(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 228 147 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
15.09.2010 Bulletin 2010/37

(21) Application number: **08866559.1**

(22) Date of filing: **21.11.2008**

(51) Int Cl.:
B21B 27/02 *(2006.01)* ***B21B 27/00*** *(2006.01)*

(86) International application number:
PCT/JP2008/003428

(87) International publication number:
WO 2009/084148 (09.07.2009 Gazette 2009/28)

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MT NL NO PL PT RO SE SI SK TR
Designated Extension States:
AL BA MK RS

(30) Priority: **28.12.2007 JP 2007339157**

(71) Applicant: **Panasonic Corporation**
Kadoma-shi
Osaka 571-8501 (JP)

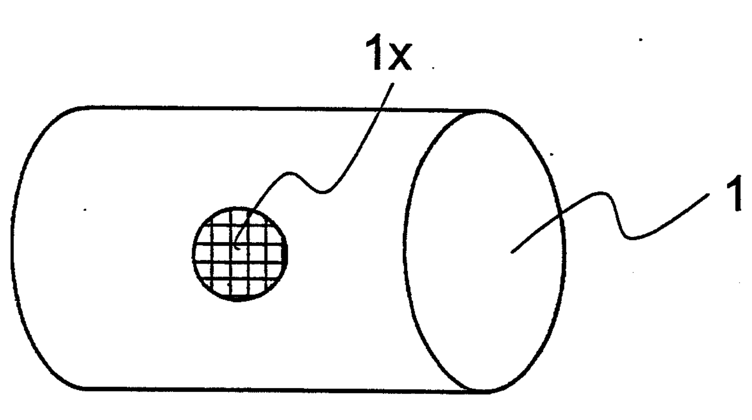
(72) Inventors:
- **KOGETSU, Yasutaka**
  Osaka-shi, Osaka 540-6207 (JP)
- **NISHIMURA, Takuhiro**
  Osaka-shi, Osaka 540-6207 (JP)
- **TAKANO, Hiroaki**
  Tokyo 101-8971 (JP)
- **YOKOMIZO, Kenji**
  Tokyo 101-8971 (JP)

(74) Representative: **TBK-Patent**
Bavariaring 4-6
80336 München (DE)

(54) **ROLLER FOR MACHINING METAL FOIL**

(57) A metal foil machining roller of the present invention is a metal foil machining roller in which a plurality of recessed portions are formed on a circumferential surface of the roller, wherein at least a surface layer portion contains a metal material with a Rockwell hardness in A scale of HRA 81.2 to 90.0 and a transverse rupture strength of 3 GPa to 6 GPa. By pressure-molding a metal foil by using the metal foil machining roller, protrusion portions of an approximately uniform shape with dimensions of several microns to several tens of microns can be formed efficiently on a surface of the metal foil on an industrial scale.

FIG. 3



EP 2 228 147 A1

Description

Technical Field

[0001] The present invention relates to a metal foil machining roller. More specifically, the present invention mainly relates to an improvement in a metal material that constitutes a metal foil machining roller in which a plurality of recessed portions are formed in a surface thereof.

Background Art

[0002] Conventionally, a plating method, an etching method and the like are generally utilized to form protrusion portions on the surface of a metal foil with a thickness of several tens of microns. However, in the case of forming several tens to several hundreds of micron-sized protrusion portions per $1cm^2$ of a metal foil surface by such a method, precision machining that involves a large number of steps is performed, which requires complicated operations and a long time, yet a sufficiently low defect rate cannot be achieved. Treatment of wastewater generated through the use of a plating solution, an etching solution and the like is also a problem. In addition, protrusion portions that are formed by such a method do not have sufficient bonding strength with a metal foil, so they often separate from the metal foil when external stress is applied. Accordingly, it cannot be said that the plating method, the etching method and the like are industrially advantageous in manufacturing a metal foil that has protrusion portions on the surface thereof.

[0003] Atechnique of pressure-molding a plate-shaped metal material by allowing the plate-shaped metal material to pass through a press-contact nip portion that is formed by a pair of rollers that are pressed into contact with each other is widely used. A typical example of a pressure-molding technique could be the cold-drawing of a steel material, for example.

A dull roller in which, for example, a crater-like recessed portion and a raised portion that is raised along the periphery of the crater-like recessed portion are formed on the surface of the dull roller has been proposed (see, for example, Patent Document 1). Dull rollers are used to form what are called dull marks on the surface of a cold-drawn steel plate between a cold-drawing step and an annealing step. By doing so, seizure of the steel plate is prevented in the case of the annealing step being batch annealing. In the case of the annealing step being continuous annealing, a steel plate is prevented from meandering when the steel plate is delivered into an annealing furnace.

[0004] Patent Document 1 also describes that the raised portion formed on the dull roller surface is firmly pressed against the steel plate surface, causing a plastic flow of the steel plate material locally on the steel plate surface, as a result of which the steel plate material flows into the recessed portion of the dull roller, roughening the steel plate. Patent Document 1 further describes that a dull roller is manufactured by directing a laser pulse onto a roller with a smooth surface while rotating the roller so as to melt the roller surface at a regular interval to form crater-like recessed portions at a regular interval.

[0005] However, Patent Document 1 merely discloses a technique of making the surface of a several hundreds of μm to several mm thick cold-drawn steel plate more rough, and it contains no disclosure of the formation of protrusion portions on the surface of a metal foil with a thickness of only several tens of μm. Moreover, Patent Document 1 does not describe a specific material for the dull roller, so the dull roller is considered to be made of a commonly used material. Such a commonly used material can be, for example, a steel material that is harder than a steel plate to be cold drawn. With a dull roller made of such a material, crater-like recessed portions formed on the surface are easily worn out or the like and disappear. Accordingly, it cannot be utilized for industrial scale formation of protrusion portions. In addition, when a dull roller is manufactured by subjecting a roller made of such a material to laser machining, recessed portions that have a desired opening shape cannot be formed. For example, when an attempt is made to form recessed portions with a rhombic opening shape, the opening periphery of the recessed portions melt due to the residual heat of the laser, resulting in an elliptic shape.

[0006] Also, a drawing roller in which recesses and protrusions are formed on the surface of the roller, the recessed portions have a depth of 5 to 100 μm, and the ratio of the total tip surface area of protrusion portions with respect to the total surface area is 10 to 80% has been proposed (see, for example, Patent Document 2). However, the technique of Patent Document 2 is also a technique of forming dull marks on the surface of a several hundreds of μm to several mm thick cold-draw steel plate, and is not a technique of forming projecting protrusion portions on the surface of a several tens of μm thick metal foil. Patent Document 2 also does not describe a specific material for the drawing roller, so, as is the case with the dull roller of Patent Document 1, the drawing roller of Patent Document 2 cannot be utilized for industrial scale formation of protrusion portions, and it is not possible to form recessed portions of a desired opening shape with the drawing roller.

[0007] Also, a drawing apparatus that indudes a first work roller in which a plurality of annular recessed portions (annular grooves for forming protrusions) that extend along a circumferential direction are formed and a second work roller with a smooth circumferential surface has been proposed (see, for example, Patent Document 3). In the drawing apparatus of Patent Document 3, the first work roller and the second work roller are pressed into contact such that their axes are parallel to each other, so as to form a press-contact nip portion. When a long plate-shaped metal material is allowed to pass through the press-contact nip portion, a plurality of projections are formed on one surface of the plate-shaped material in a thickness direction, and a metal plate for manufacturing a flat tube is obtained. By bending the metal plate for manufacturing a flat tube, a flat tube is obtained. Such a flat tube is used as a coolant flow tube for a capacitor.

[0008] Patent Document 3 proposes a cemented carbide as a material for the first work roller, and also discloses cemented carbides such as JIS V10 to V60. However, the technique of Patent Document 3 is not intended to machine a metal foil with a thickness of several tens of μm. Patent Document 3 discloses only engraving as a specific example of a method of forming annular recessed portions, and it contains no disclosure of laser machining. It is very difficult to form a plurality of micron-sized recessed portions at an interval of about 10 to 50 μm by engraving. Even when a plurality of miaon-sized recessed portions are formed in a cemented carbide by laser machining, recessed portions with openings of a uniform shape and diameter are not necessarily obtained. In Patent Document 3, a cemented carbide is used only for the purpose of preventing the bottom faces of annular recessed portions from wearing out

[0009] Meanwhile, conventionally a technique of boring a hole in an electronic component such as a ceramic green sheet, circuit board or the like by laser machining is well known (see, for example, Patent Document 4). That is, laser machining is often utilized to form recessed portions in the surface of a ceramic layer, resin layer or the like. However, there has been no proposal or report of a technical conception in which a large number of micron-sized recessed portions, namely, several hundreds to several tens of millions of recessed portions are formed on a metal surface by laser machining. Moreover, when a large number of such recessed portions are formed on the surface of a commonly used metal such as stainless steel, the opening shape and opening diameter of the recessed portions formed on the metal surface will be non-uniform. Also, a problem arises in that the formed recessed portions will have reduced mechanical strength, wear resistance and the like, as a result of which wear, deformation, breakage and the like will likely occur.

