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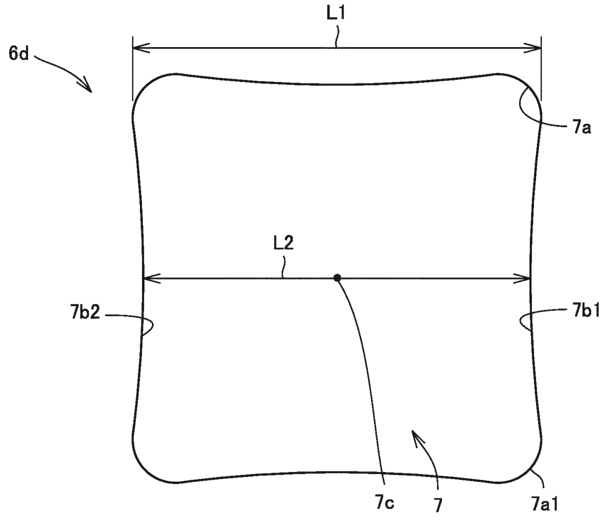
(54) # IRREGULAR-SHAPED DIE AND METHOD FOR FABRICATING IRREGULAR-SHAPED LINE

(57) An irregularly-shaped diamond die is an irregularly-shaped die for producing an irregularly-shaped wire, wherein a processing hole having a bearing portion is provided, a first side and a second side that face each other are provided in a cross section of the bearing portion perpendicular to a wire drawing direction, and each of the first side and the second side has a shape that is convex toward a center side of the processing hole in the cross section.

FIG.5



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Description

TECHNICAL FIELD

[0001] The present invention relates to an irregularly-shaped die and a method for producing an irregularly-shaped wire using the same. The present application claims the priority based on Japanese Patent Application No. 2021-184040 filed on November 11, 2021. The entire contents of the description in this Japanese patent application are incorporated herein by reference.

BACKGROUND ART

[0002] Conventionally, an irregularly-shaped die is disclosed in, for example, International Publication No. 2018/123513 (PTL 1).

CITATION LIST

PATENT LITERATURE

[0003] PTL 1: International Publication No. 2018/123513

SUMMARY OF INVENTION

[0004] An irregularly-shaped die according to the present disclosure is an irregularly-shaped die for producing an irregularly-shaped wire, wherein a processing hole having a bearing portion is provided, a first side and a second side that face each other are provided in a bearing cross section of the bearing portion perpendicular to a wire drawing direction, and each of the first side and the second side has a shape that is convex toward a center side of the processing hole in the bearing cross section.

BRIEF DESCRIPTION OF DRAWINGS

[0005]

Fig. 1 is a cross-sectional view of an irregularly-shaped diamond die 10 according to an embodiment, diamond 1 that constitutes irregularly-shaped diamond die 10, a case 2 that houses diamond 1, and a sintered alloy 3 interposed therebetween.
Fig. 2 is a front view of diamond 1 shown in Fig. 1.
Fig. 3 is a cross-sectional view taken along line III-III in Fig. 2.
Fig. 4 is an enlarged cross-sectional view of a bearing portion 6d taken along line IV-IV in Fig. 3.
Fig. 5 is an enlarged cross-sectional view of bearing portion 6d of a processing hole 7 according to the embodiment.
Fig. 6 is an enlarged cross-sectional view of bearing portion 6d of processing hole 7 according to the embodiment.
Fig. 7 is an enlarged cross-sectional view of bearing portion 6d of processing hole 7 according to the embodiment.
Fig. 8 is an enlarged cross-sectional view of bearing portion 6d of processing hole 7 according to the embodiment.
Fig. 9 is an enlarged cross-sectional view of bearing portion 6d of processing hole 7 according to the embodiment.
Fig. 10 is an enlarged cross-sectional view of bearing portion 6d of processing hole 7 according to the embodiment.
Fig. 11 is a cross-sectional view of a reduction portion 6c of processing hole 7 according to the embodiment, and is a cross-sectional view corresponding to Fig. 5.
Fig. 12 is a cross-sectional view of processing hole 7 in a wire drawing direction, for illustrating an opening angle.
Fig. 13 is a plan view of processing holes of three diamond dies, for illustrating a method for producing an irregularly-shaped wire according to the embodiment.

DESCRIPTION OF EMBODIMENTS

[Problem to be Solved by the Present Disclosure]

[0006] The accuracy of an irregularly-shaped wire produced using a conventional irregularly-shaped die is low.

[Effect of the Present Disclosure]

[0007] According to the present disclosure, the processing accuracy of an irregularly-shaped wire can be improved.

