn. The copper alloy material according to this invention is a copper alloy material made of a Cu-Fe-P-Zn-Sn based copper alloy as described above. Fe and P contained in this copper alloy material are essential elements, but as described above, they are elements related to cracking during processing and decrease in hot workability. Also, this copper alloy material may contain S (sulfur) as an impurity element derived from the manufacturing raw material (copper material) generally used. This copper alloy material decreases reliability due to the solid solution of S, and is particularly prone to cracking at the stage of hot rolling. Therefore, this copper alloy material preferably contains Mn as an essential element, which reduces S in the solid solution state by actively generating MnS.

[0035] The S contained in the general manufacturing raw material of this copper alloy material can be considered to be about 0.001% to 0.005% in practical use. The composition ratio (Mn: S) of MnS is 1:1 in atomic ratio and 63:37 in mass ratio. Therefore, assuming that all S reacts with Mn, Mn is required to be about 1.7 times the mass of S in mass ratio. For example, a copper alloy material containing 0.001% or more and 0.005% or less of S by mass needs to contain 0.0017% or more and 0.0085% or less of Mn in calculation. However, in reality, not all Mn reacts with S to form MnS. Therefore, it is practical to contain Mn in an amount that has sufficient margin for the amount of S, and to contain Mn in an amount of 2 to 5 times (mass ratio) of S. From this viewpoint, in the copper alloy material according to this invention, when the content of S is predicted to be 0.001% or more and 0.005% or less, it is preferable to set Mn in the range of 0.002% or more and 0.025% or less in accordance with the amount of S. Also, if S is 0.002% or less, it is preferable to set Mn in the range of 0.010% or less in accordance with the amount of S. This makes it possible to produce a copper alloy material that has good reliability and is particularly resistant to cracking at the stage of hot rolling.

<Cu (Copper)>

[0036] The copper alloy material according to this invention, excluding the above-mentioned essential elements Fe, P, Zn, and Sn, consists of the remainder being Cu and impurity elements. When the copper alloy material according to this invention further contains Mn, the remainder consists of Cu and impurity elements, the remainder excluding the above-mentioned essential elements Fe, P, Zn, Sn, and Mn. In this copper alloy material, Cu is contained in a range of generally 96% or more and 98% or less depending on the content rate of the above-mentioned essential elements. In this copper alloy material, the remainder excluding Cu and the above-mentioned essential elements is impurity elements. In the copper alloy material, Cu (copper) is the main element constituting the mother phase of the copper alloy and is contained the most. Copper materials made of copper and copper alloy materials made of copper alloys have excellent conductivity and are widely used as materials for electrical and electronic components. For example, copper materials made of oxygen-free copper such as C1020 and C1100 standardized by JIS have a conductivity of about 100% IACS and a tensile strength of about 195 MPa (Temper designation O) to 315 MPa (Temper designation H). Also, a copper alloy material made of C1940 has a conductivity of 60% IACS or more and less than 100% IACS and a tensile strength of about 275 MPa (Temper designation O3) to 590 MPa (Temper designation ESH). Also, a copper alloy material made of C7025 has a conductivity of about 45.0% IACS and a tensile strength of about 650 MPa (Temper designation 1/2H).

<Impurity Element>

[0037] The copper alloy material according to the present invention contains impurity elements. The impurity elements are inevitably mixed in the production process of the copper alloy material and are not intentionally added. Examples of the impurity element include elements such as Ag (silver), Pb (lead), Ni (nickel), and S (sulfur), depending on the production raw materials and production facilities to be used. If these impurity elements are mixed in too much, there is a risk that various properties (tensile strength, electrical conductivity, bending workability, etc.) of the copper alloy material will be deteriorated. In addition, S in a solid solution state in this copper alloy material causes deterioration in rolling workability, particularly cracking during hot rolling as described above. From this viewpoint, the content of impurity elements in the copper alloy material is suppressed to be as small as possible, for example, to 0.05% or less, preferably 0.03% or less, and more preferably 0.01% or less in total.

[0038] In addition, in the copper alloy material according to the present invention, Fe and P are related to work cracking and a decrease in hot workability as described above; Sn is related to mechanical strength and heat resistance; and impurity elements such as Ag, Pb, Ni, and S are related to deterioration in tensile strength and bending workability. In addition, when Mn is further contained, the relationship between Mn and S relates to a decrease in rolling workability and cracking at the stage of hot rolling. Considering the influences of impurity elements such as Fe, P, Sn, Mn, and S described above, it is preferable that the copper alloy material according to the present invention contains Mn. In this case, preferably, a value obtained by (Mn content + total content of impurity elements) / (Fe content + P content + Sn content) $\times$ 100 (hereinafter, referred to as "MI value") is considered, and the MI value is set to, for example, 1.1 or less (> 0), and preferably 1.0 or less (> 0), whereby the rolling workability (particularly, hot workability) and the like of the copper alloy material according to the present invention can be sufficiently enhanced.

[0039] The copper-alloy material according to the present invention contains Fe, P, Zn, and Sn as essential elements in the above-described ranges, with the balance being Cu and impurity elements, so that the copper-alloy material has a tensile strength of 620MPa or more (preferably 625MPa or more, more preferably 630MPa or more) and a conductivity of 40.0% IACS or more (preferably 45.0% IACS or more) in a temperature environment of 20 ° C, and the generation of residual smut is suppressed as will be described later. This copper-alloy material has the above-described tensile strength and conductivity and suppresses the occurrence of residual smut, and thus is considered to be sufficiently usable as a substitute material for copper-alloy materials made of Cu-Fe-Zn-P copper alloys such as C1940 and copper-alloy materials made of higher-strength C7025.

[0040] Furthermore, the copper alloy material according to this invention contains Fe, P, Zn, Sn, and Mn as essential elements within the aforementioned range, with the remainder consisting of Cu and impurity elements. As a result, this copper alloy material exhibits an elongation at break exceeding 20% under a temperature environment of 950°C, improving its reliability and particularly reducing its susceptibility to cracking during hot rolling. This copper alloy material, possessing the aforementioned tensile strength, electrical conductivity, and elongation at break, and with the generation of residual smut suppressed, is considered to be sufficiently usable as a substitute for copper alloy materials made from copper alloys such as C1940 of the Cu-Fe-Zn-P system, or the higher-strength C7025.

[0041] The tensile strength of the copper alloy material according to this invention primarily depends on precipitation strengthening due to the dispersion precipitation of particles of a compound containing Fe or Fe and P, and work hardening due to cold rolling. The strengthening mechanism of the copper alloy structure due to this precipitation strengthening and work hardening can be controlled by specifying the manufacturing conditions. The effect of precipitation strengthening can be obtained by controlling the heat treatment holding conditions within a specific range and uniformly dispersing precipitated particles of an appropriate size that can act as obstacles to the deformation of the copper alloy structure. The effect of work hardening can be obtained by controlling the cold rolling processing conditions within a specific range and accumulating an appropriate amount of crystals containing dislocations that can act as obstacles to the deformation of the copper alloy structure. Furthermore, the electrical conductivity of the copper alloy material according to this invention essentially depends on Cu, but also utilizes the effect of increasing the purity of the parent phase Cu due to the aforementioned particle precipitation.

[0042] For a copper alloy material made from a Cu-Fe-P-Zn-Sn system copper alloy to have a tensile strength of 620 MPa or more (preferably 625 MPa or more, more preferably 630 MPa or more) and an electrical conductivity of 40.0% IACS or more (preferably 45.0% IACS or more) under a temperature environment of 20°C, its manufacturing method is important. That is, the manufacturing method of the copper alloy material according to this invention includes the following steps (1) to (8), and is a manufacturing method that implements these steps in this order.

(1) A melting casting step to produce a copper alloy casting material consisting of 1.6% or more and 2.6% or less of Fe, 0.01% or more and 0.3% or less (preferably 0.01% or more and 0.20% or less) of P, 0.01% or more and 0.3% or less of Zn, 0.3% or more and 0.8% or less of Sn as essential elements, with the remainder consisting of Cu and impurity elements.

(2) A hot rolling step to produce a hot-rolled material using the copper alloy casting material.

(3) A first cold rolling step to produce a first cold-rolled material using the hot-rolled material.

(4) A first heat treatment step to produce a first heat-treated material by heat-retaining of the first cold-rolled material at a temperature of 500°C or more and 600°C or less for 4 hours or less.

(5) A second cold rolling step to produce a second cold-rolled material by cold rolling the first heat-treated material with a rolling degree of 20% or more and 90% or less.

(6) A second heat treatment step to produce a second heat-treated material by heat-retaining of the second cold-rolled material at a temperature of 380°C or more and 480°C or less for 1 hour or more and 12 hours or less.

(7) A third cold rolling step to produce a third cold-rolled material by cold rolling the second heat-treated material with a rolling degree of 60% or more and 80% or less.

(8) A third heat treatment step to produce a copper alloy material by heat-retaining of the third cold-rolled material at a temperature of 250°C or more and 380°C or more for 4 hours or less.

[0043] According to the manufacturing method having the flow of the main steps (1) to (8) as described above, it is possible to produce a copper alloy material that contains 1.6% or more and 2.6% or less of Fe, 0.01% or more and 0.3% or less (preferably 0.01% or more and 0.20% or less) of P, 0.01% or more and 0.3% or less of Zn, 0.3% or more and 0.8% or less of Sn as essential elements, with the remainder consisting of Cu and impurity elements, and that has a tensile strength of 620 MPa or more and an electrical conductivity of 40.0% IACS or more under a temperature environment of 20°C.

[0044] In the step (1) described above, preferably, a copper alloy casting material is produced that contains Fe, P, Zn, Sn, and further, 0.002% or more and 0.025% or less of Mn as essential elements, with the remainder consisting of Cu and impurity elements. In that case, in the step (1) described above, a copper alloy casting material is produced with the MI value, for example, 1.1 or less (>0), preferably 1.0 or less (>0). Then, the steps (2) to (8) described above are implemented in this order. According to this manufacturing method, it is possible to produce a preferred copper alloy material that contains Fe, P, Zn, Sn within the aforementioned range, further, 0.002% or more and 0.025% or less of Mn, with the remainder consisting of Cu and impurity elements. This preferred copper alloy material can have a tensile strength of 620 MPa or more and an electrical conductivity of 40.0% IACS or more under a temperature environment of 20°C, and further, an elongation at break exceeding 20% under a temperature environment of 950°C.

[0045] Hereinafter, the manufacturing method of the copper alloy material according to this invention will be explained along the flow of the main steps shown in Figure 1. In the manufacturing method of the copper alloy material according to this invention, in the flow of the main steps shown in Figure 1, it is also possible to make a step that repeats the combination of the first cold rolling step and the first heat treatment step as necessary, and it is also possible to make a step that repeats the combination of the first heat treatment step and the second cold rolling step.

(1) Melting Casting Process

[0046] In the melting casting process, a copper alloy casting material with added Fe, P, Zn, and Sn is produced. Specifically, the copper alloy material obtained through the third heat treatment process is prepared to contain 1.6% or more and 2.6% or less of Fe, 0.01% or more and 0.3% or less of P, 0.01% or more and 0.3% or less of Zn, and 0.3% or more and 0.8% or less (preferably, exceeding 0.3% and 0.8% or less) of Sn in mass%, with the remainder consisting of Cu and impurity elements, to produce a copper alloy casting material. The general S content of the raw materials for this copper alloy material is, for example, about 0.001% to 0.005%. Therefore, to suppress or mitigate the influence of S, it is preferable that this copper alloy material further contains Mn. In that case, the Mn content is adjusted to be 0.002% or more and 0.025% or less, and preferably, the MI value is also adjusted. The MI value is adjusted to be, for example, 1.1 or less (>0), preferably 1.0 or less (>0).

(2) Hot Rolling Process

[0047] In the hot rolling process, a hot-rolled material is produced by performing hot rolling using the copper alloy casting material produced in the above melting casting process. The hot rolling conditions such as the heat-retaining temperature and the rolling degree can be selected arbitrarily from general conditions. Generally, in the case of copper materials and copper alloy materials, hot rolling is performed under a wide temperature range of 700°C to 1000°C depending on their composition. And, in the case of copper alloy materials with a relatively large total content of added elements, hot rolling is performed under a temperature of 900°C to 1000°C. From this viewpoint, in the copper alloy material according to this invention, the evaluation of its high-temperature characteristics is performed under a temperature (about 950°C) near the center of 900°C to 1000°C.

(3) First Cold Rolling Process

[0048] In the first cold rolling process, a first cold-rolled material is produced by performing cold rolling using the hot-

rolled material produced in the above hot rolling process. The cold rolling conditions such as the rolling degree can be arbitrary.