[0010] Furthermore, a technique is commonly performed in which a resin sheet is pressure-molded by using a ceramic roller in which a plurality of recessed portions are formed on the circumferential surface so as to emboss the surface of the resin sheet. However, when a metal foil is pressure-molded by using a ceramic roller in which recessed portions are formed on the circumferential surface, a large number of cracks, chips, fractures and the like occur in the circumferential surface of the ceramic roller, so it is not possible to continuously pressure-mold such a metal foil.

[Patent Document 1] Japanese Laid-Open Patent Publication No. S63-10013

[Patent Document 2] Japanese Laid-Open Patent Publication No. H10-166010

[Patent Document 3] Japanese Laid-Open Patent Publication No. 2005-997

[Patent Document 4] Japanese Laid-Open Patent Publication No. 2005-111524

Disclosure of the Invention

Problem to be Solved by the Invention

[0011] It is an object of the present invention to provide a metal foil machining roller in which a plurality of recessed portions are formed on a circumferential surface, wherein the recessed portions are unlikely to wear out, deform or the like, and it is possible to efficiently manufacture a metal foil that has protrusion portions even when metal foil machining is performed on an industrial scale.

Means for Solving the Problem

[0012] The present inventors conducted in-depth studies to solve the above problems, and found during the course of the studies that two properties, namely, Rockwell hardness and transverse rupture strength, among the various properties of metal materials significantly affect the opening shape and opening diameter of recessed portions during laser machining.

The present inventors conducted further studies based on this finding. As a result, they found that by forming micron-sized recessed portions in the surface of a roller made of a metal material that has a specific Rockwell hardness and transverse rupture strength, even though the number of recessed portions is large (several hundreds to several tens of millions of recessed portions), it is possible to form approximately uniform recessed portions in which non-uniformity in the opening shape and opening diameter is very small. They also found that the recessed portions have a high level of durability against external stress, such as a fictional force, and are unlikely to undergo wear, deformation, breakage and the like. With this background, the present invention has been accomplished.

[0013] That is, the present invention relates to a metal foil machining roller in which a plurality of recessed portions are formed on a circumferential surface by laser machining, wherein at least a surface layer portion in which the recessed portions are formed indudes a metal material that has a Rockwell hardness in A scale of HRA 81.2 to 90.0 and a transverse rupture strength of 3 GPa to 6 GPa.

[0014] It is preferable that a aoss-sectional shape of the recessed portions in a direction vertical to the circumferential surface of the metal foil machining roller is a taper shape in which a cross-sectional width becomes gradually or continuously smaller from the circumferential surface of the metal foil machining roller toward a bottom face of the recessed portions.

It is preferable that an opening shape of the recessed portions in the circumferential surface of the metal foil machining roller is an approximately circular shape, an approximately elliptic shape, an approximately rhombic shape or an approximately regular polygonal shape.

It is preferable that an opening diameter of the recessed portions in the circumferential surface of the metal foil machining roller is 1 μm to 35 μm.

It is preferable that a pitch of the recessed portions in a direction of an axis of the metal foil machining roller in the circumferential surface of the metal foil machining roller is 4 μm or more.

[0015] It is preferable that the metal material has a Rockwell hardness in A scale of HRA 83.9 to 89.

It is preferable that the metal material has a transverse rupture strength of 3.3 GPa to 5.5 Gpa.

It is preferable that the metal material contains at least one high melting point metal material selected from the group consisting of a cemented carbide, a cermet, a high speed steel, a die steel and a forged steel.

It is preferable that the metal foil machining roller is used such that the bottom face of the recessed portions and a surface of a metal foil do not come into contact.

Effect of the Invention

[0016] In a metal foil machining roller according to the present invention, a plurality of recessed portions are formed on the circumferential surface thereof by laser machining. In the metal foil machining roller of the present invention, a metal material that has a Rockwell hardness and a transverse rupture strength within the above ranges is contained in at least a surface layer portion in which recessed portions are formed, whereby it is possible to form openings of approximately uniform opening shape and opening diameter in the circumferential surface of the roller. It is also possible to adjust the opening shape and opening diameter to an arbitrary shape and diameter. For example, recessed portions with an opening diameter of several microns to several tens of microns can be formed. Also, recessed portions with an opening shape such as an approximately perfect circle, an approximately rhombic shape or an approximately regular polygonal shape can be formed. It is also possible to form such recessed portions at a pitch of about 10 to 50 μm.

The recessed portions have a very high level of durability against external stress, and superior releasability with protrusion portions of a metal foil that are formed in the inner spaces of the recessed portions. Accordingly, even when a metal foil is continuously machined on an industrial scale, it is possible to stably and efficiently form protrusion portions of approximately the same shape that are unlikely to wear out, deform or the like.

Brief Description of the several views of the Drawing

[0017]

Fig. 1 is a side view schematically showing a configuration of a metal foil machining apparatus.

Fig. 2 is an enlarged perspective view showing a configuration of a relevant part of the metal foil machining apparatus shown in Fig.1.

Fig. 3 is a perspective view showing an external appearance of a metal foil machining roller.

Fig. 4 is an enlarged perspective view of a surface region of the metal foil machining roller shown in Fig. 3.

Best Mode for Carrying Out the invention

[0018] A metal foil machining roller of the present invention is used to, for example, pressure-mold a metal foil so as to obtain a metal foil that has protrusion portions on either or both surfaces in a thickness direction (hereinafter referred to as a metal foil with protrusion portions). Specifically, a mold-machining apparatus that indudes a metal foil machining roller of the present invention and a metal roller with a smooth surface is used. The metal foil machining roller and the metal roller are pressed into contact with each other such that their axes are parallel to each other, whereby a press-contact nip portion is formed. By feeding a metal foil and allowing the metal foil to pass through the press-contact nip portion such that a surface on which protrusion portions are to be formed comes into contact with the circumferential surface of the metal foil machining roller, a metal foil that has protrusion portions on one surface thereof can be obtained. Alternatively, by allowing two metal foil machining rollers to be pressed into contact with each other for use, a metal foil that has protrusion portions on both surfaces thereof can be obtained.

[0019] Examples of metal foils that can be pressure-molded by the metal foil machining roller of the present invention include, but are not particularly limited to, a copper foil, a copper alloy foil, a tin foil, a stainless steel foil, an aluminum foil, an aluminum alloy foil, a lead foil, a nickel foil, a zinc foil, and so on. It is preferable that the metal foils that can be pressure-molded by the metal foil machining roller of the present invention have properties such as an easily deformable grain boundary and a low annealing temperature. The thickness of the metal foil is preferably, but not particularly limited to, 10 to 100 μm, and more preferably 10 to 50 μm.

[0020] A metal foil with protrusion portions formed of a copper foil, a copper alloy foil or the like through the use of the metal foil machining roller of the present invention can be preferably used as, for example, a negative electrode current collector for a lithium secondary battery. In the surfaces of the individual protrusion portions of the metal foil with protrusion portions formed of a copper foil, a copper alloy foil or the like, columns that contain a negative electrode active material and function as a negative electrode active material layer are formed by vacuum deposition. As the negative electrode active material, for example, silicon, silicon oxide, a silicon-containing alloy, a silicon compound, tin, tin oxide, a tin-containing alloy, a tin compound or the like can be used.

By forming a negative electrode active material layer consisting of such columns on the protrusion portion surface, stress that is generated by expansion and contraction of the negative electrode active material when absorbing and desorbing lithium ions is absorbed, as a result of which not only deformation of the negative electrode current collector, but also deformation of the negative electrode, as well as separation of the negative electrode active material layer from the negative electrode current collector, and the like are prevented. As a consequence, it is possible to obtain a lithium ion secondary battery that has superior charge/discharge cycle properties, long-term safety and the like and that is capable of providing high power output

The metal foil with protrusion portions obtained by the present invention can also be preferably used as, for example, a metal foil or metal layer for use in a flexible printed circuit board, a metal substrate for a lead frame or the like.

[0021] The metal foil machining roller of the present invention has two features. The first feature is that a plurality of recessed portions are formed on the circumferential surface of the metal foil machining roller. The second feature is that at least a surface layer portion in which recessed portions are formed contains a metal material that has specific properties.

The recessed portions are spatial regions that have an opening in the circumferential surface (hereinafter referred to simply as "roller circumferential surface") of the metal foil machining roller of the present invention and that are recessed or dented inwardly from the roller circumferential surface. The bottom face of the recessed portions may be approximately a flat plane, or may have a dome-like shape, or the like.