[Details of Embodiment of the Present Invention]

(Overall Configuration)

[0008] An overview of a diamond die for wire drawing of an irregularly-shaped wire will be described with reference to the drawings. Fig. 1 is a cross-sectional view of an irregularly-shaped diamond die 10 according to an embodiment, diamond 1 that constitutes irregularly-shaped diamond die 10, a case 2 that houses diamond 1, and a sintered alloy 3 interposed therebetween. Fig. 1 is a cross-sectional view showing a state in which irregularly-shaped diamond die 10 can be used, with diamond 1 housed in the die case. Diamond 1 is housed in case 2. Diamond 1 is attached to case 2 using sintered alloy 3. In irregularly-shaped diamond die 10 serving as an irregularly-shaped die, a portion that processes a wire is made of, for example, diamond 1.

[0009] Fig. 2 is a front view of diamond 1 shown in Fig. 1. Fig. 3 is a cross-sectional view taken along line III-III in Fig. 2. Fig. 4 is an enlarged cross-sectional view of a bearing portion 6d taken along line IV-IV in Fig. 3. As shown in Figs. 2 to 4, diamond 1 has polycrystalline diamond 5 surrounded by a support ring 4 made of cemented carbide. A central portion includes a hole inner surface 6 and a processing hole 7, and a wire to be subjected to wire drawing passes through processing hole 7 while coming into contact with hole inner surface 6. Hole inner surface 6 is further divided and details thereof are shown in Fig. 3. Hole inner surface 6 is divided into a bell portion 6a, an approach portion 6b, a reduction portion 6c, a bearing portion 6d, a back relief portion 6e, and an exit portion 6f in this order, and processing hole 7 has a shape similar to a quadrangular shape when viewed from the front, as shown in Fig. 2. Bearing portion 6d is a region of processing hole 7 including a portion having a smallest diameter.

[0010] At least a surface extending from bell portion 6a to bearing portion 6d, of hole inner surface 6 formed by processing hole 7, is formed by a smooth curved surface in a thickness direction of diamond. In other words, unlike a configuration in which each of bell portion 6a, approach portion 6b, reduction portion 6c, and bearing portion 6d is formed linearly and boundary portions thereof are rounded, the portions as a whole are formed by a smooth curved surface. This curved surface is formed by a curved surface of single R or a curved surface of composite R, and boundary portions thereof have a shape that is not clearly known.

[0011] A wire diameter of a wire subjected to a wire drawing process using irregularly-shaped diamond die 10 is less than 0.1 mm, which is thin. In the case of subjecting such an ultrafine wire to the wire drawing process, when the surface extending from bell portion 6a to bearing portion 6d is formed by a smooth curved surface, a wire drawing resistance does not change greatly, and wire breakage is less likely to occur in spite of the ultrafine wire. In addition, from the perspective of supplying a lubricant, excellent lubrication conditions are achieved when the surface extending from bell portion 6a to bearing portion 6d is formed by a smooth curved line.

[0012] Polycrystalline diamond 5 around processing hole 7 is single polycrystalline diamond that is continuous in a circumferential direction of processing hole 7. Since polycrystalline diamond 5 around processing hole 7 is single polycrystalline diamond that is continuous in the circumferential direction of the processing hole, polycrystalline diamond 5 has a higher strength than a strength of divided diamond. As a result, the accuracy of the processing hole can be higher and the surface roughness of the wire subjected to wire drawing can be smaller.

(Lengths of Bearing Portion 6d and Reduction Portion 6c)

[0013] When bearing portion 6d has a quadrangular front shape and L2 represents a distance between the facing surfaces of the quadrangular shape (a minimum distance between a first side 7b 1 and a second side 7b2), a region having a length of 1.0 L2 in the wire drawing direction corresponds to bearing portion 6d. A portion having a smallest inner diameter corresponds to the center of bearing portion 6d, and a region extending upward by 0.5 L2 and downward by 0.5 L2 in the wire drawing direction from the portion corresponds to bearing portion 6d. Generally, longer length of bearing portion 6d is more preferable from the perspective of improving the life of irregularly-shaped diamond die 10, i.e., preventing wear and shape change of polycrystalline diamond 5. Furthermore, a region extending by 1.0 L2 from an upstream end of bearing portion 6d in the wire drawing direction (a region extending upstream in the wire drawing direction from the center of bearing portion 6d by a length of more than 0.5 L2 and up to 1.5 L2) corresponds to reduction portion 6c.

[0014] However, when an ultrafine wire is subjected to wire drawing, wire breakage is a big problem, and thus, bearing portion 6d cannot be made long. In order to prevent wire breakage, it is necessary to take measures from the following two perspectives, i.e., decreasing a contact area between polycrystalline diamond 5 and the wire, and decreasing the friction force per unit area. Therefore, first of all, from the perspective of decreasing the contact area with the wire, it is preferable to make bearing portion 6d short. As a result, the friction force is reduced.