(4) First Heat Treatment Process

[0049] In the first heat treatment process, a first heat-treated material is produced by performing heat-retaining of the first cold-rolled material at a temperature of 500°C or more and 600°C or less for 4 hours or less. This first heat treatment process is a heat treatment performed after the first cold rolling, which is the first rolling, to sufficiently release the strain accumulated in the copper alloy structure. In the conventional general manufacturing method of copper alloy materials, the heat treatment at this stage is performed by heat-retaining at a relatively high temperature (for example, 700°C or more and 900°C or less). In contrast, in the first heat treatment process of this invention, heat-retaining is performed at a relatively low temperature of 500°C or more and 600°C or less for 4 hours or less. By this relatively low-temperature heat-retaining, not only the effect of appropriately releasing the strain of the copper alloy structure but also the effect of precipitating particles of a compound containing Fe or Fe and P in an appropriate amount can be obtained. The particles appropriately dispersed and precipitated in the copper alloy structure at this stage act to further improve the tensile strength of the copper alloy material finally obtained.

[0050] If the heat-retaining temperature in the first heat treatment process is excessively low (less than 500°C), not only the release of the strain of the copper alloy structure is insufficient, but also the precipitation of the above-mentioned particles into the copper alloy structure is insufficient. Also, if the heat-retaining temperature in the first heat treatment process is excessively high (more than 600°C) or the heat-retaining time is excessively long (more than 4 hours), the strain of the copper alloy structure is sufficiently released, but the above-mentioned particles precipitated in the copper alloy structure become excessively coarse, which may hinder the improvement of the tensile strength of the copper alloy material. Also, if the heat-retaining temperature in the first heat treatment process is at the relatively high temperature mentioned above (for example, 700°C or more and 900°C or less), there is a risk that the precipitation of the above-mentioned particles itself does not occur. From this viewpoint, in the first heat treatment process, heat-retaining is performed on the first cold-rolled material at a temperature of 500°C or more and 600°C or less for 4 hours or less, and preferably, heat-retaining is performed at a temperature of 550°C or more and 600°C or less for 4 hours or less (preferably 2 hours or less) to obtain a copper alloy structure with a good balance of strain release and precipitation of the above-mentioned particle.

(5) Second Cold Rolling Process

[0051] In the second cold rolling process, a second cold-rolled material is produced by performing cold rolling on the first heat-treated material produced in the above first heat treatment process with a rolling degree of 20% or more and 90% or less. This second cold rolling process is a process for introducing and sufficiently accumulating dislocations into the copper alloy structure of the first heat-treated material produced in the first heat treatment process and further work-hardening the copper alloy structure. The dislocations introduced into the crystals constituting the copper alloy structure act as the starting point for precipitating particles responsible for precipitation strengthening of the copper alloy structure. Therefore, by uniformly introducing and sufficiently accumulating dislocations into the copper alloy structure at this stage, it is possible to uniformly precipitate particles responsible for precipitation strengthening in the copper alloy structure in the next second heat treatment process. As a result, it is possible to further improve the tensile strength of the copper alloy material finally obtained.

[0052] If the rolling degree in the second cold rolling process is excessively small (less than 20%), the introduction and accumulation of dislocations into the copper alloy structure are insufficient, and the number of particles precipitated in the copper alloy structure in the next second heat treatment process tends to be insufficient. Also, if the rolling degree in the second cold rolling process is excessively large (more than 90%), the particles precipitated in the copper alloy structure in the next second heat treatment process grow excessively large, and the effect of precipitation strengthening may not be obtained. From this viewpoint, in the second cold rolling process, cold rolling is performed on the first heat-treated material produced in the above first heat treatment process with a rolling degree of 20% or more and 90% or less, and preferably cold rolling is performed with a rolling degree of 40% or more and 75% or less to obtain a good balance of the synergistic effect of precipitation strengthening and work hardening finally.

(6) Second Heat Treatment Process

[0053] In the second heat treatment process, a second heat-treated material is produced by performing heat-retaining of the second cold-rolled material produced in the above second cold rolling process at a temperature of 380°C or more and 480°C or less for 1 hour or more and 12 hours or less. This second heat treatment process is a heat treatment process performed after the above-mentioned second cold rolling and is an aging treatment process for sufficiently dispersing and

precipitating particles responsible for precipitation strengthening in the copper alloy structure of the second cold-rolled material using dislocations introduced and accumulated during cold rolling. In the case of a conventional general manufacturing method of copper alloy materials made from a Cu-Fe-P system, the heat-retaining of the aging treatment is performed at a temperature of, for example, 400°C or more and 600°C or less. In contrast, in the second heat treatment process of this invention, heat-retaining is performed at a relatively lower temperature of 380°C or more and 480°C or less for 1 hour or more and 12 hours or less. By this relatively lower temperature heat-retaining, the particles of a compound containing Fe or Fe and P precipitated in the copper alloy structure can be further refined and more uniformly dispersed. As a result, the effect of precipitation strengthening on the copper alloy structure can be sufficiently obtained. Also, by this relatively lower temperature heat-retaining, the strain in the copper alloy structure is intentionally insufficiently released, and the synergistic effect of precipitation strengthening and work hardening obtained up to the second cold rolling process can be sufficiently obtained.

[0054] In the second heat treatment process, if the heat-retaining temperature is excessively low (less than 380°C) or the heat-retaining time is excessively short (less than 1 hour), the precipitation of the aforementioned particles into the copper alloy structure may be insufficient, and the tensile strength and electrical conductivity of the copper alloy material finally obtained may be insufficient. Also, if the heat-retaining temperature in the second heat treatment process is excessively high (more than 480°C) or the heat-retaining time is excessively long (more than 12 hours), the aforementioned particles precipitated in the copper alloy structure grow excessively, the effect of precipitation strengthening decreases, and the strain in the copper alloy structure is excessively released beyond the intended level, and the synergistic effect of precipitation strengthening and work hardening obtained up to the second cold rolling process is lost. As a result, the tensile strength of the copper alloy material finally obtained may be insufficient. From this viewpoint, in the second heat treatment process, heat-retaining is performed on the second cold-rolled material at a temperature of 380°C or more and 480°C or less for 1 hour or more and 12 hours or less, and preferably, heat-retaining is performed at a temperature of 400°C or more and 460°C or less for 1 hour or more and 12 hours or less (preferably 2 hours or more and 8 hours or less) to obtain a copper alloy structure with a good balance of strain release and the aforementioned particle precipitation.

(7) Third Cold Rolling Process

[0055] In the third cold rolling process, a third cold-rolled material is produced by performing cold rolling on the second heat-treated material produced in the above second heat treatment process with a rolling degree of 60% or more and 80% or less. Also, in this process, the thickness (product thickness) of the copper alloy material finally desired can be adjusted. This third cold rolling process is a process for further introducing and sufficiently accumulating dislocations into the copper alloy structure of the second heat-treated material produced in the second heat treatment process, in which the aforementioned particles are dispersed and precipitated, and further work-hardening the copper alloy structure. As a result, the synergistic effect of precipitation strengthening and work hardening obtained up to the second heat treatment process is sufficiently enhanced, and the tensile strength of the copper alloy material finally obtained can be sufficiently improved.

[0056] If the rolling degree in the third cold rolling process is excessively small (less than 60%), the copper alloy structure is not sufficiently work-hardened, and the synergistic effect of precipitation strengthening and work hardening may not be sufficiently enhanced. Also, if the rolling degree in the third cold rolling process is excessively large (more than 80%), the strain in the copper alloy structure is excessively accumulated, and the excessively accumulated strain is excessively released beyond the intended level in the next third heat treatment process, and the tensile strength of the copper alloy material finally obtained may not be sufficiently improved. From this viewpoint, in the third cold rolling process, cold rolling is performed on the second heat-treated material produced in the above second heat treatment process with a rolling degree of 60% or more and 80% or less, and preferably, cold rolling is performed with a rolling degree of 65% or more and 75% or less to obtain a good balance of the synergistic effect of precipitation strengthening and work hardening finally.

(8) Third Heat Treatment Process

[0057] In the third heat treatment process, the copper alloy material intended is produced by performing heat-retaining of the third cold-rolled material produced in the above third cold rolling process at a temperature of 250°C or more and 380°C or more for 4 hours or less. The heat-retaining in this process may be 0 hours, that is, it may immediately enter cooling as soon as it is heated and reaches the target retention temperature. This third heat treatment process is a process for appropriately releasing the strain accumulated in the copper alloy structure of the third cold-rolled material produced in the above-mentioned third cold rolling, and improving the mechanical properties such as elongation and bendability of the copper alloy material intended. In the case of a conventional general manufacturing method of copper alloy materials made from a Cu-Fe-P system, the heat-retaining of the heat treatment (annealing) intended for strain release is performed at a temperature of, for example, 400°C or more and 500°C or less. In contrast, in the third heat treatment process of this invention, heat-retaining is performed at a lower temperature of 250°C or more and 380°C or less for 4 hours or less. By this

heat-retaining at a lower temperature than conventional, the strain in the copper alloy structure due to rolling is appropriately released but not excessively released, and by obtaining a copper alloy structure containing an appropriate amount of strain, the decrease in tensile strength of the copper alloy material intended can be minimized.

[0058] If the heat-retaining temperature in the third heat treatment process is excessively low (less than 250°C), the release of the strain in the third cold-rolled material's copper alloy structure may be insufficient, and the mechanical properties such as elongation and bendability of the copper alloy material intended may not be improved. Also, if the heat-retaining temperature in the third heat treatment process is excessively high (more than 380°C) or the heat-retaining time is excessively long (more than 4 hours), the release of the strain in the third cold-rolled material's copper alloy structure is excessive, and the tensile strength of the copper alloy material intended may not be obtained. From this viewpoint, in the third heat treatment process, heat-retaining is performed on the third cold-rolled material at a temperature of 250°C or more and 380°C or less for 4 hours or less, and preferably, heat-retaining is performed at a temperature of 280°C or more and 350°C or less for 1 hour or less to obtain a copper alloy structure with a good balance of tensile strength and elongation and bendability of the copper alloy material intended.

[0059] As described above, according to this invention, it is possible to provide a copper alloy material and a manufacturing method of a copper alloy material that have no problem of the aforementioned residual smut like a copper alloy material made from a Cu-Fe-Zn-P system such as C1940, and have almost the same electrical conductivity (conductivity) and mechanical strength (tensile strength) as a copper alloy material made from a Cu-Ni-Si system such as C7025, which is of higher strength.

EXAMPLES

[0060] The effectiveness of the copper alloy material and the manufacturing method of the copper alloy material according to this invention will be explained by giving actual evaluation results. First, Table 1 shows the composition (added elements), main manufacturing conditions, and mechanical properties, etc., of the copper alloy materials of Samples 1 to 29 (Example, Comparative Examples). Also, as Reference Examples, the copper alloy materials of Samples 30 and 31 are listed. In Samples 1 to 29, Mn is not intentionally added. Also, the remainder of Samples 1 to 29 other than the added elements may be interpreted as Cu and impurity elements, and impurity elements of less than 0.01% (Ag, Pb, Ni, and S, etc.) are omitted from the description.

[Table 1]

Sample number	Additive elements (mass%)					1st Heat Treatment Process	2nd Cold Rolling Process	2nd Heat Treatment Process
	Fe	P	Zn	Sn	Mn	Heat-Retaining Condition	Rolling Degree (%)	Heat-Retaining Condition
1	2.20	0.03	0.12	0.60	< 0.001	580°C, 3 min.	64	450°C, 4h
2	2.20	0.03	0.12	0.60	< 0.001	580°C, 3 min.	64	420°C, 4h
3	2.20	0.03	0.12	0.60	< 0.001	580°C, 3 min.	64	420°C, 4h
4	2.20	0.03	0.12	0.30	< 0.001	580°C, 3 min.	64	450°C, 4h
5	2.20	0.03	0.12	0.60	< 0.001	550°C, 3 min.	73	420°C, 4h
6	2.20	0.03	0.12	0.60	< 0.001	550°C, 3 min.	46	450°C, 4h
7	2.20	0.03	0.12	0.60	< 0.001	580°C, 3 min.	73	420°C, 4h
8	2.20	0.03	0.12	0.60	< 0.001	600°C, 3 min.	73	420°C, 4h
9	2.20	0.03	0.12	0.60	< 0.001	600°C, 3 min.	46	450°C, 4h
10	1.50	0.03	0.12	0.60	< 0.001	580°C, 3 min.	64	450°C, 4h
11	2.80	0.03	0.12	0.60	< 0.001	580°C, 3 min.	64	450°C, 4h
12	2.20	0.22	0.12	0.60	< 0.001	580°C, 3 min.	64	450°C, 4h
13	2.20	0.03	0.40	0.60	< 0.001	580°C, 3 min.	64	450°C, 4h
14	2.20	0.03	0.12	0.20	< 0.001	580°C, 3 min.	64	450°C, 4h
15	2.20	0.03	0.12	0.90	< 0.001	580°C, 3 min.	64	450°C, 4h

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(continued)