[0022] Normally, individual recessed portions are formed independently of each other such that adjacent recessed portions are not connected to each other. However, the present invention is not limited to this configuration, and the recessed portions may be partially connected into a single piece, or entirely connected into a single piece. Preferably, individual recessed portions are formed independently of each other so as not to be connected to each other.

The opening shape of the recessed portions in the roller circumferential surface can be, but is not particularly limited to, an approximately circular shape, an approximately elliptic shape, an approximately rhombic shape, an approximately regular polygonal shape or the like. Preferred regular polygonal shapes are a triangle, a quadrangle, a pentagon, a hexagon, a heptagon, and an octagon, and a quadrangle and a hexagon are more preferable. As used herein, "approximately circular shape" encompasses a circular shape and a shape dose to the circular shape. The same applies to other shapes.

[0023] The opening diameter of the recessed portions in the roller circumferential surface is preferably, but is not particularly limited to, 1 μm to 35 μm, and more preferably 2 to 30 μm. When the opening diameter is less than 1 μm, it is difficult to obtain recessed portions with an approximately uniform opening diameter. An opening diameter exceeding 35 μm is inappropriate for surface machining of a metal foil with a thickness of about several tens of μm. In addition, the recessed portions may be worn out, deformed or the like by the stress applied when pressure-molding a metal foil. When the opening shape is an approximately circular shape, an approximately elliptic shape or an approximately regular polygonal shape, the opening diameter is the length of the diameter of the smallest perfect circle that encloses the circular shape, the elliptic shape or the regular polygonal shape. When the opening shape is an approximately rhombic shape, the opening diameter is the length of a longer diagonal line of the diagonal lines of the rhombic shape.

[0024] There is no particular limitation on the depth of the recessed portions. The depth can be selected as appropriate according to, for example, the height of protrusion portions to be formed on a metal foil surface, or the like, but it is preferable that the depth is 0.2 to 1.5 times the opening diameter, and more preferably, 0.3 to 1.2 times the opening diameter. With recessed portions with a depth of less than 0.2 times the opening diameter, protrusion portions of a uniform size and shape may not be formed on a metal foil surface. On the other hand, it is extremely difficult to form recessed portions with a depth exceeding 1.5 times the opening diameter by a laser machining method. With a cutting method, it takes a considerable amount of time to form recessed portions, or it is substantially impossible to form recessed portions. As used herein, the depth of recessed portions refers to the length of a vertical line that extends from the deepest point of the bottom face of the recessed portions to an imaginary roller circumferential surface assumed to exist on the opening of the recessed portions.

[0025] In the roller circumferential surface, the pitch at which recessed portions are formed is not particularly limited both in a direction (longitudinal direction) of the axis of the roller and in a direction of the circumference. The pitch of recessed portions in the axial direction can be selected as appropriate according to the opening diameter and opening shape of recessed portions, the roller length, the design values of a metal foil with protrusion portions to be obtained, and so on. The pitch is preferably 4 μm or more, more preferably 8 to 30 μm, and particularly preferably 15 to 30 μm. When the pitch of recessed portions in the axial direction is less than 4 μm, recessed portions are likely connected to each other when formed by a laser machining method. Accordingly, the area between adjacent recessed portions in the roller surface will be extremely small. As a result, the dividing portion between adjacent recessed portions may be deformed by the stress applied when pressure-molding a metal foil. The upper limit value for the pitch in the axial direction can be selected as appropriate according to the roller length or the like.

[0026] Likewise, the pitch of recessed portions in the circumferential direction can be selected as appropriate according to the opening diameter and opening shape of recessed portions, the length of the circumference of the roller, the design values of a metal foil with protrusion portions to be obtained, and so on. The pitch is preferably 4 μm or more, and more preferably 5 to 20 μm. When the pitch of recessed portions in the circumferential direction is less than 4 μm, recessed portions are likely to be connected to each other when formed by a laser machining method. Accordingly, the area that divides adjacent recessed portions in the roller surface will be extremely small, as a result of which the partition between adjacent recessed portions may be deformed by the stress applied when pressure-molding a metal foil. The upper limit value for the pitch in the circumferential direction can be selected as appropriate according to the length of the circumference of the roller or the like.

[0027] In this specification, the pitch in the axial direction (longitudinal direction) is the distance (length) between two parallel lines that pass through the centers of two adjacent recessed portions in the axial direction and extend in the circumferential direction. The pitch in the circumferential direction is the distance (length) between two parallel lines that pass through the centers of two adjacent recessed portions in the circumferential direction and extend in the axial direction. The center of a recessed portion means the center of the opening of the recessed portion. The center of the opening means, when the opening shape of the recessed portion is an approximately circular shape, an approximately elliptic shape or an approximately regular polygonal shape, the center of the smallest perfect drde that encloses the circular shape, the elliptic shape or the regular polygonal shape. When the opening shape of the recessed portion is an approximately rhombic shape, the center of the opening means the point at which two diagonal lines intersect.

[0028] It is preferable that the cross-sectional shape of recessed portions in a direction vertical to the circumferential surface of the roller is a taper shape in which the cross-sectional width becomes gradually or continuously smaller from the roller circumferential surface toward the bottom face of the recessed portions. With such recessed portions with a taper-shaped cross section, when forming protrusion portions on a surface of a metal foil by pressure-molding the metal foil, the releasability between the recessed portions in the roller circumferential surface and the protrusion portions of the metal foil is improved significantly, as a result of which it is very unlikely that defects, such as the deformation of protrusion portions, occur.

Recess portions are formed by laser machining, and the laser machining will be described later in detail.

[0029] In the metal foil machining roller of the present invention, at least a surface layer portion in which recessed portions are formed contains a specific metal material. The metal material has a Rockwell hardness in A scale of HRA 812 to 90.0, preferably HRA 83.9 to 89.0, and a transverse rupture strength of 3 GPa to 6 GPa, preferably 3.3 GPa to 5.5 GPa.

[0030] When the Rockwell hardness in A scale is less than HRA 81.2, the roller can be flattened or bent in the axial direction when pressure-molding a metal foil, failing to apply enough pressure to the metal foil, and resulting in insufficient formation of protrusion portions or resulting in protrusion portions with a reduced height, or it may not be possible to form uniform protrusion portions with a size and shape approximately dose to the design values. Accordingly, it may not be possible to obtain a desired metal foil with protrusion portions. In addition, due to wearing out of the surface of the metal foil machining roller, the recessed portions are easily worn out, deformed or the like. On the other hand, when the Rockwell hardness in A scale exceeds HRA 90.0, fractures, chips, cracks and the like are likely to occur in the recessed portions of the metal foil machining roller, which may result in insufficient pressure-molding of a metal foil, such as deformed protrusion portions being formed, or protrusion portions being formed at an unwanted position.

[0031] In this specification, Rockwell hardness (HRA) is specifically a value calculated from the following equation based on JIS Z-2245:

$$HRA = 100-0.5h$$

where h represents a difference h in penetration depth of a diamond penetrator.

The difference h in penetration depth of a diamond penetrator is determined as follows. With the use of a diamond penetrator that has a tip with a radius of curvature of 0.2 mm and a conical angle of 120°, an initial load of 98.07 N is applied to the surface of a sample. Then, a test load of 588.4 N is applied, and the initial load is again applied. The depth to which the diamond penetrator has penetrated is measured twice, that is, at the time of the first application of the initial load and the second application of the initial load. The difference between these measured values is defined as the difference h in penetration depth of a diamond penetrator.

[0032] When the transverse rupture strength is less than 3 GPa, fractures, chips, cracks and the like are likely to occur in the recessed portions of the metal foil machining roller, which may result in insufficient pressure-molding of a metal foil, such as deformed protrusion portions being formed, or protrusion portions being formed at an unwanted position. Accordingly, there is a possibility that the metal foil machining roller may not withstand long-term use and insufficient formation of protrusion portions may occur even during the initial period of use and the defect rate increases. On the other hand, when the transverse rupture strength exceeds 6 GPa, the roller can be flattened or bent in the axial direction when pressure-molding a metal foil, failing to apply enough pressure to the metal foil, and resulting in insufficient formation of protrusion portions or resulting in protrusion portions with a reduced height, or it may not be possible to form uniform protrusion portions with a size and shape approximately dose to the design values. In addition, the wear resistance of the surface of the metal foil machining roller is reduced, as a result of which wear, deformation and the like are likely to occur in the recessed portions. Furthermore, the releasability between the metal foil machining roller and a mold-machined metal foil is reduced, which may cause defects, such as the metal foil being caught in the metal foil machining roller.