[0015] In addition, since the smooth curved surface makes it possible to decrease the contact area, to prevent the lubricant from running out, and to stabilize the wire drawing resistance, the wire breakage prevention effect is remarkable. Furthermore, in the case of subjecting bearing portion 6d to polishing, it is difficult to achieve a smooth surface having a small surface roughness when the length of bearing portion 6d is long. However, since the length of bearing portion 6d is short, polishing can be performed with high accuracy, which also provides the effect of stabilizing the wire drawing resistance.

(Surface Roughness Sa of Bearing Portion 6d)

[0016] Surface roughness Sa of bearing portion 6d is, for example, equal to or less than 0.05 μm. The surface roughness Sa is defined by ISO 25178. A range in which there are 20 or more peaks and valleys therein is set as a measurement range. Measurement is conducted under the conditions of with measurement pretreatment, with inclination correction, and without a Gaussian filter. Bearing portion 6d is a portion of processing hole 7 having a smallest diameter and the surface roughness of bearing portion 6d is deeply related to the surface roughness of the wire. When the surface roughness Sa of bearing portion 6d exceeds 0.05 μm, the surface roughness of the wire becomes coarse. In order to achieve a high-accuracy and long-life die, the surface roughness Sa of bearing portion 6d is more preferably equal to or less than 0.03 μm, and most preferably equal to or less than 0.01 μm. Smaller surface roughness Sa of bearing portion 6d is more preferable. However, in consideration of the cost effectiveness on industrial production, the surface roughness Sa of bearing portion 6d is preferably equal to or more than 0.002 μm.

[0017] In order to measure the surface roughness Sa of bearing portion 6d, a transfer material (e.g., RepliSet manufactured by Marumoto Struers K.K.) is filled into processing hole 7 of the irregularly-shaped die and a replica onto which the surface of processing hole 7 has been transferred is produced. This replica is observed using a laser microscope (e.g., VK-X series shape analysis laser microscope manufactured by Keyence Corp.) and the surface roughness Sa is measured at arbitrary three locations. An average value of the surface roughnesses Sa measured at these three locations is defined as the surface roughness Sa of bearing portion 6d. As to the surface roughness Sa of the wire subjected to wire drawing as well, the surface is observed using the laser microscope and the surface roughness Sa is measured at arbitrary three locations. An average value of the surface roughnesses Sa at these three locations is defined as the surface roughness Sa of the wire.

(Surface Roughness of Reduction Portion 6c)

[0018] Preferably, the surface roughness Sa of reduction portion 6c is equal to or less than 0.1 μm. When the surface roughness Sa of reduction portion 6c is equal to or less than 0.1 μm, the surface roughness of reduction portion 6c located upstream of bearing portion 6d is small, and thus, the surface roughness of the wire subjected to wire drawing can be made small.

[0019] In order to achieve a high-accuracy and long-life die, the surface roughness Sa of reduction portion 6c is more preferably equal to or less than 0.05 μm, and most preferably equal to or less than 0.03 μm. Smaller surface roughness Sa of reduction portion 6c is more preferable. However, in consideration of the cost effectiveness on industrial production, the surface roughness Sa of reduction portion 6c is preferably equal to or more than 0.01 μm.

[0020] The surface roughness of reduction portion 6c is measured using the same method as the method for measuring the surface roughness of bearing portion 6d.

(Lengths of Sides and R of Corner Portion)

[0021] The wire subjected to wire drawing is used as a winding of a motor, and the like. In such an application, winding the wire at high density is required, and thus, smaller R of the corner portion of the wire is more preferable. Therefore, the R of corner portion 7a of the quadrangular shape in the bearing portion is equal to or less than 20 μm. Smaller R of the corner portion is more preferable. However, in consideration of the cost effectiveness on industrial production, the R of corner portion 7a is preferably equal to or more than 1 μm.

[0022] Although the case in which processing hole 7 has a quadrangular shape is described in the present embodiment, the shape of processing hole 7 is not limited to the quadrangular shape and may be another polygonal shape such as a triangular shape or a hexagonal shape. It is preferable that many cross sections orthogonal to a longitudinal direction of the wire include a straight line portion. Furthermore, when the sides have different lengths, the length of the longest side is preferably equal to or less than 100 μm. There is no lower limit to the length of the longest side. However, when the longest side is too short, the manufacturing cost is high on industrial production. Therefore, in consideration of the cost effectiveness, the length of the longest side is preferably equal to or more than 5 μm.