Sample number	Additive elements (mass%)					1st Heat Treatment Process	2nd Cold Rolling Process	2nd Heat Treatment Process
	Fe	P	Zn	Sn	Mn	Heat-Retaining Condition	Rolling Degree (%)	Heat-Retaining Condition
16	2.20	0.03	0.12	0.30	< 0.001	450°C, 3 min.	64	450°C, 4h
17	2.20	0.03	0.12	0.60	< 0.001	650°C, 3 min.	64	450°C, 4h
18	2.20	0.03	0.12	0.60	< 0.001	580°C, 5h	64	450°C, 4h
19	2.20	0.03	0.12	0.60	< 0.001	580°C, 3 min.	17	450°C, 4h
20	2.20	0.03	0.12	0.60	< 0.001	580°C, 3 min.	91	450°C, 4h
21	2.20	0.03	0.12	0.60	< 0.001	580°C, 3 min.	64	350°C, 4h
22	2.20	0.03	0.12	0.60	< 0.001	580°C, 3 min.	64	500°C, 4h
23	2.20	0.03	0.12	0.60	< 0.001	580°C, 3 min.	64	420°C, 0.5h
24	2.20	0.03	0.12	0.60	< 0.001	580°C, 3 min.	64	450°C, 20h
25	2.20	0.03	0.12	0.60	< 0.001	580°C, 3 min.	79	450°C, 4h
26	2.20	0.03	0.12	0.60	< 0.001	580°C, 3 min.	28	450°C, 4h
27	2.20	0.03	0.12	0.60	< 0.001	580°C, 3 min.	64	450°C, 4h
28	2.20	0.03	0.12	0.60	< 0.001	580°C, 3 min.	64	450°C, 4h
29	2.20	0.03	0.12	0.60	< 0.001	580°C, 3 min.	64	450°C, 4h
30	C1940 equivalent material (quality ESH)					-	-	-
31	C7025 equivalent material (1/2H by quality)					-	-	-

Table 1 (continued)

Sample Number	3rd Cold Rolling Process	3rd Heat Treatment Process	Characteristics of copper alloy materials, etc.				Notes
	Rolling Degree (%)	Heat-Retaining Condition	Tensile strength (MPa)	Electrical conductivity (% IACS)	Bendability	Presence or Absence of residual smut	
1	70	350°C, 1 min.	670	48.2	Good	Absent	Example
2	70	300°C, 1 min.	692	45.8	Good	Absent	Example
3	70	280°C, 1 min.	711	41.8	Good	Absent	Example
4	70	350°C, 1 min.	624	51.0	Good	Absent	Example
5	60	350°C, 1 min.	646	47.7	Good	Absent	Example
6	80	350°C, 1 min.	654	45.8	Good	Absent	Example
7	60	350°C, 1 min.	645	47.3	Good	Absent	Example

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(continued)

Sample Number	3rd Cold Rolling Process	3rd Heat Treatment Process	Characteristics of copper alloy materials, etc.				Notes
	Rolling Degree (%)	Heat-Retaining Condition	Tensile strength (MPa)	Electrical conductivity (% IACS)	Bendability	Presence or Absence of residual smut	
8	60	350°C, 1 min.	636	46.9	Good	Absent	Example
9	80	350°C, 1 min.	662	47.4	Good	Absent	Example
10	70	350°C, 1 min.	575	56.3	Good	Absent	Comparative Example
11	70	350°C, 1 min.	672	38.8	Poor	Absent	Comparative Example
12	70	350°C, 1 min.	675	48.8	Poor	Absent	Inventive Example
13	70	350°C, 1 min.	674	39.2	Poor	Absent	Comparative Example
14	70	350°C, 1 min.	604	55.0	Good	Absent	Comparative Example
15	70	350°C, 1 min.	696	39.8	Poor	Absent	Comparative Example
16	70	350°C, 1 min.	610	50.5	Good	Absent	Comparative Example
17	70	350°C, 1 min.	596	51.8	Good	Absent	Comparative Example
18	70	350°C, 1 min.	612	51.0	Good	Absent	Comparative Example
19	80	350°C, 1 min.	624	39.6	Good	Absent	Comparative Example
20	60	350°C, 1 min.	610	48.8	Good	Absent	Comparative Example
21	70	350°C, 1 min.	606	38.0	Good	Absent	Comparative Example
22	70	350°C, 1 min.	575	50.5	Good	Absent	Comparative Example
23	70	350°C, 1 min.	598	39.7	Good	Absent	Comparative Example
24	70	350°C, 1 min.	602	52.0	Good	Absent	Comparative Example
25	50	350°C, 1 min.	569	48.2	Good	Absent	Comparative Example
26	85	350°C, 1 min.	580	46.0	Good	Absent	Comparative Example
27	70	200°C, 1 min.	718	39.8	Poor	Absent	Comparative Example

(continued)

Sample Number	3rd Cold Rolling Process	3rd Heat Treatment Process	Characteristics of copper alloy materials, etc.				Notes
	Rolling Degree (%)	Heat-Retaining Condition	Tensile strength (MPa)	Electrical conductivity (% IACS)	Bendability	Presence or Absence of residual smut	
28	70	400°C, 1 min.	603	48.2	Good	Absent	Comparative Example
29	70	350°C, 5h	614	49.6	Good	Absent	Comparative Example
30	-	-	540	63.0	Good	Absent	Reference Example
31	-	-	650	45.0	Good	Present	Reference Example

[0061] The copper alloy material of Sample 1 shown in Table 1 contains 2.2 mass% of Fe, 0.03 mass% of P, 0.12 mass% of Zn, and 0.60 mass% of Sn, with the remainder being Cu and impurity elements. This copper alloy material was produced through the following processes (1) to (8).

(1) In the melting and casting process, additive materials containing predetermined additive elements were added to a molten parent material made of oxygen-free copper using a high-frequency melting furnace, and the mixture was melted in a nitrogen atmosphere. After adjusting the composition, the mixture was cast to produce a copper alloy casting material with a thickness of about 25 mm, a width of about 30 mm, and a length of about 150 mm.

(2) In the hot rolling process, the copper alloy casting material was hot-rolled at a temperature of about 950°C to produce a hot-rolled material with a thickness of about 8 mm.

(3) In the first cold rolling process, the hot-rolled material was cold-rolled to a total rolling degree of about 83% to produce a first cold-rolled material with a thickness of about 1.4 mm.

(4) In the first heat treatment process, the first cold-rolled material was heated and retained at a temperature of about 580°C for about 3 minutes to produce a first heat-treated material.

(5) In the second cold rolling process, the first heat-treated material was cold-rolled to a total rolling degree of about 64% to produce a second cold-rolled material with a thickness of about 0.5 mm. In this case, the total rolling degree of the first and second cold rolling processes was about 94%.

(6) In the second heat treatment process, the second cold-rolled material was heated and retained at a temperature of about 450°C for about 4 hours to produce a second heat-treated material.

(7) In the third cold rolling process, the second heat-treated material was cold-rolled to a total rolling degree of about 70% to produce a third cold-rolled material with a thickness of about 0.15 mm. In this case, the total rolling degree of the second and third cold rolling processes was about 89%, and the total rolling degree of the first, second, and third cold rolling processes was about 98%.

(8) In the third heat treatment process, the third cold-rolled material was heated and retained at a temperature of about 350°C for about 1 minute to finally obtain a copper alloy material of Sample 1 with a thickness of about 0.15 mm. The copper alloy material of Sample 1 is an example of the present invention.

[0062] The copper alloy material of Sample 2 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through substantially the same production process as the copper alloy material of Sample 1, except that the heat retention in the second heat treatment process was set to a temperature of about 420°C. The copper alloy material of Sample 2 is an example of the present invention.

[0063] The copper alloy material of Sample 3 shown in Table 1 was produced to have the same final thickness as the

copper alloy material of sample 1 through substantially the same production process as the copper alloy material of Sample 1, except that the heat retention in the second heat treatment process was set to a temperature of about 420°C and the heat retention in the third heat treatment process was set to a temperature of about 280°C. The copper alloy material of Sample 3 is an example of the present invention.

[0064] The copper alloy material of Sample 4 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through substantially the same production process as the copper alloy material of Sample 1, except that the Sn content in the copper alloy material finally obtained in the melting and casting process was set to about 0.30 mass%. The copper alloy material of Sample 4 is an example of the present invention.

[0065] The copper alloy material of Sample 5 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through substantially the same production process as the copper alloy material of Sample 1, except that the heat retention in the first heat treatment process was set to a temperature of about 550°C, the rolling degree in the second cold rolling process was set to about 73%, the heat retention in the second heat treatment process was set to a temperature of about 420°C, and the rolling degree in the third cold rolling process was set to about 60%. In this case, the total rolling degree of the second and third cold rolling processes was about 89%. The copper alloy material of Sample 5 is an example of the present invention.

[0066] The copper alloy material of Sample 6 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through substantially the same production process as the copper alloy material of Sample 1, except that the heat retention in the first heat treatment process was set to a temperature of about 550°C, the rolling degree in the second cold rolling process was set to about 46%, and the rolling degree in the third cold rolling process was set to about 80%. In this case, the total rolling degree of the second and third cold rolling processes was about 89%. The copper alloy material of Sample 6 is an example of the present invention.

[0067] The copper alloy material of Sample 7 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through substantially the same production process as the copper alloy material of Sample 1, except that the rolling degree in the second cold rolling process was set to about 73%, the heat retention in the second heat treatment process was set to a temperature of about 420°C, and the rolling degree in the third cold rolling process was set to about 60%. The copper alloy material of Sample 7 is an example of the present invention.

[0068] The copper alloy material of Sample 8 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through substantially the same production process as the copper alloy material of Sample 1, except that the heat retention in the first heat treatment process was set to a temperature of about 600°C, the rolling degree in the second cold rolling process was set to about 73%, the heat retention in the second heat treatment process was set to a temperature of about 420°C, and the rolling degree in the third cold rolling process was set to about 60%. The copper alloy material of Sample 8 is an example of the present invention.

[0069] The copper alloy material of Sample 9 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through substantially the same production process as the copper alloy material of Sample 1, except that the heat retention in the first heat treatment process was set to a temperature of about 600°C, the rolling degree in the second cold rolling process was set to about 46%, and the rolling degree in the third cold rolling process was set to about 80%. The copper alloy material of Sample 9 is an example of the present invention.

[0070] The copper alloy material of Sample 10 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through substantially the same production process as the copper alloy material of Sample 1, except that the Fe content in the copper alloy material finally obtained in the melting and casting process was set to about 1.50 mass%. The copper alloy material of Sample 10 is a comparative example, and the Fe content is outside the range of this invention.

[0071] The copper alloy material of Sample 11 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through substantially the same production process as the copper alloy material of Sample 1, except that the Fe content in the copper alloy material finally obtained in the melting and casting process was set to about 2.80 mass%. The copper alloy material of Sample 11 is a comparative example, and the Fe content is outside the range of this invention.

[0072] The copper alloy material of Sample 12 shown in Table 1 was produced through substantially the same production process as the copper alloy material of Sample 1, except that the P content in the copper alloy material finally obtained in the melting and casting process was set to about 0.22 mass%. The copper alloy material of Sample 12 is an example of the present invention.

[0073] The copper alloy material of Sample 13 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through substantially the same production process as the copper alloy material of Sample 1, except that the Zn content in the copper alloy material finally obtained in the melting and casting process was set to about 0.40 mass%. The copper alloy material of Sample 13 is a comparative example, and the Zn content is outside the range of this invention.

[0074] The copper alloy material of Sample 14 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through substantially the same production process as the copper alloy material of

Sample 1, except that the Sn content in the copper alloy material finally obtained in the melting and casting process was set to about 0.20 mass%. The copper alloy material of Sample 14 is a comparative example, and the Sn content is outside the range of this invention.

[0075] The copper alloy material of Sample 15 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through substantially the same production process as the copper alloy material of Sample 1, except that the Sn content in the copper alloy material finally obtained in the melting and casting process was set to about 0.90 mass%. The copper alloy material of Sample 15 is a comparative example, and the Sn content is outside the range of this invention.

[0076] The copper alloy material of Sample 16 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through a process substantially equivalent to that of the copper alloy material of Sample 1, except that the Sn content in the copper alloy material finally obtained in the component adjustment of the melting and casting process is set to be about 0.30 mass%, and the heat-retaining of the first heat treatment process is set to a temperature of about 450°C. The copper alloy material of Sample 16 is a comparative example, and the first heat treatment process is outside the scope of this invention.

[0077] The copper alloy material of Sample 17 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through a process substantially equivalent to that of the copper alloy material of Sample 1, except that the heat-retaining of the first heat treatment process is set to a temperature of about 650°C. The copper alloy material of Sample 17 is a comparative example because the first heat treatment process is outside the scope of this invention.

[0078] The copper alloy material of Sample 18 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through a process substantially equivalent to that of the copper alloy material of Sample 1, except that the heat-retaining of the first heat treatment process is set to a time of about 5 hours. The copper alloy material of Sample 18 is a comparative example because the first heat treatment process is outside the scope of this invention.