[0033] In this specification, the transverse rupture strength is specifically a value measured in the following manner based on JIS Z-2248. As a test piece, a round bar with a diameter D of 13 mm and a length of 300 mm is used. Transverse rupture strength measurement testing is carried out as a three-point bending test by using a universal testing machine and a bend testing apparatus attached to the universal testing machine and by setting a distance between supporting points L to 200 mm. Where a load when the test piece ruptures is set to a maximum load W_{max}, transverse rupture strength σ_b can be calculated from the following equation:

$$\sigma_b = 8W_{max}L/\pi D^3$$

[0034] In the present invention, it is preferable to use, as a metal material that has a Rockwell hardness and a transverse rupture strength within the prescribed value ranges given above, at least one high melting point metal material selected from the group consisting of a cemented carbide, a cermet, a high speed steel, a die steel and a forged steel. Among them, it is more preferable to use a cemented carbide, a high speed steel, a forged steel or the like, and a forged steel is particularly preferable. Metal materials that belong to such high melting point metal materials and that have a prescribed Rockwell hardness and transverse rupture strength are capable of undergoing laser machining, and have very superior shape- and size-reproducibility. In addition, even when metal foil mold-machining with which recessed portions are formed in such a metal material by laser machining is repeatedly carried out, it is very unlikely that the recessed portions undergo wear, deformation, breakage or the like, so the level of long-term endurance is high. The metal foil machining roller may contain one or more metal materials.

[0035] As the cemented carbide, any known cemented carbide can be used and, specifically, for example, cemented carbides obtained by sintering particles of carbide of a metal that belongs to Group IVA, Group VA and Group VIA in the periodic table with a metal binder such as Fe, Co or Ni can be used. Specific examples of such cemented carbides include tungsten carbide-based cemented carbides such as a WC-Co-based alloy, a WC-Cr_3C_2-Co-based alloy, a WC-TaC-Co-based alloy, a WC-TiC-Co-based alloy, a WGNbC-Co-based alloy, a WC-TaC-NbC-Co-based alloy, a WC-TiC-TaC-NbC-Co-based alloy, a WC-TiC-TaC-Co-based alloy a WC-ZrC-Co-based alloy, a WC-TiC-ZrC-Co-based alloy, a WC-TaC-VC-Co-based alloy, a WC-TiC-Cr_3C_2-Co-based alloy, a WC-TiC-TaC-based alloy, a WC-Ni-based alloy, a WC-Co-Ni-based alloy, a WC-Cr_3C_2-Mo_2G-Ni-based alloy, a WC-Ti (C,N)-TaC-based alloy, a WC-Ti(C, N)-based alloy; a Cr_3C_2-Ni-based alloy; and so on.

[0036] As the cermet, any known cermet can be used and, specific examples include a TiC-Ni-based material, a TiC-Mo-Ni-based material, a TiC-Co-based material, a TiC-Mo_2C-Ni-based material, a TiC-Mo_2C-ZrC-Ni-based material, a TiC-Mo_2C-Co-based material, a Mo_2C-Ni-based material, a Ti(C,N)-Mo_2C-Ni-based material, a TiC-TiN-Mo_2C-Ni-based material, a TiC-TiN-Mo_2C-Co-based material, a TiC-TiN-Mo_2C-TaC-Ni-based material, a TiC-TiN-Mo_2C-WC-TaC-Ni-based material, a TiC-WC-Ni-based material, a Ti(C,N)-WC-Ni-based material, a TiC-Mo-based material, a Ti(C,N)-Mo-based material, boride-based materials (a MoB-Ni-based material, a $B_4C/(W,Mo)B_2$-based material, etc.), and so on. Among them, titanium carbonitride-based cermits, such as a Ti (C,N)-Mo_2C-Ni-based material, a TiC-TiN-Mo_2GNi-based material, a TiC-TiN-Mo_2C-Co-based material, a TiC-TiN-Mo_2C-TaC-Ni-based material, a TiC-TiN-Mo_2C-WC-TaC-Ni-based material, a Ti(C,N)-WC-Ni-based material and a Ti(C,N)-Mo-based material, are preferable.

[0037] High speed steel is a material with increased hardness achieved by adding a metal such as molybdenum, tungsten or vanadium to iron, and subjecting it to a heat treatment. As the high speed steel, any known high speed steel can be used. Examples include: a high speed steel composed primarily of iron, and containing carbon, tungsten, vanadium, molybdenum and chromium; a high speed steel composed primarily of iron, and containing carbon, tungsten, vanadium, molybdenum, cobalt and chromium; a high speed steel composed primarily of iron, and containing carbon, vanadium, molybdenum and chromium; a high speed steel composed primarily of iron, and containing silicon, manganese, chromium, molybdenum and vanadium; a high speed steel composed primarily of iron, and containing carbon, silicon, manganese, chromium, molybdenum and vanadium; a high speed steel composed primarily of iron, and containing carbon, silicon, manganese, chromium, molybdenum, tungsten, cobalt and vanadium; and so on.

[0038] As a die steel, any known die steel can be used, such as, for example, a die steel containing iron, carbon, tungsten, vanadium, molybdenum and chromium; a die steel containing iron, carbon, vanadium, molybdenum and chromium; a die steel containing iron, carbon, silicon, manganese, sulfur, chromium, molybdenum and/ortungsten, vanadium, nickel, copper and aluminum; and so on.

[0039] Forged steel is a material manufactured by heating a steel ingot formed by casting molten steel into a mold, or a steel billet manufactured from such a steel ingot, forging it by means of a press and a hammer or drawing and forting it by means of a press and a hammer, and subjecting it to a heat treatment. As the forged steel, any known forged steel can be used. Examples include: a forged steel composed primarily of iron, and containing carbon, chromium and nickel: a forged steel composed primarily of iron, and containing silicon, chromium and nickel; a forged steel containing nickel, chromium and molybdenum; a forged steel composed primarily of iron, and containing carbon, silicon, manganese, nickel, chromium, molybdenum and vanadium; a forged steel composed primarily of iron, and containing carbon, silicon, manganese, nickel, chromium and molybdenum; and so on.

A metal material that exhibits a prescribed Rockwell hardness and transverse rupture strength can be obtained by selecting a component composition as appropriate from among the high melting point metal materials listed above. As for the high melting point metal materials subjected to a heat treatment during the production step thereof, such as forged steel, by selecting a heat treatment temperature as appropriate, a material with a desired Rockwell hardness and transverse rupture strength can be obtained.

[0040] In the metal foil machining roller of the present invention, the thickness of a surface layer portion that contains a metal material with a prescribed Rockwell hardness and transverse rupture strength is preferably, but not particularly limited to, about 5 to 50 mm.

A metal foil machining roller that has such a surface layer portion can be produced by, in the case of the metal material being a high melting point metal material, for example, thermal fitting or cool fitting a cylinder made of the high melting point metal material to a core roller. As used herein, "thermal fitting" means that a high melting point metal material cylinder produced to have an inner diameter slightly smaller than the outer diameter of a core roller is fitted to the core roller by heating the high melting point metal material cylinder to expand it. "Cool fitting" means that a core roller contracted by cooling is fitted to a high melting point metal material cylinder produced to have an inner diameter slightly smaller than the outer diameter of the core roller. The core roller can be, for example, a roller made of stainless steel, iron or the like. In the metal foil machining roller of the present invention, not only the surface layer portion, but also the entire roller may be made of a metal material with a prescribed Rockwell hardness and transverse rupture strength.

[0041] The recessed portions in the circumferential surface of the metal foil machining roller of the present invention are formed by laser machining. That is, a conventional boring method that employs a laser can be used to form recessed portions. In laser machining, a laser machining apparatus that indudes a roller rotating apparatus, a laser oscillator, a machining head, a light guide path, a mask unit and an actuator can be used.

The roller rotating apparatus includes, for example, a roller support and a drive device. The roller support supports a roller in which at least a surface layer portion contains a metal material with a prescribed Rockwell hardness and transverse rupture strength and recessed portions are not formed in the circumferential surface so as to be capable of rotation around its axis. The drive device drives the roller (hereinafter referred to as a "roller in which recessed portions are to be formed") supported by the roller support to thereby rotate the roller around the axis.

[0042] The laser oscillator is an apparatus that outputs laser light. As the laser oscillator, any known laser oscillator can be used, such as a solid-state laser oscillator (Nd:YAG laser, Nd:YVO_4 laser) that employs a laser medium obtained by mixing neodymium ions with a YAG crystal (yttrium, aluminum, garnet) or YVO_4 crystal. Other examples include a carbon dioxide laser, an excimer laser and so on.

The output power of the laser oscillator is, for example, 50 mW to 200 W. The laser light frequency is preferably 100 Hz to 100 kHz. The laser light irradiation time is preferably, but not particularly limited to, 10 ps to 200 ns per instance. When the irradiation time is less than 10 ps, heat conduction due to laser light irradiation does not occur, so only a monoatomic layer can be removed, which may result in insufficient formation of recessed portions. On the other hand, when the irradiation time exceeds 200 ns, laser light may sweep the surface of the roller in which recessed portions are to be formed due to rotation of the roller.