[0079] The copper alloy material of Sample 19 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through a process substantially equivalent to that of the copper alloy material of Sample 1, except that the rolling degree of the second cold rolling process is set to about 17%, and the rolling degree of the third cold rolling process is set to about 80%. In this case, the total rolling degree by the second and third cold rolling processes is about 83%. The copper alloy material of Sample 19 is a comparative example, and the second cold rolling process is outside the scope of this invention.

[0080] The copper alloy material of Sample 20 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through a process substantially equivalent to that of the copper alloy material of Sample 1, except that the rolling degree of the second cold rolling process is set to about 91%, and the rolling degree of the third cold rolling process is set to about 60%. In this case, the total rolling degree by the second and third cold rolling processes is about 96%. The copper alloy material of Sample 20 is a comparative example, and the second cold rolling process is outside the scope of this invention.

[0081] The copper alloy material of Sample 21 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through a process substantially equivalent to that of the copper alloy material of Sample 1, except that the heat-retaining of the second heat treatment process is set to a temperature of about 350°C. The copper alloy material of Sample 21 is a comparative example, and the second heat treatment process is outside the scope of this invention.

[0082] The copper alloy material of Sample 22 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through a process substantially equivalent to that of the copper alloy material of Sample 1, except that the heat-retaining of the second heat treatment process is set to a temperature of about 500°C. The copper alloy material of Sample 22 is a comparative example, and the second heat treatment process is outside the scope of this invention.

[0083] The copper alloy material of Sample 23 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through a process substantially equivalent to that of the copper alloy material of Sample 1, except that the heat-retaining of the second heat treatment process is set to a temperature of about 420°C for about 0.5 hours. The copper alloy material of Sample 23 is a comparative example, and the second heat treatment process is outside the scope of this invention.

[0084] The copper alloy material of Sample 24 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through a process substantially equivalent to that of the copper alloy material of Sample 1, except that the heat-retaining of the second heat treatment process is set to a temperature of about 450°C for about 20 hours. The copper alloy material of Sample 24 is a comparative example, and the second heat treatment process is outside the scope of this invention.

[0085] The copper alloy material of Sample 25 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through a process substantially equivalent to that of the copper alloy material of Sample

1, except that the rolling degree of the second cold rolling process is set to about 79%, and the rolling degree of the third cold rolling process is set to about 50%. In this case, the total rolling degree by the second and third cold rolling processes is about 90%. The copper alloy material of Sample 25 is a comparative example, and the third cold rolling process is outside the scope of this invention.

[0086] The copper alloy material of Sample 26 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through a process substantially equivalent to that of the copper alloy material of Sample 1, except that the rolling degree of the second cold rolling process is set to about 28%, and the rolling degree of the third cold rolling process is set to about 85%. In this case, the total rolling degree by the second and third cold rolling processes is about 89%. The copper alloy material of Sample 26 is a comparative example, and the third cold rolling process is outside the scope of this invention.

[0087] The copper alloy material of Sample 27 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through a process substantially equivalent to that of the copper alloy material of Sample 1, except that the heat-retaining of the third heat treatment process is set to a temperature of about 200°C. The copper alloy material of Sample 27 is a comparative example, and the third heat treatment process is outside the scope of this invention.

[0088] The copper alloy material of Sample 28 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through a process substantially equivalent to that of the copper alloy material of Sample 1, except that the heat-retaining of the third heat treatment process is set to a temperature of about 400°C. The copper alloy material of Sample 28 is a comparative example, and the third heat treatment process is outside the scope of this invention.

[0089] The copper alloy material of Sample 29 shown in Table 1 was produced to have the same final thickness as the copper alloy material of sample 1 through a process substantially equivalent to that of the copper alloy material of Sample 1, except that the heat-retaining of the third heat treatment process is set to a time of about 5 hours. The copper alloy material of Sample 29 is a comparative example, and the third heat treatment process is outside the scope of this invention.

[0090] The copper alloy material of Sample 30 shown in Table 1 is a commercially available material having a composition equivalent to C1940 (Cu - 2.2 mass% Fe - 0.03 mass% P - 0.12 mass% Zn), Temper designation of ESH, and a thickness equivalent to that of the copper alloy material of Sample 1. The copper alloy material of Sample 30 is a reference example.

[0091] The copper alloy material of Sample 31 shown in Table 1 is a commercially available material having a composition equivalent to C7025 (Cu - 3 mass% Ni - 0.65 mass% Si - 0.15 mass% Mg), Temper designation of 1/2-H, and a thickness equivalent to that of the copper alloy material of Sample 1. The copper alloy material of Sample 31 is a reference example.

[0092] The characteristics of the copper alloy materials of Samples 1 to 31 were actually confirmed and evaluated by focusing on the tensile strength, electrical conductivity, bendability, and the presence or absence of residual smut, as shown in Table 1. Specifically, the tensile strength of the copper alloy material was measured in accordance with JIS-Z2241:2011, which specifies the method for tensile testing of metallic materials, under normal temperature conditions (about 20°C). The electrical conductivity of the copper alloy material was measured in accordance with JIS-Z0505:1975, which specifies the method for measuring the electrical conductivity of non-ferrous metal materials, under normal temperature conditions (about 20°C). The bendability of the copper alloy material was evaluated by the W bending test adopted as a bending test in JIS-H3110:2018 under normal temperature conditions (about 20°C). Specifically, when the test piece (copper alloy material) was bent with a bending radius (inner radius) of 0.15 mm, if no cracks were confirmed on the outer surface of the bend of the test piece, it was judged as "Good", and even if the cracks were small, if cracks were confirmed, it was judged as "Poor". The presence or absence of residual smut was confirmed by observing the surface of the test piece (copper alloy material) which was pretreated, immersed in a chemical polishing solution for about 1 minute, washed with water, and dried. At this time, the chemical polishing solution was an acidic aqueous solution containing about 20 mass% of sulfuric acid and about 8 mass% of hydrogen peroxide, and was kept at about 40°C. The surface area of the test piece immersed in the chemical polishing solution was about 2000 mm² (on both sides with a width of 20 mm and a length of 50 mm). The pretreatment of the test piece was carried out in the order of ethanol degreasing, alkali electrolytic degreasing, immersion in a 5% sulfuric acid aqueous solution (neutralization), water washing, and drying.

[0093] Regarding the reference examples shown in Table 1, the tensile strength of the copper alloy material of Sample 30 was 540 MPa, which was less than 620 MPa. The conductivity was 63.0% IACS, which was more than 40.0% IACS. The bendability was rated as "Good", and there was no residual smut. Also, the tensile strength of the copper alloy material of Sample 31 was 650 MPa, which was more than 620 MPa. The conductivity was 45.0% IACS, which was more than 40.0% IACS. The bendability was rated as "Good", and residual smut was present.

<Influence of Fe>

[0094] The copper alloy materials of Samples 1, 10, and 11 shown in Table 2 (extracted from Table 1) were produced to have substantially equivalent thicknesses through substantially equivalent production processes except that Fe contents were different in the final copper alloy material obtained by adjusting the composition in the melting and casting process.

Specifically, the Fe content of Sample 1 was 2.20%, which is within the range of 1.6% to 2.6% defined in this invention. In contrast, Sample 10 had a smaller Fe content of 1.50 mass%, and Sample 11 had a larger Fe content of 2.80%, both of which were outside the above range.

[Table 2]

Sample number	Added elements (mass%)					Characteristics of copper alloy materials				Notes
	Fe	P	Zn	Sn	Mn	Tensile Strength (MPa)	Conductivity (% IACS)	Bendability	Presense or Absence of Residual Smut	
1	2.20	0.03	0.12	0.60	< 0.001	670	48.2	Good	Absent	Example
10	1.50	0.03	0.12	0.60	< 0.001	575	56.3	Good	Absent	Comparative Example
11	2.80	0.03	0.12	0.60	< 0.001	672	38.8	Poor	Absent	Comparative Example

[0095] As shown in Table 2, the tensile strength of Samples 1 and 11 was 670 MPa and 672 MPa, respectively, both of which were more than 620 MPa. In contrast, the tensile strength of Sample 10 was 575 MPa, which was less than 620 MPa. Also, the conductivity of Samples 1 and 10 was 48.2% IACS and 56.3% IACS, respectively, both of which were more than 40.0% IACS. In contrast, the conductivity of Sample 11 was 38.8% IACS, which was less than 40.0% IACS. Also, the bendability of Samples 1 and 10 was rated as "Good", while that of Sample 11 was rated as "Poor". Also, residual smut was absent in any of Samples 1, 10, and 11.

[0096] By comparing the evaluation of the copper alloy materials of Samples 1, 10, and 11 with different Fe contents, it was found that when the Fe content decreases and is outside the above range, the tensile strength of the copper alloy material decreases and does not reach 620 MPa. Also, when the Fe content increases and is outside the above range, the conductivity of the copper alloy material decreases and does not reach 40.0% IACS. Also, it was found that the Fe content has little influence on the bendability and residual smut of the copper alloy material. Therefore, from the viewpoint of having no residual smut, a tensile strength of more than 620 MPa, a conductivity of more than 40.0% IACS, and good bendability, it is effective in practical use to have a copper alloy material containing Fe of 1.6% to 2.6%.

<Influence of P>

[0097] The copper alloy materials of Samples 1 and 12 shown in Table 3 (extracted from Table 1) were produced to have substantially equivalent thicknesses through substantially equivalent production processes except that P contents were different in the final copper alloy material obtained by adjusting the composition in the melting and casting process, and were produced through substantially equivalent production processes to have substantially equivalent thicknesses. Specifically, the P content of Sample 1 was 0.03%, which is within the range of 0.01% to 0.3% defined in this invention. Also, Sample 12 had a larger P content of 0.22 mass%, which is within the above range, but is outside the range of 0.01% to 0.20% which the inventors consider more preferable.

[Table 3]

Sample Number	Added elements (mass%)					Characteristics of copper alloy materials etc.				Notes
	Fe	P	Zn	Sn	Mn	Tensile Strength (MPa)	Conductivity (% IACS)	Bendability	Presence or Absence of Residual Smut	
1	2.20	0.03	0.12	0.60	< 0.001	670	48.2	Good	Absent	Example

(continued)

Sample Number	Added elements (mass%)					Characteristics of copper alloy materials etc.				Notes
	Fe	P	Zn	Sn	Mn	Tensile Strength (MPa)	Conductivity (% IACS)	Bendability	Presence or Absence of Residual Smut	
12	2.20	0.22	0.12	0.60	< 0.001	675	48.8	Poor	Absent	Example

[0098] As shown in Table 3, the tensile strength of Samples 1 and 12 was more than 620 MPa, and the tensile strength of Sample 12 was 675 MPa which was larger than that of Sample 1 (670 MPa). Also, the conductivity of Samples 1 and 12 was more than 40.0% IACS, and the conductivity of Sample 12 was larger than that of Sample 1 (48.2% IACS), being 48.8% IACS. Also, the bendability of Sample 1 was rated as "Good", while that of Sample 12 was rated as "Poor". Also, residual smut was absent in both of Samples 1 and 12.

[0099] By comparing the evaluation of the copper alloy materials of Samples 1 and 12 with different P contents, it was found that the P content has little influence on the tensile strength and conductivity of the copper alloy material. Also, it was found that when the P content increases, the bendability of the copper alloy material tends to deteriorate. Also, it was found that the P content has little influence on the residual smut of the copper alloy material. Therefore, from the viewpoint of having no residual smut, a tensile strength of more than 620 MPa, a conductivity of more than 40.0% IACS, and good bendability, it is effective in practical use to have a copper alloy material containing P of 0.01% to 0.3% defined in this invention. Also, from the viewpoint of having good bendability, it is effective in practical use to have a copper alloy material containing P of 0.01% to 0.20%.

<Influence of Zn>

[0100] The copper alloy materials of Samples 1 and 13 shown in Table 4 (extracted from Table 1) were produced to have substantially equivalent thicknesses through substantially equivalent production processes except that Zn contents were different in the final copper alloy material obtained by adjusting the composition in the melting and casting process. Specifically, the Zn content of Sample 1 was 0.12%, which is within the range of 0.01% to 0.3% defined in this invention. In contrast, Sample 13 had a larger Zn content of 0.40%, which was outside the above range.

[Table 4]

Sample number	Additive elements (mass%)					Characteristics of copper alloy materials, etc.				Note
	Fe	P	Zn	Sn	Mn	Tensile Strength (MPa)	Conductivity (% IACS)	Bendability	Presence or Absence of Residual Smut	
1	2.20	0.03	0.12	0.60	< 0.001	670	48.2	Good	Absent	Example
13	2.20	0.03	0.40	0.60	< 0.001	674	39.2	Poor	Absent	Comparative Example

[0101] As shown in Table 4, the tensile strength of Samples 1 and 12 was more than 620 MPa, and the tensile strength of Sample 13 was 674 MPa, which was larger than that of Sample 1 (670 MPa). Also, the conductivity of Sample 1 (48.2% IACS) was more than 40.0% IACS, while the conductivity of Sample 13 was 39.2% IACS, which was less than 40.0% IACS. Also, the bendability of Sample 1 was rated as "Good", while that of Sample 13 was rated as "Poor". Also, residual smut was absent in both Samples 1 and 13.

[0102] By comparing the evaluation of the copper alloy materials of Samples 1 and 13 with different Zn contents, it was found that when the Zn content increases and is outside the above range, the conductivity of the copper alloy material decreases and does not reach 40.0% IACS, and the bendability of the copper alloy material tends to deteriorate. Also, it

was found that the Zn content has little influence on the tensile strength and residual smut of the copper alloy material. Therefore, from the viewpoint of having no residual smut, a tensile strength of more than 620 MPa, a conductivity of more than 40.0% IACS, and good bendability, it is effective in practical use to have a copper alloy material containing Zn of 0.01% to 0.3%.

<Influence of Sn>

[0103] The copper alloy materials of Samples 1, 4, 14, and 15 shown in Table 5 (extracted from Table 1) were produced to have substantially equivalent thicknesses through substantially equivalent production processes except that Sn contents were different in the final copper alloy material obtained by adjusting the composition in the melting and casting process. Specifically, the Sn content of Sample 1 was 0.60%, and that of Sample 13 was 0.30%, both of which are within the range of 0.3% to 0.8% defined in this invention. In contrast, Sample 4 had a smaller Sn content of 0.20 mass%, and Sample 14 had a larger Sn content of 0.90%, both of which were outside the above range.

[Table 5]

Sample number	Additive elements (mass%)					Characteristics of copper alloy materials				Notes
	Fe	P	Zn	Sn	Mn	Tensile Strength (MPa)	Conductivity (% IACS)	Bendability	Presence or Absence of Residual Smut	
1	2.20	0.03	0.12	0.60	< 0.001	670	48.2	Excellent	Absent	Example
4	2.20	0.03	0.12	0.30	< 0.001	624	51.0	Excellent	Absent	Example
14	2.20	0.03	0.12	0.20	< 0.001	604	55.0	Excellent	Absent	Comparative Example
15	2.20	0.03	0.12	0.90	< 0.001	696	39.8	Poor	Absent	Comparative Example

[0104] As shown in Table 5, the tensile strength was 620 MPa or more for samples 1, 4, and 15, and less than 620 MPa for sample 14. Specifically, the tensile strength of sample 1 (670 MPa) was smaller for sample 4 at 624 MPa, even smaller for sample 14 at 604 MPa, but larger for sample 15 at 690 MPa. Also, the conductivity was 40.0% IACS or more for samples 1, 4, and 14, and less than 40.0% IACS for sample 15. Specifically, compared to the conductivity of sample 1 (48.2% IACS), sample 4 was larger at 51.0% IACS, sample 14 was even larger at 55.0% IACS, but sample 15 was smaller at 39.8% IACS. Furthermore, the bendability was "Good" for samples 1, 4, and 14, but "inferior" for sample 15. Also, the residual smut was "Absent" for all samples 1, 4, 14, and 15.

[0105] By comparing the evaluation of the copper alloy materials of samples 1, 4, 14, and 15 with different Sn content, it was found that as the Sn content decreases, the tensile strength of the copper alloy material tends to decrease. Also, it was found that when the Sn content decreases further and falls outside the above range, the tensile strength of the copper alloy material does not reach 620 MPa. Furthermore, by comparing the evaluation of the copper alloy materials of samples 1 and 4, it was found that when the copper alloy material contains more than 0.3% Sn, a tensile strength of 625 MPa or more can be obtained. Also, it was found that as the Sn content decreases, the conductivity of the copper alloy material tends to increase. Furthermore, it was found that when the Sn content increases and falls outside the above range, the conductivity of the copper alloy material further decreases and does not reach 40.0% IACS. Also, it was found that as the Sn content increases, the bendability of the copper alloy material tends to deteriorate. Furthermore, it was found that the Sn content has little influence on the residual smut. Therefore, from the viewpoint of having no residual smut, having a tensile strength of 620 MPa or more, having a conductivity of 40.0% IACS or more, and having good bendability, in practical use, copper alloy materials containing 0.3% to 0.8% Sn are effective.

<Influence of First Heat Treatment Process>

[0106] Focusing on the copper alloy materials of samples 1, 4, 16, 17, and 18 shown in Table 6 (extracted from Table 1), the influence of the first heat treatment process will be explained. The copper alloy materials of samples 1, 16, 17, and 18

were produced to have substantially equivalent thicknesses through substantially equivalent production processes except that the heat-retaining conditions of the first heat treatment process were varied. Also, the copper alloy materials of samples 1, 17, and 18 were adjusted to have a Sn content of 0.60%, and the copper alloy materials of samples 4 and 16 were adjusted to have a Sn content of 0.30%. Specifically, the heat-retaining conditions of the first heat treatment process are about 3 minutes at 580°C for samples 1 and 4, which are within the range of 500°C to 600°C for 4 hours or less, which is defined in this invention. On the other hand, sample 16 is at a lower temperature of 450°C, and sample 17 is at a higher temperature of 650°C, which was outside the above range although the retention time was the same as samples 1 and 4. Also, sample 18 is for a longer time of about 5 hours, which was outside the above range although the retention temperature was the same as samples 1 and 4.

[Table 6]

Sample Number	Additive Elements (mass%)					1st Heat Treatment Process	2nd Cold Rolling Process	2nd Heat Treatment Process
	Fe	P	Zn	Sn	Mn	Heat-Retaining Condition	Rolling Degree (%)	Heat-Retaining Condition
1	2.20	0.03	0.12	0.60	< 0.001	580°C, 3 min.	64	450°C, 4h
4	2.20	0.03	0.12	0.30	< 0.001	580°C, 3 min.	64	450°C, 4h
16	2.20	0.03	0.12	0.30	< 0.001	450°C, 3 min.	64	450°C, 4h
17	2.20	0.03	0.12	0.60	< 0.001	650°C, 3 min.	64	450°C, 4h
18	2.20	0.03	0.12	0.60	< 0.001	580°C, 5h	64	450°C, 4h

Table 6 (continued)

Sample Number	3rd Cold Rolling Process	3rd Heat Treatment Process	Characteristics of copper alloy materials, etc.				Notes
	Rolling Degree (%)	Heat-Retaining Condition	Tensile strength (MPa)	Electrical conductivity (% IACS)	Bendability	Presence or Absence of residual smut	
1	70	350°C, 1 min.	670	48.2	Good	Absent	Example
4	70	350°C, 1 min.	624	51.0	Good	Absent	Example
16	70	350°C, 1 min.	610	50.5	Good	Absent	Comparative Example
17	70	350°C, 1 min.	596	51.8	Good	Absent	Comparative Example
18	70	350°C, 1 min.	612	51.0	Good	Absent	Comparative Example

[0107] As shown in Table 6, the tensile strength was 620 MPa or more for sample 1 (670 MPa), and although sample 4 was smaller at 624 MPa due to the smaller Sn content than sample 1, it was still 620 MPa or more. On the other hand, sample 16, which was set outside the above range as a low-temperature retention, was 610 MPa, sample 17, which was set outside the above range as a high-temperature hold, was 596 MPa, and sample 18, which was set outside the above range as a long-time hold, was 612 MPa, all of which were less than 620 MPa. Also, the conductivity was 48.2% IACS for sample 1, which was 40.0% IACS or more, 51.0% IACS for samples 4 and 18, 50.5% IACS for sample 16, and 51.8% IACS for sample 17. Also, the bendability was "Good" for samples 1, 16, 17, and 18. Also, the residual smut was "absent" for samples 1, 16, 17, and 18.

[0108] By comparing the evaluation of the copper alloy materials of sample 1 with sample 17 and by comparing the evaluation of the copper alloy materials of sample 4 with sample 16 with different heat-retaining temperatures of the first heat treatment process, it was found that when the heat-retaining temperature of the first heat treatment process was high

or low and falls outside the above range, the tensile strength of the copper alloy material tends to decrease and does not reach 620 MPa. Also, by comparing the evaluation of the copper alloy materials of samples 1 and 18, it was found that when the heat-retaining time of the first heat treatment process was long and falls outside the above range, the tensile strength of the copper alloy material tends to decrease and does not reach 620 MPa. Also, by comparing the evaluation of the copper alloy materials of samples 1, 4, 16, 17, and 18, it was found that the heat-retaining conditions of the first heat treatment process have little influence on the conductivity, bendability, and residual smut of the copper alloy material. Therefore, from the viewpoint of having no residual smut, having a tensile strength of 620 MPa or more, having a conductivity of 40.0% IACS or more, and having good bendability, in practical use, the first heat treatment process of producing the first heat-treated material by heat-retaining of the first cold-rolled material at a temperature of 500°C to 600°C for 4 hours or less is effective.

<Influence of Second Cold Rolling Process>

[0109] Focusing on the copper alloy materials of samples 1, 6, 19, and 20 shown in Table 7 (extracted from Table 1), the influence of the second cold rolling process will be explained. The copper alloy materials of samples 1, 6, 19, and 30 were produced to have substantially equivalent thicknesses through substantially equivalent production processes except that the rolling degree in the second cold rolling process was varied. Specifically, the rolling degree in the second cold rolling process was 64% for sample 1 and 46% for sample 6, which were within the range of 20% to 90% defined in this invention. On the other hand, sample 19 is 17% and sample 20 is 91%, which were outside the above range.

[Table 7]

Sample number	1st Heat Treatment Process	2nd Cold Rolling Process	2nd Heat Treatment Process	3rd Cold Rolling Process	3rd Heat Treatment Process
	Heat-Retaining Condition	Rolling Degree (%)	Heat-Retaining Condition	Rolling Degree (%)	Heat-Retaining Condition
1	580°C, 3 min.	64	450°C, 4h	70	350°C, 1 min.
6	550°C, 3 min.	46	450°C, 4h	80	350°C, 1 min.
19	580°C, 3 min.	17	450°C, 4h	80	350°C, 1 min.
20	580°C, 3 min.	91	450°C, 4h	60	350°C, 1 min.

Table 7 (continued)

Sample Number	Characteristics of copper alloy materials, etc.				Notes
	Tensile strength (MPa)	Electrical conductivity (% IACS)	Bendability	Presence or Absence of residual smut	
1	670	48.2	Good	Absent	Example
6	654	45.8	Good	Absent	Example
19	624	39.6	Good	Absent	Comparative Example
20	610	48.8	Good	Absent	Comparative Example

[0110] As shown in Table 7, the tensile strength was 620 MPa or more for sample 1 (670 MPa), and was smaller at 654 MPa for sample 6 which had a smaller rolling degree, all of them were 620 MPa or more. On the other hand, sample 20, which had a larger rolling degree and was set outside the above range, was even smaller at 610 MPa and was less than 620 MPa. Also, the conductivity was 40.0% IACS or more for sample 1 (48.2% IACS), and about the same, 48.8% IACS for sample 20 which had a larger rolling degree set outside the above range. On the other hand, sample 6, which had a smaller rolling degree, was smaller at 45.8% IACS. Also, sample 19, which had a smaller rolling degree set outside the above range, was even smaller at 39.6% IACS and was less than 40.0% IACS. Also, the bendability was "Good" for samples 1, 6, 19, and 20. Also, the residual smut was "absent" for samples 1, 6, 19, and 20.

[0111] By comparing the evaluation of the copper alloy materials of samples 1, 6 and 19, with different rolling degree in the second cold rolling process, it was found that the tensile strength of the copper alloy material tends to decrease as the rolling degree of the second cold rolling process decreases. Also, by comparing the evaluation of the copper alloy materials

of samples 1, 6, 19, and 20, it was found that when the rolling degree of the second cold rolling process was excessive and exceeds the above range, the tensile strength of the copper alloy material decreases and does not reach 620 MPa. Furthermore, by comparing the evaluation of samples 1, 6, 19, and 20 of copper alloy materials, it was found that the rolling degree of the second cold rolling process does not easily affect the conductivity of the copper alloy material even if it is excessive and exceeds the above range, and if it is too small and exceeds the above range, the conductivity of the copper alloy material decreases and does not reach 40.0% IACS. Also, by comparing the evaluation of samples 1, 6, 19, and 20 of copper alloy materials, it was found that the rolling degree of the second cold rolling process does not easily affect the bending workability and residual smut of the copper alloy material. Therefore, from the viewpoint of having no residual smut, having a tensile strength of 620 MPa or more, having a conductivity of 40.0% IACS or more, and having good bending workability, the second cold rolling process of producing the second cold-rolled material by cold rolling the first heat treated material at a rolling degree of 20% or more and 90% or less is effective in practical use.