[0043] The machining head is a member that is provided on a downstream side from the light guide path in a direction in which the laser oscillator outputs laser light The machining head collects laser light output from the laser oscillator and transmitted through the light guide path, and irradiates the outer circumferential surface of the roller in which recessed portions are to be formed. The machining head includes, for example, a condenser lens. The condenser lens is provided perpendicular to the traveling path of laser light, and collects laser light transmitted through the light guide path and irradiates the outer circumferential surface of the roller in which recessed portions are to be formed. The focal length of the condenser lens is preferably selected from, but not particularly limited to, a range ranging from 5 mm to 200 mm. An assist gas is introduced into the machining head. As the assist gas, for example, oxygen, nitrogen, helium, argon, a mixed gas containing two or more of these, or the like can be used. The pressure of the assist gas may be selected from, for example, a range ranging from 0.1 MPa to 1 MPa.

[0044] The light guide path is a member that is provided on a downstream side from the laser oscillator in a direction in which the laser oscillator outputs laser light, and that guides laser light output from the laser oscillator to the machining head. The light guide path includes, for example, a plurality of reflecting mirrors. By disposing a plurality of reflecting mirrors at appropriate positions, laser light is reflected by the reflecting mirrors and guided to the machining head. One mirror of the plurality of reflecting mirrors that is closest to the machining head and that directly guides laser light to the machining head is provided so as to be capable of reciprocation in conjunction with the reciprocation of the machining head.

[0045] The mask unit is a member that is provided somewhere midway in the light guide path, and that shapes the outline of laser light into a desired shape. In the mask unit, laser-passing apertures, that is, through apertures with the same shape as the opening shape of recessed portions to be formed, are formed. The laser light that has passed through the laser-passing apertures is formed in outline to conform to the opening shape of the laser-passing apertures, and is imaged by the condenser lens of the machining head to form an image with the same shape as the opening shape of the laser-passing apertures on the outer circumferential surface of the roller in which recessed portions are to be formed. That is, the opening shape of laser-passing apertures is the opening shape of recessed portions.

[0046] The actuator is provided vertically below the laser oscillator, the machining head, the light guide path and the mask unit, and collectively supports these apparatuses and members so as to be capable of reciprocation. The actuator reciprocates these apparatuses and members parallel to the longitudinal direction of the roller in which recessed portions are to be formed.

Such a laser machining apparatus is widely, commercially available. Even with a laser machining apparatus without a roller rotating apparatus, by mounting a roller rotating apparatus at a prescribed position, laser machining for forming recessed portions can be carried out.

[0047] Recess portions are formed by applying laser light to the circumferential surface of the roller in which recessed portions are to be formed continuously or intermittently, preferably intermittently, by the laser machining apparatus. After the formation of recessed portions, the roller in which recessed portions are to be formed is rotated, or the machining head or the like is moved in the longitudinal direction of the roller in which recessed portions are to be formed by the actuator, and new recessed portions are formed. Through the repetition of this operation, recessed portions are formed in a desired region of the roller in which recessed portions are to be formed, and the metal foil machining roller of the present invention is obtained.

A situation may arise in which when recessed portions are formed by laser machining, a bulge is formed along the perimeter of the opening of the recessed portions in the roller circumferential surface. Such a bulge is preferably removed by, for example, polishing or the like. Polishing can be earned out according to any known method. For example, it is possible to perform polishing by using diamond particles as an abrasive and a polishing apparatus including a polishing pad while supplying a medium such as water.

[0048] The manufacture of a metal foil with protrusion portions by using the metal foil machining roller of the present invention will be described next in detail. Fig. 1 is a side view schematically showing a configuration of a metal foil machining apparatus 10. Fig. 2 is an enlarged perspective view showing a configuration of a relevant part (machining means 4) of the metal foil machining apparatus 10 shown in Fig.1. Fig. 3 is a perspective view showing an external appearance of a metal foil machining roller 1. Fig. 4 is an enlarged perspective view of a surface region 1 x of the metal foil machining roller 1 shown in Fig. 3.

[0049] A metal foil 2 with protrusion portions is a metal foil in which protrusion portions 9 are formed in the surface, and can be manufactured by for example, the metal foil machining apparatus 10 shown in Fig.1. The metal foil machining apparatus 10 includes a metal foil feeding means 3, a machining means 4 and a metal foil winding means 5.

The metal foil feeding means 3 is, specifically, a metal foil feeding roller. The metal foil feeding roller is axially supported by a supporting means (not shown) so as to be capable of rotation around the axis. A metal foil 8 is wound around the circumferential surface of the metal foil feeding roller. The metal foil 8 is fed to a press-contact nip portion 6 of the machining means 4.

[0050] The machining means 4 includes, as shown in Figs.1 and 2, two metal foil machining rollers 1. The two metal foil machining rollers 1 are pressed into contact such that their axes are parallel to each other, whereby the press-contact nip portion 6 is formed. Athin sheet-like material such as the metal foil 8 can be passed through the press-contact nip portion 6. The metal foil machining rollers 1 are each axially supported by supporting means (not shown) so as to be capable of rotation, and provided so as to be capable of being rotated around the axis by a drive means (not shown). The two metal foil machining rollers 1 both may function as drive rollers, or it is also possible to employ a configuration in which one of the metal foil machining rollers 1 function as a drive roller and the other functions as a driven roller that is rotated in conjunction with the rotation of the drive roller.

In order to prevent the metal machining rollers 1 from being bent or deformed, a back roller (not shown) is pressed into contact with each of the metal machining rollers 1. The axis of the metal machining rollers 1 and the axis of the back-up rollers are parallel to each other The metal foil 8 is guided from an inlet of the press-contact nip portion 6 to an outlet of the same by the two metal foil machining rollers 1 being rotated, and the metal foil 8 is pressure-molded, whereby a metal foil 2 with protrusion portions in which protrusion portions 9 are formed on the surface of the metal foil 8 is obtained.

[0051] The metal foil machining rollers 1 are rollers according to the present invention in which a plurality of recessed portions 1a are formed on the circumferential surface.

In this embodiment, the arrangement pattern of recessed portions 1a in the circumferential surface of a metal foil machining roller 1 of the present is as follows. As shown in Fig. 4, a procession of a plurality of recessed portions 1 a at a pitch P_1 in the longitudinal direction of the metal foil machining roller 1 is defined as a unit line 7. A plurality of unit lines 7 are arranged at a pitch P_2 in the circumferential direction of the metal foil machining roller 1. The pitch P_1 and the pitch P_2 can be set freely. It should be noted that, in the circumferential direction of the metal foil machining roller 1, adjacent unit lines 7 are arranged such that the recessed portions 1 a are offset to each other in the longitudinal direction of the metal foil machining roller 1.

In this embodiment, the recessed portions 1 a are offset at $0.5P_1$ in the longitudinal direction, but the value is not limited thereto, and can be set freely. In addition, in this embodiment, the recessed portions 1a in the circumferential surface of the metal foil machining roller 1 have an approximately circular opening shape, but the opening shape is not limited thereto, and can be, for example, an approximately elliptic shape, an approximately rhombic shape, an approximately equilateral triangular shape, an approximately square shape, an approximately regular hexagonal shape, an approximately regular octangle shape or the like.

[0052] The cross section of recessed portions 1a in a direction vertical to the circumferential surface of the metal foil machining roller 1 has a taper shape in which a width of the cross section in a direction parallel to the circumferential surface of the metal foil machining roller 1 becomes gradually smaller from the circumferential surface of the metal foil machining roller 1 toward the bottom portion of the recessed portions 1 a, whereby the releasability of a pressure-molded metal foil 2 with protrusion portions from the metal foil machining roller 1 is improved.

The diameter of the metal foil machining roller 1 is preferably, but not particularly limited to, about 30 mm to 200 mm. The press-contact pressure (linear pressure) of two metal foil machining rollers 1 is preferably, but not particularly limited to, about 5 kN · cm to 20 kN · cm.

[0053] In this embodiment, the metal foil machining rollers 1 of the present invention are used as two rollers forming a press-contact nip portion 6, but the configuration is not limited thereto. For example, it is possible to employ a configuration in which the metal foil machining roller 1 of the present invention is used as one of two rollers, and a roller with a smooth surface without recessed portions on the surface is used as the other roller. In this case, a metal foil in which protrusion portions are formed on one surface in a thickness direction is obtained.

As described above, a metal foil 8 is passed through the press-contact nip portion 6 and the metal foil 8 is compressed, at which point a hermetically sealed space surrounded by a recessed portion 1a and the surface of the metal foil 8 is formed. Air remains in the hermetically sealed space. When the pressure force (press-contact pressure) of the metal foil machining roller 1 against the metal foil 8 is within the above-mentioned appropriate range, the hermetically sealed space is maintained while the metal foil 8 is machined, so a non-contact state is maintained between the bottom face of the recessed portion 1a and the surface of the metal foil 8 with the remaining air interposed therebetween.