<Influence of Heat-Retaining Condition of Second Heat Treatment Process>

[0112] Focusing on samples 1, 21, 22, 23, and 24 of copper alloy materials shown in Table 8 (extracted from Table 1), the influence of the second heat treatment process will be explained. Samples 1, 21, 22, 23, and 24 of copper alloy materials were made to have substantially equivalent thicknesses through substantially equivalent production processes except that the heat-retaining conditions of the second heat treatment process were different. Specifically, the heat-retaining conditions of the second heat treatment process were about 4 hours at 450°C for sample 1, which were within the range of 380°C or higher and 480°C or lower for 1 hour or longer and 12 hours or shorter as defined in this invention. On the other hand, retention temperature of sample 21 was at a lower temperature of 350°C, and that of sample 22 was at a higher temperature of 500°C, which were outside the above range although the retention time was the same as sample 1. Also, the retention time of sample 23 was a shorter time of about 0.5 hours, and that of sample 24 was a longer time of about 20 hours, so the retention temperature is within the above range, but the retention time is outside the above range.

[Table 8]

Sample number	1st Heat Treatment Process	2nd Cold Rolling Process	2nd Heat Treatment Process	3rd Cold Rolling Process	3rd Heat Treatment Process
	Heat-Retaining Condition	Rolling Degree (%)	Heat-Retaining Condition	Rolling Degree (%)	Heat-Retaining Condition
1	580°C, 3 min.	64	450°C, 4h	70	350°C, 1 min.
21	580°C, 3 min.	64	350°C, 4h	70	350°C, 1 min.
22	580°C, 3 min.	64	500°C, 4h	70	350°C, 1 min.
23	580°C, 3 min.	64	420°C, 0.5h	70	350°C, 1 min.
24	580°C, 3 min.	64	450°C, 20h	70	350°C, 1 min.

Table 8 (continued)

Sample Number	Characteristics of copper alloy materials, etc.				Notes
	Tensile strength (MPa)	Electrical conductivity (% IACS)	Bendability	Presence or Absence of residual smut	
1	670	48.2	Good	Absent	Example
21	606	38.0	Good	Absent	Comparative Example
22	575	50.5	Good	Absent	Comparative Example
23	598	39.7	Good	Absent	Comparative Example
24	602	52.0	Good	Absent	Comparative Example

[0113] As shown in Table 8, the tensile strength of samples 21 (606 MPa) and 22 (575 MPa), which were made outside the above range as low temperature or high temperature retention, and samples 23 (598 MPa) and 24 (602 MPa), which were made outside the above range as short time or long time retention, all decreased to less than 620 MPa compared to

sample 1 (670 MPa) with a tensile strength of 620 MPa or more. Also, the conductivity of sample 21 (38.0% IACS) which was made outside the above range as low temperature retention and sample 23 (39.7% IACS) which was made outside the above range as short time retention, both decreased to less than 40.0% IACS compared to sample 1 (48.2% IACS) with a conductivity of 40.0% IACS or more. Also, both of the conductivity of sample 22 (50.5% IACS) which was made outside the above range as high temperature retention and sample 24 (52.0% IACS) which were made outside the above range as long time retention increased. Also, the bending workability of samples 1, 21, 22, 23, and 24 were all "Good". Also, the residual smut of samples 1, 21, 22, 23, and 24 were all "absent".

[0114] By comparing the evaluation of samples 1, 21, 22, 23, and 24 of copper alloy materials with different heat-retaining temperatures of the second heat treatment process, it was found that when the heat-retaining of the second heat treatment process was performed at high temperature or low temperature exceeding the above range, the tensile strength of the copper alloy material tends to decrease and does not reach 620 MPa. Also, by comparing the evaluation of samples 1, 21, and 23 of copper alloy materials, it was found that when the heat-retaining of the second heat treatment process was performed at low temperature or short time exceeding the above range, the conductivity of the copper alloy material tends to decrease and does not reach 40.0% IACS. Also, by comparing the evaluation of samples 1, 22, and 24 of copper alloy materials, it was found that when the heat-retaining of the second heat treatment process was performed at high temperature or long time, the conductivity of the copper alloy material tends to increase. Also, by comparing the evaluation of samples 1, 21, 22, 23, and 24 of copper alloy materials, it was found that the heat-retaining conditions of the second heat treatment process do not easily affect the bending workability and residual smut of the copper alloy material. Therefore, from the viewpoint of having no residual smut, having a tensile strength of 620 MPa or more, having a conductivity of 40.0% IACS or more, and having good bending workability, the second heat treatment process of producing the second heat treated material by heat-retaining at a temperature of 380°C or higher and 480°C or lower for 1 hour or longer and 12 hours or shorter for the second cold-rolled material is effective in practical use.

<Influence of Rolling Degree of Third Cold Rolling Process>

[0115] Focusing on samples 1, 25, and 26 of copper alloy materials shown in Table 9 (extracted from Table 1), the influence of the third cold rolling process will be explained. Samples 1, 25, and 26 of copper alloy materials were made to have substantially equivalent thicknesses through substantially equivalent production processes except that the rolling degree of the third cold rolling process was different. Specifically, the rolling degree of the third cold rolling process was 70% for sample 1, which was within the range of 60% or more and 80% or less as defined in this invention. On the other hand, sample 25 was 50%, and sample 26 was 85%, which were outside the above range.

[Table 9]

Sample number	1st Heat Treatment Process	2nd Cold Rolling Process	2nd Heat Treatment Process	3rd Cold Rolling Process	3rd Heat Treatment Process
	Heat-Retaining Condition	Rolling Degree (%)	Heat-Retaining Condition	Rolling Degree (%)	Heat-Retaining Condition
1	580°C, 3 min.	64	450°C, 4h	70	350°C, 1 min.
25	580°C, 3 min.	79	450°C, 4h	50	350°C, 1 min.
26	580°C, 3 min.	28	450°C, 4h	85	350°C, 1 min.

Table 9 (continued)

Sample Number	Characteristics of copper alloy materials, etc.				Notes
	Tensile strength (MPa)	Electrical conductivity (% IACS)	Bendability	Presence or Absence of residual smut	
1	670	48.2	Good	Absent	Example
25	569	48.2	Good	Absent	Comparative Example
26	580	46.0	Good	Absent	Comparative Example

[0116] As shown in Table 9, the tensile strength of both of sample 25 (569 MPa) which was made outside the above range by reducing the rolling degree and sample 26 (580 MPa) which was made outside the above range by increasing the rolling

degree decreased to less than 620 MPa compared to sample 1 (670 MPa) with a tensile strength of 620 MPa or more. Also, the conductivity of sample 25 (48.2% IACS) which was made outside the above range by reducing the rolling degree, was the same as that of sample 1 (48.2% IACS) with a conductivity of 40.0% IACS or more, and sample 26 (46.0% IACS) which was made outside the above range by increasing the rolling degree was smaller than that of sample 1, although it did not become less than 40.0% IACS. Also, the bending workability of samples 1, 25, and 26 were all "Good". Also, the residual smut of samples 1, 25, and 26 all were "absent".

[0117] By comparing the evaluation of samples 1, 25, and 26 of copper alloy materials with different rolling degrees in the third cold rolling process, it was found that when the rolling degree of the third cold rolling process exceeds the above range, the tensile strength of the copper alloy material tends to decrease and does not reach 620 MPa. Also, it was found that even if the rolling degree of the third cold rolling process was too small exceeding the above range, it tends not to affect the conductivity of the copper alloy material. Also, it was found that when the rolling degree of the third cold rolling process was too large exceeding the above range, the conductivity of the copper alloy material tends to decrease. Also, it was found that the rolling degree of the third cold rolling process does not easily affect the bending workability and residual smut of the copper alloy material. Therefore, from the viewpoint of having no residual smut, having a tensile strength of 620 MPa or more, having a conductivity of 40.0% IACS or more, and having good bending workability, the third cold rolling process of producing the third cold-rolled material by cold rolling the second heat treated material at a rolling degree of 60% or more and 80% or less is effective in practical use.

<Influence of Heat-Retaining Condition of Third Heat Treatment Process>

[0118] Focusing on samples 1, 27, 28, and 29 of copper alloy materials shown in Table 10 (extracted from Table 1), the influence of the third heat treatment process will be explained. Samples 1, 27, 28, and 29 of copper alloy materials were made to have substantially equivalent thicknesses through substantially equivalent production processes except that the heat-retaining conditions of the third heat treatment process were different. Specifically, the heat-retaining conditions of the third heat treatment process were about 1 minute at 430°C for sample 1, which were within the range of 250°C or higher and 380°C or higher for 4 hours or less as defined in this invention. On the other hand, sample 27 is at a lower temperature of 200°C, and sample 28 is at a higher temperature of 400°C, so the retention time was the same as sample 1, but it was outside the above range. Also, sample 29 was for a longer time of about 5 hours, although the retention temperature was the same as sample 1, but the retention time was outside the above range.

[Table 10]

Sample number	1st Heat Treatment Process	2nd Cold Rolling Process	2nd Heat Treatment Process	3rd Cold Rolling Process	3rd Heat Treatment Process
	Heat-Retaining Condition	Rolling Degree (%)	Heat-Retaining Condition	Rolling Degree (%)	Heat-Retaining Condition
1	580°C, 3 min.	64	450°C, 4h	70	350°C, 1 min.
27	580°C, 3 min.	64	450°C, 4h	70	200°C, 1 min.
28	580°C, 3 min.	64	450°C, 4h	70	400°C, 1 min.
29	580°C, 3 min.	64	450°C, 4h	70	350°C, 5h

Table 10 continued

Sample Number	Characteristics of copper alloy materials etc.				Notes
	Tensile strength (MPa)	Electrical conductivity (% IACS)	Bendability	Presence or Absence of residual smut	
1	670	48.2	Good	Absent	Example
27	718	39.8	Poor	Absent	Comparative Example
28	603	48.2	Good	Absent	Comparative Example
29	614	49.6	Good	Absent	Comparative Example

[0119] As shown in Table 10, the tensile strength of sample 27 (718 MPa) which was outside the above range as low

temperature retention increased, but sample 28 (603 MPa) which was outside the above range as high temperature retention decreased to less than 620 MPa compared to sample 1 (670 MPa) with a tensile strength of 620 MPa or more. Also, the conductivity of sample 28 (48.2% IACS) which was outside the above range as high temperature retention was the same as that of sample 1 (48.2% IACS) with a conductivity of 40.0% IACS or more, but sample 27 (39.8% IACS) which was made outside the above range as low temperature retention decreased to less than 40.0% IACS. Also, the bending workability of samples 1, 28, and 29 were "Good", while that of sample 27 was "Poor". Also, the residual smut of samples 1, 27, 28, and 29 were all "absent".

[0120] By comparing the evaluation of samples 1, 28 of copper alloy materials with different heat-retaining temperatures of the third heat treatment process and samples 1, 29 of copper alloy materials, it was found that when the heat-retaining of the third heat treatment process is performed at high temperature or long time exceeding the above range, the tensile strength of the copper alloy material tends to decrease and does not reach 620 MPa. Also, by comparing the evaluation of samples 1, 27 of copper alloy materials, it was found that when the heat-retaining of the third heat treatment process is performed at low temperature, the tensile strength of the copper alloy material tends to increase. Also, by comparing the evaluation of samples 1, 27 of copper alloy materials with different heat-retaining temperatures of the third heat treatment process, it was found that when the heat-retaining of the third heat treatment process is performed at low temperature exceeding the above range, the conductivity of the copper alloy material tends to decrease and does not reach 40.0% IACS. Also, by comparing the evaluation of samples 1, 28 of copper alloy materials, it was found that when the heat-retaining of the third heat treatment process was performed at high temperature, the conductivity of the copper alloy material tends to increase. Also, by comparing the evaluation of samples 1, 27 of copper alloy materials, it was found that when the heat-retaining of the third heat treatment process is performed at low temperature exceeding the above range, the bending workability of the copper alloy material tends to deteriorate. Also, by comparing the evaluation of samples 1, 27, 28, and 29 of copper alloy materials, it was found that the heat-retaining conditions of the third heat treatment process do not easily affect the residual smut of the copper alloy material. Therefore, from the viewpoint of having no residual smut, having a tensile strength of 620 MPa or more, having a conductivity of 40.0% IACS or more, and having good bending workability, the third heat treatment process of producing the copper alloy material by heat-retaining at a temperature of 250°C or higher and 380°C or higher for 4 hours or less for the third cold-rolled material is effective in practical use.

<Influence of Mn>

[0121] In order to evaluate the influence of Mn, a copper alloy material (sample 1A) that does not intentionally contain Mn and a copper alloy material (samples 1B to 1F) that intentionally contains Mn were produced. Samples 1A to 1F of copper alloy materials were made to have substantially equivalent thicknesses through substantially equivalent production processes except that the Mn content of the finally obtained copper alloy material was different in the melting casting process. Then, for samples 1A to 1F of copper alloy materials, the tensile strength, conductivity, and bending workability at room temperature (about 20°C) were measured and confirmed, and the presence or absence of residual smut was confirmed in the same way as for sample 1 shown in Table 1. Also, as mentioned above, the elongation at break was measured in accordance with JIS-G0567:2020, which defines the high temperature tensile test method, under a high temperature environment of about 950°C.

[0122] Table 11 shows the composition (added elements), main manufacturing conditions, and mechanical properties of samples 1A to 1F (examples of the present invention) of copper alloy materials. Note that the remainder of samples 1A to 1F shown in Table 11, other than the added elements, may be interpreted as Cu and impurity elements, and impurity elements (Ag, Pb, Ni, and S, etc.) of less than 0.01% are omitted from the description.

[Table 11]

Sample number	Additive elements (mass%)					1st Heat Treatment Process	2nd Cold Rolling Process	2nd Heat Treatment Process	3rd Cold Rolling Process
	Fe	P	Zn	Sn	Mn	Heat-Retaining Condition	Degree of rolling (%)	Heat-Retaining Condition	Degree of rolling (%)
1A	2.20	0.02	0.12	0.60	< 0.001	580°C, 3 min.	64	450°C, 4h	70
1B	2.20	0.02	0.12	0.60	0.001	580°C, 3 min.	64	420°C, 4h	70
1C	2.20	0.02	0.12	0.60	0.002	580°C, 3 min.	64	420°C, 4h	70
1D	2.20	0.02	0.12	0.30	0.006	580°C, 3 min.	64	450°C, 4h	70
1E	2.20	0.02	0.12	0.60	0.010	550°C, 3 min.	73	420°C, 4h	60

(continued)

Sample number	Additive elements (mass%)					1st Heat Treatment Process	2nd Cold Rolling Process	2nd Heat Treatment Process	3rd Cold Rolling Process
	Fe	P	Zn	Sn	Mn	Heat-Retaining Condition	Degree of rolling (%)	Heat-Retaining Condition	Degree of rolling (%)
1F	2.20	0.02	0.12	0.60	0.020	550°C, 3 min.	46	450°C, 4h	80

Table 11 (continued)

Sample number	3rd heat treatment Process	Characteristics of copper alloy materials, etc.					Notes
	Heat-Retaining Condition	Tensile strength (MPa)	Electrical conductivity (% IACS)	Bendability	Presence or Absence of residual smut	Elongation at break (%)	
1A	350°C, 1 min.	658	47.2	Good	Absent	20.0	Example
1B	300°C, 1 min.	657	47.2	Good	Absent	19.8	Example
1C	280°C, 1 min.	658	46.8	Good	Absent	29.0	Example
1D	350°C, 1 min.	660	47.0	Good	Absent	31.4	Example
1E	350°C, 1 min.	663	46.7	Good	Absent	37.0	Example
1F	350°C, 1 min.	666	46.0	Good	Absent	32.0	Example

[0123] As shown in Table 11, the Mn content of sample 1A, which does not intentionally contain Mn, is less than 0.001%. Also, the Mn content of the copper alloy material that intentionally contains Mn is about 0.001% for sample 1B, about 0.002% for sample 1C, about 0.006% for sample 1D, about 0.010% for sample 1E, and about 0.020% for sample 1F. Therefore, the Mn content of samples 1C to 1F is within the range of Mn content (0.002% or more and 0.025% or less) mentioned above as a preferable copper alloy material in this invention.

[0124] Under normal temperature conditions (approximately 20°C), the tensile strength, conductivity, and bendability of samples 1A to 1F were evaluated, and the presence or absence of residual smut was assessed. As shown in Table 11, the tensile strength of all samples was above 620 MPa, within the range of 650 to 670 MPa. When the Mn content was 0.002% or less (samples 1A to 1C), the tensile strength was less than 660 MPa, and when the Mn content exceeded 0.002% (samples 1D to 1F), the tensile strength was 660 MPa or more. Therefore, the tensile strength is not significantly affected by the presence of Mn, and even with a Mn content of 0.002% to 0.025%, the tensile strength is likely to be above 620 MPa. The conductivity of samples 1A to 1F was also above 40% IACS, within the range of 46.0 to 47.2% IACS. Therefore, the conductivity is not significantly affected by the presence of Mn, and even with a Mn content of 0.002% to 0.025%, the conductivity is likely to be above 40% IACS. The bendability of samples 1A to 1F was rated as "Good". Therefore, the bendability is not significantly affected by the presence of Mn, and even with a Mn content of 0.002% to 0.025%, the bendability is likely to be "Good". The residual smut of samples 1A to 1F was rated as "absent". Therefore, the residual smut is not significantly affected by the presence of Mn, and even with a Mn content of 0.002% to 0.025%, the residual smut is likely to be "absent".

[0125] Also, under high temperature conditions (approximately 950°C), the elongation at break of samples 1A to 1F was evaluated. As shown in Table 11, the elongation at break of samples 1A to 1F was generally above 20%. Specifically, the elongation at break may be less than 20% when the Mn content is 0.001% or less (samples 1A, 1B), and it is definitely above 20% when the Mn content is 0.002% or more (samples 1C to 1F), and it was found to be 30% or more when the Mn content is 0.006% or more (samples 1D to 1F). Also, the elongation at break was found to be a maximum of 37.0% when the Mn content is 0.010% (sample 1E), and it decreased to 32.0% when the Mn content is 0.020% (sample 1F). Therefore, the elongation at break is easily affected by the content of Mn, and it is definitely more than 20% with a Mn content of 0.002% to 0.025%, and it is likely to be more than 30% with a Mn content of 0.005% to 0.020%.

[0126] As stated above, a copper alloy material containing Fe, P, Zn, and Sn within the above range is effective in practical use from the viewpoint of having no residual smut, having a tensile strength of 620 MPa or more and a conductivity of 40.0% IACS or more under normal temperature conditions (approximately 20°C), having good bendability, and having

an elongation at break of more than 20% under high temperature conditions (approximately 950°C).

[0127] Next, based on the measured Mn, Fe, P, Sn content shown in Table 11, an attempt was made to calculate the MI value. The MI value, as stated above, is a value obtained by (Mn content + total impurity element content) / (Fe content + P content + Sn content) x 100. The total content of Fe, P, and Sn is 2.82%. For example, when the total content of impurity elements is 0.001%, based on the measured values shown in Table 11, it can be confirmed that the MI value increases from 0.04 (sample 1A) to 0.74 (sample 1F) in proportion to the increase in Mn content from 0% (sample 1A) to 0.020% (sample 1F). However, in samples 1A to 1F, the content of some impurity elements is less than 0.01%, but it is not realistic to measure all impurity elements, and the exact value of the total content of impurity elements is unknown. Therefore, assuming the total content of impurity elements, an attempt was made to predict the relationship between Mn content, MI value, and elongation at break based on the measured values shown in Table 11.

[0128] Specifically, the total content of impurity elements was set to three conditions of 0.010% (low purity), 0.005% (normal purity), and 0.001% (high purity), which are considered practically reasonable, and a first model showing the relationship between Mn content (measured value) and MI value (conditional calculated value) based on the measured values shown in Table 11 was derived, and a second model showing the relationship between MI value (conditional calculated value) and elongation at break (measured value) was derived. Then, using the first model, the range of MI values corresponding to the range of Mn content was predicted, and using the second model, the range of elongation at break corresponding to the range of MI values was predicted. Using a general-purpose spreadsheet software (Microsoft Excel) considering practicality and ease of use, a graph (scatter plot) of Mn content (measured value) and MI value (conditional calculated value) is created, and a linear (first-order) approximation formula is obtained and used as a regression model in the first model.

[0129] In the first model, the Mn content (set value) is the independent variable x, and the MI value (predicted value) is the first dependent variable p. The prediction interval is $0.000 \leq x \leq 0.030$. Similarly, a graph (scatter plot) of MI value (conditional calculated value) and elongation at break (measured value) is created, and a polynomial (second-order) approximation formula is obtained and used as a regression model in the second model. In the second model, the MI value (predicted value) of the first dependent variable p of the first model is the independent variable, and the elongation at break (predicted value) is the second dependent variable y. The reliability of the first and second models was judged to be "reliable" unconditionally if the coefficient of determination (R^2) was 0.7 or more ($R^2 \geq 1$), referring to the concept of the field of machine learning.

[0130] Tables 12 to 13 show the predicted results of Mn content (set value), MI value (predicted value), and elongation at break (predicted value) when the total content of impurity elements is set to 0.010% (low purity), 0.005% (normal purity), and 0.001% (high purity) based on the measured values shown in Table 11. In addition, when S, which has a particularly large influence on rolling workability, is the main impurity element, it is considered that the S content of general manufacturing raw materials is about 0.001% to 0.005%, and from the viewpoint of easy measurement and high practicality, the total content of impurity elements can be selectively set from 0.001% to 0.005% for prediction. Also, when the main impurity elements are Ag, Pb, Ni, and S mentioned above, the total content of Ag, Pb, Ni, and S can be set as the total content of impurity elements for prediction.

[Table 12]

Elongation at break (predicted)									
Independent variables x	First model $p = Ax + B$			First dependent variable P	Second model $y = Cp^2+Dp+E$				Second dependent variable y
	Modulus A	Modulus B	R ²		Factor D	Factor E	Factor F	R ²	
0.000	35.344	0.3666	0.9895	0.37	-74.975	122.91	-13.896	0.8590	21.1
0.001				0.40					23.4
0.002				0.44					25.5
0.006				0.58					32.1
0.010				0.72					35.7
0.018				1.00					34.0
0.020				1.07					31.6
0.025				1.25					22.6
0.030				1.43					8.8
x: Mn content (%), p: MI value, y: elongation at break (%), and condition of total impurity content: 0.010%									

[0131] As shown in Table 12, when the total content of impurity elements is 0.010% (low purity) relative to the total content of Fe, P, and Sn (2.82%), the prediction results of the first model are, for example, $p = 0.37$ when $x = 0.000$, $p = 0.44$ when $x = 0.002$, $p = 1.00$ when $x = 0.018$, and $p = 1.25$ when $x = 0.025$. Then, the prediction results of the second model are, for example, $y = 21.1$ when $p = 0.37$, $y = 25.5$ when $p = 0.44$, $y = 34.0$ when $p = 1.00$, and $y = 22.6$ when $p = 1.25$. The R^2 of the first model (0.9895) and the R^2 of the second model (0.8590) are both sufficiently larger than the reliability criterion of 0.7. Therefore, the prediction results of the first and second models are considered to be less likely to be significantly affected by outliers, and can be judged as "reliable".

[0132] From this, it can be understood that even when x is 0.000, y is 20 or more. Also, it can be understood that when x increases larger than 0.018 and p increases larger than 1.00, y decreases smaller. Also, it can be understood that when y is at its maximum (35.7), p is 0.72 and x is 0.010. Therefore, if the Mn content is adjusted to be between 0.002% and 0.025%, the MI value is between 0.44 and 1.25, and an elongation at break of 25.5% to 22.6% (maximum 35.7%) can be obtained. Also, if the Mn content is adjusted to be between 0.010% and 0.018%, the MI value is between 0.72 and 1.00, and a larger elongation at break of 34.0% to 35.7% can be obtained. Therefore, when Mn is contained in a low-purity material, considering practicality and stability, the MI value should be adjusted to be, for example, 0.45 or more (preferably 0.50 or more) and 1.1 or less (preferably 1.0 or less, more preferably 0.9 or less).

[Table 13]

Elongation at break (predicted)									
Independent variable x	First model $p = Ax + B$			First dependent variable P	Second model $y = Cp^2+Dp+E$				Second dependent variable y
	Modulus A	Modulus B	R ²		Factor D	Factor E	Factor F	R ²	
0.000	35.38	0.1856	0.9950	0.19	-78.023	99.704	4.9447	0.8712	20.8
0.001				0.22					23.2
0.002				0.26					25.4
0.006				0.40					32.3
0.010				0.54					36.0
0.020				0.89					31.8
0.023				1.00					26.6
0.025				1.07					22.3
0.030				1.25					7.9
x: Mn content (%), p: MI value, y: elongation at break (%), and condition of total impurity content: 0.005%									

[0133] As shown in Table 13, when the total content of impurity elements is 0.005% (medium purity) relative to the total content of Fe, P, and Sn (2.82%), the prediction results of the first model are, for example, $p = 0.19$ when $x = 0.000$, $p = 0.26$ when $x = 0.002$, $p = 1.00$ when $x = 0.023$, and $p = 1.07$ when $x = 0.025$. Then, the prediction results of the second model are, for example, $y = 20.8$ when $p = 0.19$, $y = 25.4$ when $p = 0.26$, $y = 26.6$ when $p = 1.00$, and $y = 22.3$ when $p = 1.07$. The R^2 of the first model (0.9950) and the R^2 of the second model (0.8712) are both sufficiently larger than the reliability criterion of 0.7. Therefore, the prediction results of the first and second models are considered to be less likely to be significantly affected by outliers, and can be judged as "reliable".