[0054] The metal foil winding means 5 is, specifically, a metal foil winding roller. The metal foil winding roller is axially supported by a supporting means (not shown) so as to be capable of rotation around the axis. The metal foil winding roller is also rotated by a drive means (not shown). The metal foil winding roller winds the metal foil 2 with protrusion portions formed by the machining means 4 around the circumferential surface of the metal foil winding roller while rotating.

The metal foil 2 with protrusion portions is manufactured by using the metal foil machining apparatus 10 and pressure-molding a metal foil 8.

Examples

[0055] Hereinafter, the present invention will be described in detail with reference to examples and comparative examples.

Example 1

[0056] A Nb:YAG laser was mounted onto a laser machining apparatus (available from Spectra Physics KK.) as a laser oscillator. The intensity of laser light output from a machining head was set to 23 μJ per instance of irradiation. Also, a condenser lens and a focal length were adjusted so that the imaging magnification of the machining head was set to 16 times. That is, the imaging size of the machining head would be 1/16 times the size of the openings of a laser machining mask. The laser machining mask was obtained by subjecting a stainless steel plate (SUS304) with a thickness of 0.3 mm, and dimensions of 22 mm × 22 mm to electro-discharge machining so as to form laser-passing apertures with an approximately rhombic shape. The diameter of the rhombic opening of the laser-passing apertures (the length of the longer diagonal line) was 0.32 mm. The length of the shorter diagonal line was 0.16 mm.

[0057] A forged steel roller (available from Daido Machinery Ltd., diameter: 50 mm, roller width: 100 mm, Rockwell hardness in A scale of the forged steel: HRA 84.9, transverse rupture strength of the forged steel: 4.0 GPa, forged steel composition (weight ratio): carbon 1 %, silicon 0.24%, manganese 0.36%, chromium 1.46%, and the remaining ratio of iron) was mounted between a roller rotating apparatus and a tailstock of the laser machining apparatus, and the surface of the forged steel roller was irradiated with laser light with an irradiation time of 50 nanoseconds and an irradiation interval of 1 millisecond. After laser light irradiation, the laser light irradiated region was moved in the longitudinal direction of the forged steel roller by 20 μm, or in the circumferential direction by 29 μm, and laser light was directed thereto in the same manner. Such movement in the circumferential direction was performed by rotating the forged steel roller. After 5,400 recessed portions had been formed by moving the laser light irradiated region in the circumferential direction, the laser light irradiated region was moved in the longitudinal direction by 20 μm and rotated in the circumferential direction by 14.5 μm and, then, an operation of forming 5,400 recessed portions in the circumferential direction was repeated. A 90 mm region was machined by moving in the roller width direction 4,500 times. In this manner, 24,300,000 recessed portions were formed in a staggered arrangement and a metal foil machining roller of the present invention was produced.

[0058] The opening shape of the formed recessed portions was an approximately rhombic shape, and the opening diameter (the length of the longer diagonal line of the rhombic shape) was 20 μm. The length of the shorter diagonal line of the rhombic shape was 10 μm. The bottom face of the recessed portions had a dome shape, and the depth of the recessed portions was about 12 μm. The pitch of the recessed portions in the longitudinal direction (the width direction of the forged steel roller) was about 20 μm, and the pitch in the transverse direction (the circumferential direction of the forged steel roller) was about 29 μm.

[0059] Two such produced metal foil machining rollers were mounted onto a metal foil machining apparatus 10. The pressure force of the press-contact nip portion of the metal foil machining apparatus 10 was set to, in terms of linear pressure, about 14.7 kN · cm (1500 kgt/cm), and a tough pitch copper foil with a width of 80 mm and a thickness of 26 μm was allowed to pass through the press-contact nip portion and machined. In the surface of the machined copper foil surface, protrusion portions corresponding to the recessed portions of the metal foil machining rollers were formed. The average height of ten protrusion portions was measured with a laser microscope (trade name: VK-9500, available from Keyence Corporation) and found to be 7.0 μm. A 2000 m length of the copper foil was machined by using 20 rollers, each roller being 100 m long. As a result, the protrusion portions formed on the copper foil surface had approximately the same shape and a height of 7.0 μm. The surface of the metal foil machining rollers was observed with a laser microscope, as a result of which no occurrence of cracking and chipping was observed.

Example 2

[0060] Metal foil machining rollers of the present invention were produced in the same manner as in Example 1, except that a cemented carbide roller (available from Fuji Die Co. Ltd., diameter: 50 mm, width: 100 mm, Rockwell hardness in A scale: HRA 90.0, transverse rupture strength: 3.1 GPa, tungsten carbide particles and cobalt (binder) included) was used.

A tough pitch copper foil with a width of 80 mm and a thickness of 26 μm was machined in the same manner as in Example 1, except that two metal foil machining rollers obtained above were mounted onto the metal foil machining apparatus 10, and the pressure at the press-contact nip portion was changed from about 14.7 kN · cm (1500 kgf/cm) to about 9.8 kN · cm (1000 kgf/cm). In the surface of the machined copper foil, protrusion portions corresponding to the recessed portions of the metal foil machining rollers were formed. The average height of ten protrusion portions measured with a laser microscope (VK-9500) was 6.5 μm. A 1000 m length of the copper foil was machined by using 10 rollers, each roller being 100 m long. As a result, the protrusion portions formed on the copper foil surface had an approximately uniform shape and a height of 6.7 μm. The surface of the metal foil machining rollers was observed with a laser microscope after machining, as a result of which no occurrence of cracking and chipping was observed. Subsequently, the copper foil was machined until 2000 m was machined in total. The shape of protrusion portions formed on the copper foil surface was approximately the same as that of the initial protrusion portions, and the protrusion portions had a height of 6.5 μm. The surface of the metal foil machining rollers was observed with a microscope, as a result of which some chipped portions in which tungsten carbide particles had been lost were observed.

Example 3

[0061] Metal foil machining rollers of the present invention were produced in the same manner as in Example 1, except that a cemented carbide roller (available from Fuji Die Co. Ltd., diameter: 50 mm, width: 100 mm, Rockwell hardness in A scale: HRA 89.0, transverse rupture strength: 3.3 GPa, tungsten carbide particles and cobalt (binder) included) was used.

A tough pitch copper foil with a width of 80 mm and a thickness of 26 μm was machined in the same manner as in Example 1, except that two metal foil machining rollers obtained above were mounted onto the metal foil machining apparatus 10, and the pressure at the press-contact nip portion was changed from about 14.7 kN · cm (1500 kgf/cm) to about 9.8 kN · cm (1000 kgf/cm). In the surface of the machined copper foil, protrusion portions corresponding to the recessed portions of the metal foil machining rollers were formed. The average height of ten protrusion portions measured with a laser microscope (VK-9500) was 6.3 μm. Furthermore, a 2000 m length of the copper foil was machined by using 20 rollers, each roller being 100 m long. As a result, the shape of protrusion portions formed on the copper foil surface was approximately the same as that of the initial protrusion portions, and the average height of ten protrusion portions was 6.4 μm. The surface of the metal foil machining rollers after machining was observed with a microscope, as a result of which no occurrence of cracking and chipping was observed.

Example 4

[0062] Metal foil machining rollers of the present invention were produced in the same manner as in Example 1, except that a forged steel roller (available from

Daido Machinery Ltd., diameter: 50 mm, width: 100 mm, Rockwell hardness in A scale: HRA 83.9, transverse rupture strength: 5.5 GPa) was used. The composition of the forged steel was carbon 1.1%, silicon 0.22%, manganese 0.38%, chromium 1.76% and the remaining amount was iron (weight ratio).

A tough pitch copper foil with a width of 80 mm and a thickness of 26 μm was machined in the same manner as in Example 1, except that two metal foil machining rollers obtained above were mounted onto the metal foil machining apparatus 10, and the pressure at the press-contact nip portion was changed from about 9.8 kN · cm (1000 kgf/cm) to about 19.6 kN · cm (2000 kgf/cm). In the surface of the machined copper foil, protrusion portions corresponding to the recessed portions of the metal foil machining rollers were formed. The average height of ten protrusion portions measured with a laser microscope (VK-9500) was 5.8 μm. Furthermore, a 2000 m length of the copper foil was machined by using 20 rollers, each roller being 100 m long. As a result, the shape of protrusion portions formed on the copper foil surface was approximately the same as that of the initial protrusion portions, and the average height of ten protrusion portions was 5.7 μm. The surface of the metal foil machining rollers after machining was observed with a microscope, as a result of which no occurrence of cracking and chipping was observed.