[0134] From this, it can be understood that even when x is 0.000, y is 20 or more. Also, it can be understood that when x increases larger than 0.010 and p increases larger than 0.54, y decreases smaller. Also, it can be understood that when y is at its maximum (36.0), p is 0.54 and x is 0.010. Therefore, if the Mn content is adjusted to be between 0.002% and 0.025%, the MI value is between 0.26 and 1.07, and an elongation at break of 25.4% to 22.3% (maximum 36.0%) can be obtained. Also, if the Mn content is adjusted to be between 0.006% and 0.020%, the MI value is between 0.40 and 0.89, and a larger elongation at break of 31.8% to 36.0% can be obtained. Therefore, when Mn is contained in a medium-purity material, considering practicality and stability, the MI value should be adjusted to be, for example, 0.30 or more (preferably 0.35 or more) and 1.1 or less (preferably 1.0 or less, more preferably 0.9 or less).

[Table 14]

Elongation at break (predicted)											
5	Independent variable x	First model $p = Ax + B$			First dependent variable p	Second model $y = Cp^2 + Dp + E$				Second dependent variable y	
		Modulus A	Modulus B	R ²		Factor D	Factor E	Factor F	R ²		
10	0.000	35.41	0.0407	0.9980	0.04	-80.731	79.769	17.376	0.8808	20.5	
	(0.0003)									(0.05)	(21.2)
	0.001									0.08	23.0
	0.002									0.11	25.3
	0.006									0.25	32.4
15	0.010									0.39	36.3
	0.020									0.75	31.8
	0.025									0.93	22.0
	0.027									1.00	16.4
	20									0.030	1.10
x: Mn content (%), p: MI value, y: elongation at break (%), and condition of total impurity content: 0.001%											

[0135] As shown in Table 14, when the total content of impurity elements is 0.001% relative to the total content of Fe, P, and Sn (2.82%), the prediction results of the first model are, for example, $p = 0.04$ when $x = 0.000$, $p = 0.05$ when $x = 0.0003$, $p = 0.11$ when $x = 0.002$, $p = 0.93$ when $x = 0.025$, and $p = 1.00$ when $x = 0.027$. Then, the prediction results of the second model are, for example, $y = 20.5$ when $p = 0.04$, $y = 21.2$ when $p = 0.05$, $y = 25.3$ when $p = 0.11$, $y = 22.0$ when $p = 0.93$, and $y = 16.4$ when $p = 1.00$. The R^2 of the first model (0.9980) and the R^2 of the second model (0.8808) are both sufficiently larger than the reliability criterion of 0.7. Therefore, the prediction results of the first and second models are considered to be less likely to be significantly affected by outliers, and can be judged as "reliable".

[0136] From this, it can be understood that even when x is 0.000, y is 20 or more. Also, it can be understood that when x is 0.027 or more, y is less than 20. Also, it can be understood that when x is larger than 0.010 and p is larger than 0.39, y is smaller. Also, it can be understood that when y is at its maximum (36.3), p is 0.39 and x is 0.010. Therefore, if the Mn content is adjusted to be between 0.002% and 0.025%, the MI value is between 0.11 and 0.93, and an elongation at break of 25.3% to 22.0% (maximum 36.3%) can be obtained. Also, if the Mn content is adjusted to be between 0.006% and 0.020%, the MI value is between 0.25 and 0.75, and a larger elongation at break of 31.8% to 36.3% can be obtained. Therefore, when Mn is contained in a high-purity material, considering practicality and stability, the MI value may be adjusted to be, for example, 0.15 or more (preferably 0.20 or more) and 0.9 or less (preferably 0.85 or less, more preferably 0.80 or less).

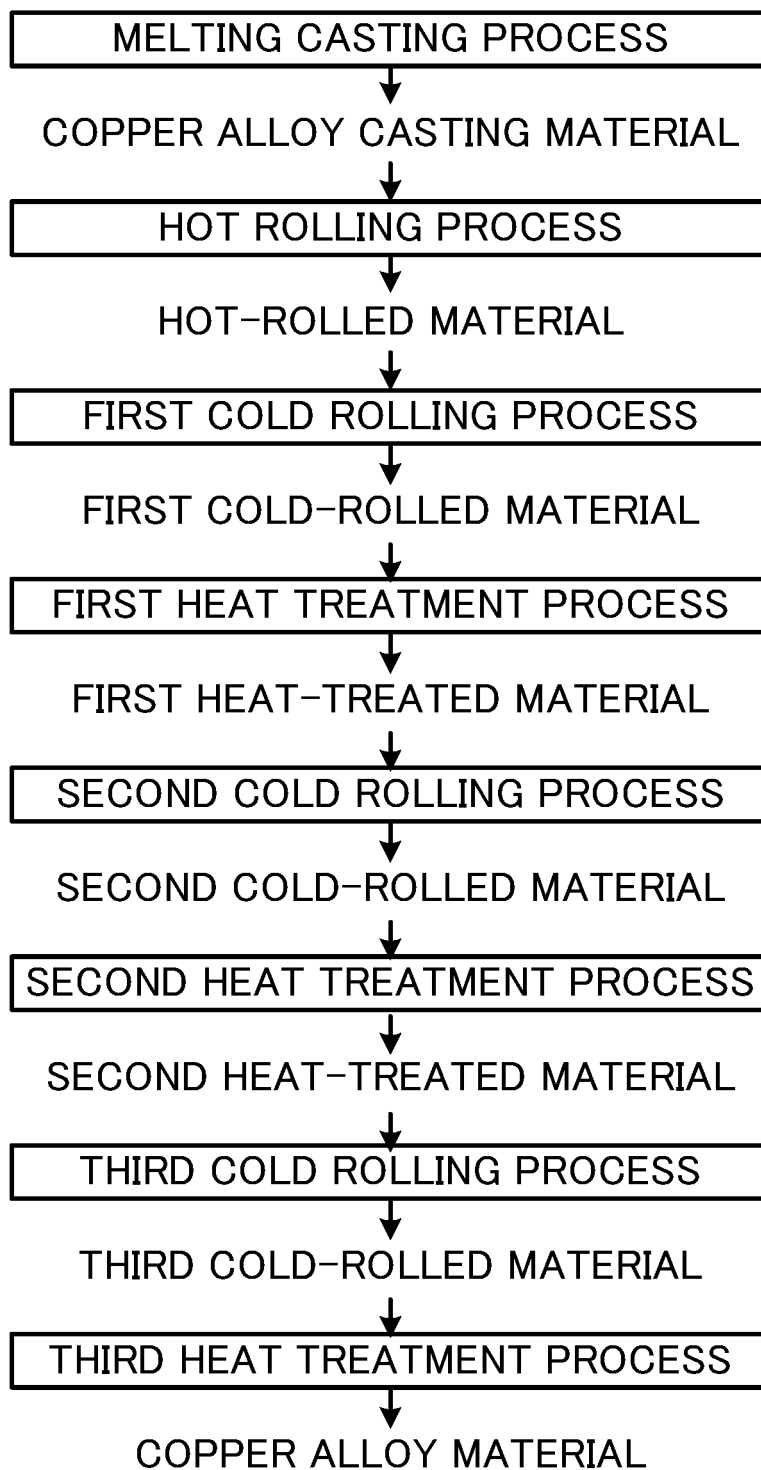
[0137] In conclusion, by controlling the content of the additive elements (Fe, P, Zn, and Sn) that constitute the copper alloy structure of the copper alloy material within a specific range, and controlling the manufacturing conditions of the first heat treatment process, the second cold rolling process, the second heat treatment process, the third cold rolling process, and the third heat treatment process in the manufacturing process of the copper alloy material shown in Figure 1 within a specific range, it was confirmed that a copper alloy material can be obtained that has no problem of residual smut like Cu-Fe-Zn-P copper alloys such as C1940, has a tensile strength and conductivity almost equivalent to Cu-Ni-Si copper alloys such as C7025. Also, by more appropriately controlling the content of the additive elements and the manufacturing conditions, it was confirmed that a copper alloy material with good bendability can be obtained. Also, by adding Mn along with the four types of additive elements and appropriately controlling the content of the four types of additive elements and Mn, it was confirmed that a copper alloy material with good elongation at break at high temperatures, good reliability, and particularly less likely to crack in the hot rolling stage can be obtained.

Claims

1. A copper alloy material having a tensile strength of 620 MPa or more and a conductivity of 40.0% IACS or more at a temperature environment of 20°C, containing, as essential elements, 1.6% to 2.6% of Fe, 0.01% to 0.3% of P, 0.01% to 0.3% of Zn, and 0.3% to 0.8% of Sn, in terms of mass %, with the balance being Cu and impurity elements.

2. The copper alloy material according to claim 1, containing 0.01% to 0.20% of P in terms of mass %.
3. A copper alloy material having an elongation at break exceeding 20% at a temperature environment of 950°C, containing, as essential elements, the Fe, P, Zn, Sn, and further, 0.002% to 0.025% of Mn, in terms of mass %, with the balance being Cu and impurity elements, according to claim 1 or 2.
4. The copper alloy material according to claim 3, wherein a value obtained by (Mn content + total content of impurity elements) / (Fe content + P content + Sn content) x 100, in terms of mass %, is 1.1 or less.
5. A method for producing a copper alloy material, comprising: a melting and casting process for producing a copper alloy casting material containing, as essential elements, 1.6% to 2.6% of Fe, 0.01% to 0.3% of P, 0.01% to 0.3% of Zn, and 0.3% to 0.8% of Sn, in terms of mass %, with the balance being Cu and impurity elements; a hot rolling process for producing a hot-rolled material using the copper alloy casting material; a first cold rolling process for producing a first cold-rolled material using the hot-rolled material; a first heat treatment process for producing a first heat-treated material by heat-retaining the first cold-rolled material at a temperature of 500°C to 600°C for 4 hours or less; a second cold rolling process for producing a second cold-rolled material by cold rolling the first heat-treated material with a rolling reduction of 20% to 90%; a second heat treatment process for producing a second heat-treated material by heat-retaining of the second cold-rolled material at a temperature of 380°C to 480°C for 1 to 12 hours; a third cold rolling process for producing a third cold-rolled material by cold rolling the second heat-treated material with a rolling reduction of 60% to 80%; and a third heat treatment process for producing a copper alloy material by heat-retaining of the third cold-rolled material at a temperature of 250°C to 380°C for 4 hours or less, wherein the melting and casting process, the hot rolling process, the first cold rolling process, the first heat treatment process, the second cold rolling process, the second heat treatment process, the third cold rolling process, and the third heat treatment process are performed in this order, to produce a copper alloy material having a tensile strength of 620 MPa or more and a conductivity of 40.0% IACS or more at a temperature environment of 20°C.
6. The method for producing a copper alloy material according to claim 5, containing 0.01% to 0.20% of P in terms of mass %.
7. A method for producing a copper alloy material having an elongation at break exceeding 20% at a temperature environment of 950°C, comprising a melting and casting process for producing a copper alloy casting material containing, as essential elements, the Fe, P, Zn, Sn, and further, 0.002% to 0.025% of Mn, in terms of mass %, with the balance being Cu and impurity elements, and then performing the hot rolling process, the first cold rolling process, the first heat treatment process, the second cold rolling process, the second heat treatment process, the third cold rolling process, and the third heat treatment process in this order, according to claim 5 or 6.
8. The method for producing a copper alloy material according to claim 7, wherein the melting and casting process for producing a copper alloy casting material is such that a value obtained by (Mn content + total content of impurity elements) / (Fe content + P content + Sn content) x 100, in terms of mass %, is 0.05 or more and 1.0 or less.

FIGURE



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/007544

A. CLASSIFICATION OF SUBJECT MATTER

C22C 9/00(2006.01)i; **C22F 1/00**(2006.01)i; **C22F 1/08**(2006.01)i

FI: C22C9/00; C22F1/08 B; C22F1/00 602; C22F1/00 630A; C22F1/00 630K; C22F1/00 661A; C22F1/00 683; C22F1/00 685; C22F1/00 691C; C22F1/00 691B; C22F1/00 694A; C22F1/00 686A

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C9/00; C22F1/00; C22F1/08

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

Published examined utility model applications of Japan 1922-1996

Published unexamined utility model applications of Japan 1971-2023

Registered utility model specifications of Japan 1996-2023

Published registered utility model applications of Japan 1994-2023

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2019-173090 A (MITSUBISHI MATERIALS CORP) 10 October 2019 (2019-10-10)	1-8
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A	JP 2010-229438 A (DOWA METALTECH KK) 14 October 2010 (2010-10-14)	1-8
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A	CN 1940104 A (SUZHOU NONFERROUS METAL PROCESS INST.) 04 April 2007 (2007-04-04)	1-8

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

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"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 09 May 2023	Date of mailing of the international search report 23 May 2023
Name and mailing address of the ISA/JP Japan Patent Office (ISA/JP) 3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915 Japan	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/007544

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JP	2010-229438	A	14 October 2010	(Family: none)	
JP	2015-17286	A	29 January 2015	(Family: none)	
JP	9-296237	A	18 November 1997	(Family: none)	
CN	1932056	A	21 March 2007	(Family: none)	
CN	1940104	A	04 April 2007	(Family: none)	

REFERENCES CITED IN THE DESCRIPTION

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