Example 5

[0063] Metal foil machining rollers of the present invention were produced in the same manner as in Example 1, except that a die steel roller (available from Daido Machinery Ltd., diameter 50 mm, roller width: 100 mm, Rockwell hardness in A scale: HRA 81.2, transverse rupture strength: 5.8 GPa) was used. The composition of die steel was carbon 1.4%, silicon 0.4%, manganese 0.6%, chromium 11.2%, molybdenum 0.9%, vanadium 0.3% and the remaining amount was iron.

A tough pitch copper foil with a width of 80 mm and a thickness of 26 μm was machined in the same manner as in Example 4, except that two metal foil machining rollers obtained above were mounted onto the metal foil machining apparatus 10. In the surface of the machined copper foil, protrusion portions corresponding to the recessed portions of the metal foil machining rollers were formed. The average height of ten protrusion portions measured with a laser microscope (VK-9500) was 4.9 μm. Furthermore, a 2000 m length of the copper foil was machined by using 20 rollers, each roller being 100 m long. As a result, the shape of protrusion portions formed on the copper foil surface was approximately the same as that of the initial protrusion portions, and the average height of ten protrusion portions was 5.0 μm. The surface of the metal foil machining rollers after machining was observed with a microscope, as a result of which no occurrence of cracking and chipping was observed.

Comparative Example 1

[0064] Metal foil machining rollers were produced in the same manner as in Example 1, except that a cemented carbide roller (available from Fuji Die Co., Ltd., diameter 50 mm, width: 100 mm, Rockwell hardness in A scale: HRA 94.0, transverse rupture strength: 1.5 GPa, tungsten carbide particles and cobalt (binder) included) was used. In the recessed portions in the circumferential surface of the metal foil machining rollers, non-uniform opening shapes and opening diameters were observed. As to the opening shape in particular, although openings with an approximately rhombic shape were observed, there were a large number of openings with an elliptic shape.

[0065] A tough pitch copper foil with a width of 80 mm and a thickness of 26 μm was machined in the same manner as in Example 1, except that two metal foil machining rollers obtained above were mounted onto the metal foil machining apparatus 10, and the pressure at the press-contact nip portion was changed from about 14.7 kN · cm (1500 kgf/cm) to about 9.8 kN · cm (1000 kgf/cm). In the surface of the machined copper foil, protrusion portions corresponding to the recessed portions of the metal foil machining rollers were formed. That is, protrusion portions of non-uniform shape were formed. The average height often protrusion portions measured with a laser microscope (VK-9500) was 7.2 μm. Furthermore, a 1000 m length of the copper foil was machined by using 10 rollers, each roller being 100 m long. As a result, among the protrusion portions formed on the copper foil surface, a large number of deformed protrusion portions were observed. The average height of ten protrusion portions was 6.2 μm. The surface of the metal foil machining rollers after machining was observed with a microscope, as a result of which deformed recessed portions and a ruined roller surface due to loss by chipping of tungsten carbide (WC) particles were observed.

Comparative Example 2

[0066] Metal foil machining rollers of the present invention were produced in the same manner as in Example 1, except that a die steel roller (available from Daido Machinery Ltd., diameter 50 mm, width: 100 mm, Rockwell hardness in A scale: HRA 78.0, transverse rupture strength: 8 GPa) was used. The composition of die steel was carbon 0.4%, silicon 1.1 %, manganese 0.5%, chromium 5.0%, molybdenum 1.0%, vanadium 1.0% and the remaining amount was iron. In the recessed portions in the circumferential surface of the metal foil machining rollers, non-uniform opening shapes and opening diameters were observed. As to the opening shape in particular, although openings with an approximately rhombic shape were observed, there were a large number of openings with an elliptic shape.

[0067] A tough pitch copper foil with a width of 80 mm and a thickness of 26 μm was machined in the same manner as in Example 1, except that two metal foil machining rollers obtained above were mounted onto the metal foil machining apparatus 10, and the pressure at the press-contact nip portion was set to about 9.8 kN · cm (1000 kgf/cm), about 14.7 kN · cm (1500 kgf/cm) or about 19.6 kN · cm (2000 kgf/cm). In the surface of the machined copper foils, protrusion portions corresponding to the recessed portions of the metal foil machining rollers were formed. That is, protrusion portions of non-uniform shape were formed. The average height of ten protrusion portions measured with a laser microscope (VK-9500) was 2.2 μm (about 9.8 kN · cm), 2.3 μm (about 14.7 kN · cm) and 2.3 μm (about 19.6 kN · cm), from which it was found that the height of protrusion portions does not increase even when the pressure at the press-contact nip portion is increased. This is presumably because the metal foil machining rollers are flattened as the pressure is increased, increasing the contact area between the roller surface and the copper foil, so the load actually applied to the copper foil does not increase.

[0068] From the results of Examples 1 to 5 and Comparative Examples 1 and 2, it is dear that, by using the metal foil machining roller of the present invention, a unit of several tens of millions of protrusion portions with an approximately uniform shape and a height of 4 μm or more can be formed over a copper foil with a length of 1000 m or more in a stable manner. The metal foil machining roller of the present invention is a roller containing a metal material with a Rockwell hardness in A scale of HRA 81.2 to 90.0 and a transverse rupture strength of 3 GPa to 6 Gpa in which recessed portions are formed. With a metal foil machining roller containing a metal material with a Rockwell hardness in A scale of HRA 81.2 or less or a transverse rupture strength of 3 Gpa or less, it is dear that the roller is flattened, and protrusion portions with a height of 3 μm or more cannot be formed in a copper foil even when the pressure at the press-contact nip portion is increased. In addition, with a metal foil machining roller containing a metal material with a Rockwell hardness in A scale of HRA 90.0 or more or a transverse rupture strength 6 Gpa or more, recessed portions are deformed due to the occurrence of chipping and the roller surface is ruined, from which it is found that stable machining is not possible.

Industrial Applicability

[0069] The metal foil machining roller of the present invention can be preferably used to form protrusion portions on the surface of a variety of metal foils. In particular, because the metal foil machining roller of the present invention exhibits a high level of durability, it is possible to efficiently manufacture a metal foil with protrusion portions with a very low defect rate even when mass-produced, so the present invention is industrially advantageous.

Claims

1. A metal foil machining roller in which a plurality of recessed portions are formed on a circumferential surface by laser machining, wherein at least a surface layer portion in which said recessed portions are formed comprises a metal material that has a Rockwell hardness in A scale of HRA 81.2 to 90.0 and a transverse rupture strength of 3 GPa to 6 Gpa.

2. The metal foil machining roller in accordance with daim 1, wherein a cross-sectional shape of said recessed portions in a direction vertical to the circumferential surface of said metal foil machining roller is a taper shape in which a cross-sectional width becomes gradually or continuously smaller from the circumferential surface of said metal foil machining roller toward a bottom face of said recessed portions.

3. The metal foil machining roller in accordance with daim 1, wherein an opening shape of said recessed portions in the circumferential surface of said metal foil machining roller is an approximately circular shape, an approximately elliptic shape, an approximately rhombic shape or an approximately regular polygonal shape.

4. The metal foil machining roller in accordance with daim 1, wherein an opening diameter of said recessed portions in the circumferential surface of said metal foil machining roller is 1 μm to 35 μm.

5. The metal foil machining roller in accordance with daim 1, wherein a pitch of said recessed portions in a direction of an axis of said roller in the circumferential surface of said metal foil machining roller is 4 μm or more.

6. The metal foil machining roller in accordance with daim 1, wherein said metal material has a Rockwell hardness in A scale of HRA 83.9 to 89.0.

7. The metal foil machining roller in accordance with daim 1, wherein said metal material has a transverse rupture strength of 3.3 GPa to 5.5 Gpa.

8. The metal foil machining roller in accordance with claim 1, wherein said metal material comprises at least one high melting point metal material selected from the group consisting of a cemented carbide, a cermet, a high speed steel, a die steel and a forged steel.

9. The metal foil machining roller in accordance with daim 1, wherein said metal foil machining roller is used such that the bottom face of said recessed portions and a surface of a metal foil do not come into contact.

FIG. 1

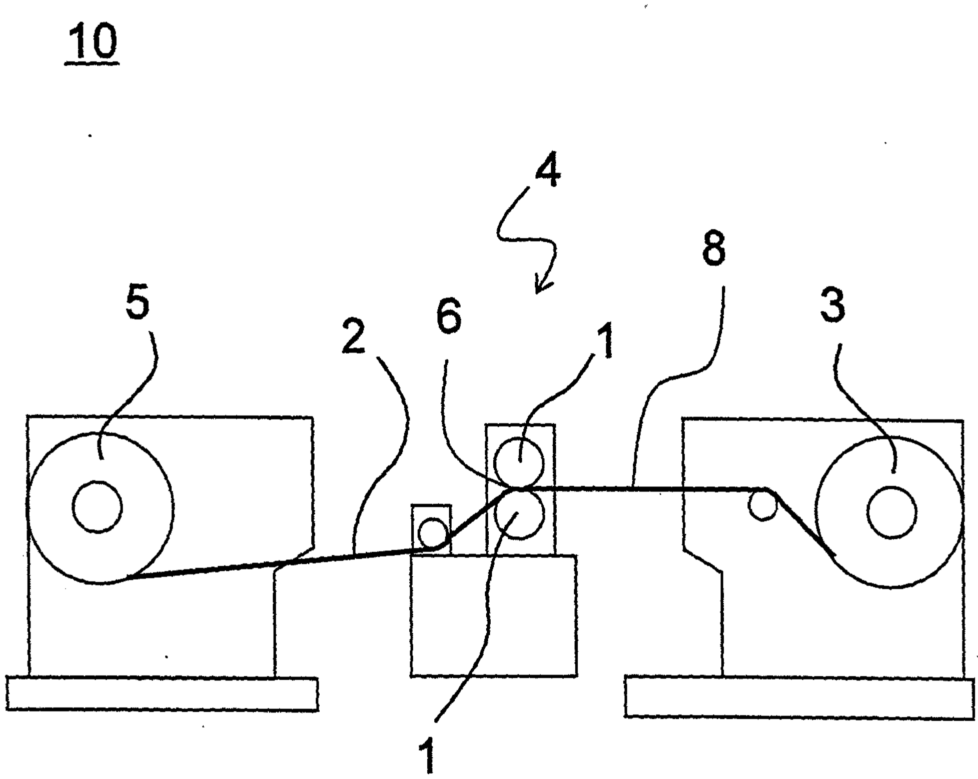


FIG. 2

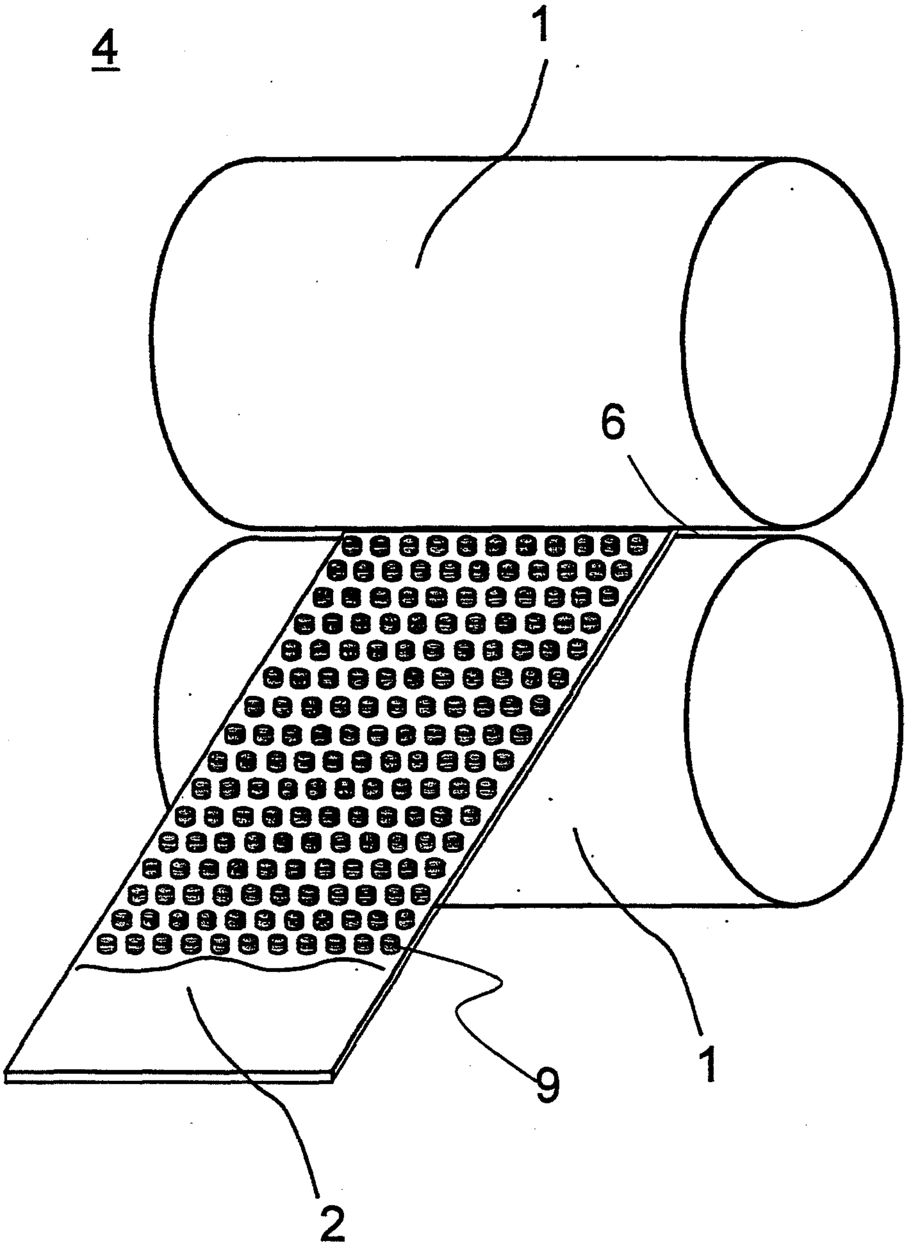


FIG. 3

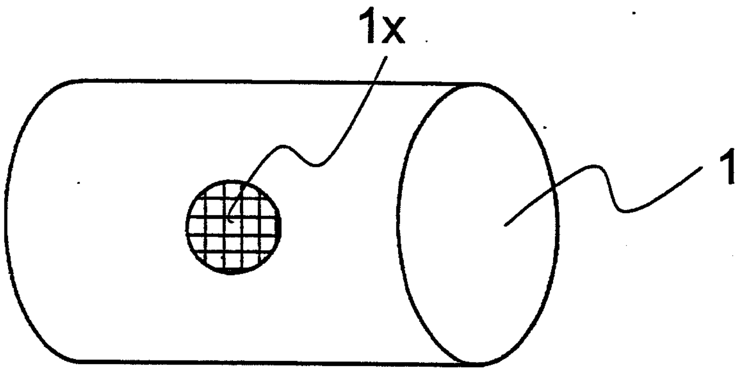
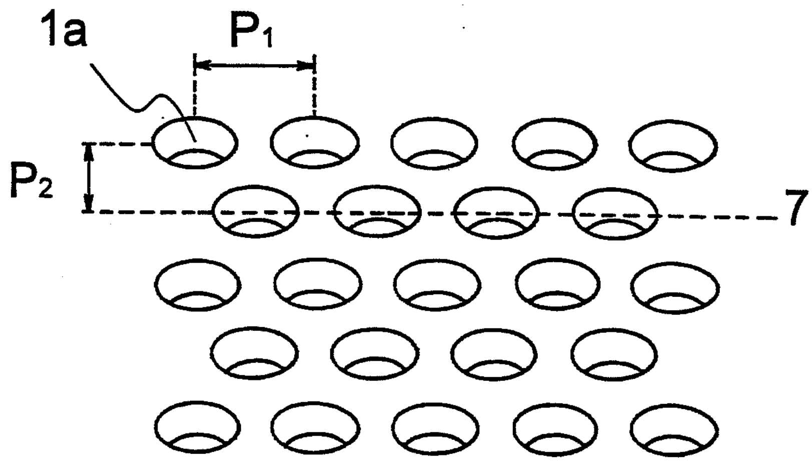


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2008/003428

A. CLASSIFICATION OF SUBJECT MATTER
B21B27/02(2006.01)i, *B21B27/00*(2006.01)i

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)
B21B27/02, B21B27/00

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2008
Kokai Jitsuyo Shinan Koho	1971-2008	Toroku Jitsuyo Shinan Koho	1994-2008

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.
Y A	JP 4-228210 A (Aluminium Co. of America), 18 August, 1992 (18.08.92), Claims; Par. Nos. [0001], [0027], [0032]; Figs. 2, 4 & US 5025547 A & EP 456162 A2 & DE 69108284 C & AU 7295991 A & CA 2037941 A	1-3,6-9 4,5
Y A	JP 2002-155336 A (Fuji Die Co., Ltd.), 31 May, 2002 (31.05.02), Claim 1; table 2 (Family: none)	1-3,6-9 4,5

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"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
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 December, 2008 (17.12.08)	06 January, 2009 (06.01.09)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (April 2007)

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP S6310013 B **[0010]**
- JP H10166010 B **[0010]**
- JP 2005000997 A **[0010]**
- JP 2005111524 A **[0010]**