[0023] First side 7b 1 and second side 7b2 are arranged to face each other. A distance between first side 7b 1 and second side 7b2 varies from place to place. L1 represents a maximum distance and L2 represents a minimum distance.

[0024] First side 7b 1 and second side 7b2 are curved to protrude toward a center 7c. Although all of the four sides protrude toward center 7c in the present embodiment, at least a pair of first side 7b 1 and second side 7b2 may only have a shape that is convex toward center 7c and the other sides do not need to have a shape that is convex toward center 7c.

[0025] Each of Figs. 5 to 10 is an enlarged cross-sectional view of bearing portion 6d of processing hole 7 according to the embodiment. Figs. 5 to 10 show processing holes 7 having different maximum distances L1 and minimum distances L2. Fig. 10 shows the shape in which a value of maximum distance L1/minimum distance L2 is the largest, and in Fig. 10, maximum distance L1/minimum distance L2 is 150%. Each of Figs. 5 to 10 shows a bearing cross section.

[0026] When processing hole 7 has a quadrangular shape, the wire is firmly processed by the straight line portions of processing hole 7. Although a metal that constitutes the processed wire moves to corner portion 7a, a sufficient amount of the metal does not move, and thus, it is difficult to fill corner portion 7a with the metal, and the processed wire does not have a quadrangular shape.

[0027] In contrast, in the shapes shown in Figs. 1 to 10, first side 7b 1 and second side 7b2 are formed to achieve maximum distance L1 in corner portion 7a, and thus, the material of the wire easily moves to corner portion 7a. As a result, the processed wire is likely to have a quadrangular shape.

[0028] In a conventional irregularly-shaped die, the wire drawing process is performed at an area reduction ratio that is set relatively high, in order to make the R of corner portion 7a smaller. Therefore, the pulling force is high, and thus, particularly in the case of an ultrafine wire, the risk of wire breakage is high and the processing strain of the wire subjected to the wire drawing process is large. In the irregularly-shaped die according to the present disclosure, even when the area reduction ratio is set relatively low, the R of corner portion 7a can be formed accurately. Therefore, the risk of wire breakage is low and the processing strain of the wire subjected to the wire drawing process is also small.

[0029] Irregularly-shaped diamond die 10 is an irregularly-shaped die for producing an irregularly-shaped wire, wherein processing hole 7 having bearing portion 6d is provided, first side 7b 1 and second side 7b2 that face each other are provided in a cross section of bearing portion 6d perpendicular to a wire drawing direction, and each of first side 7b 1 and second side 7b2 has a shape that is convex toward a center 7c side of processing hole 7 in the cross section.

[0030] Although processing hole 7 has a shape similar to a quadrangular shape in the present embodiment, the shape of processing hole 7 is not limited thereto and may be a track shape formed by connecting a straight line and a semicircle. In this case, the straight line portion has a shape that is convex toward a center.

(Opening Angle at Reduction Portion 6c)

[0031] Fig. 11 is a cross-sectional view of reduction portion 6c of processing hole 7 according to the embodiment, and is a cross-sectional view corresponding to Fig. 5. Fig. 12 is a cross-sectional view of processing hole 7 in the wire drawing direction, for illustrating an opening angle. In the present disclosure, as shown in Fig. 11, a cross-sectional shape of reduction portion 6c (reduction cross section) and a cross-sectional shape of bearing portion 6d are substantially similar figures. An angle θ formed by a tangent line 6c1 of a wall surface and a center line 7d in reduction portion 6c corresponds to an opening angle at reduction portion 6c (hereinafter, referred to as "reduction angle"). Tangent line 6c1 and reduction portion 6c are in contact with each other at a center position in the wire drawing direction in reduction portion 6c.

[0032] A reduction angle of corner portion 7a may be different from a reduction angle of each of first side 7b1 and second side 7b2.

[0033] The reduction angle of corner portion 7a may be greater than the reduction angle of each of first side 7b1 and second side 7b2.

[0034] By making the reduction angle of corner portion 7a greater than the reduction angle of each of first side 7b1 and second side 7b2 as described above, an area reduction ratio of corner portion 7a can be set to be greater than an area reduction ratio of each of first side 7b1 and second side 7b2. As a result, the wire subjected to the wire drawing process is narrowed more sharply in corner portion 7a than in each of first side 7b1 and second side 7b2. By doing so, even an ultrafine-diameter wire including corner portion 7a having a very small R, which is targeted by the irregularly-shaped die according to the present disclosure, is easily processed up to every part of corner portion 7a. Thus, the shape accuracy of the wire subjected to the wire drawing process is improved. In addition, although increasing the area reduction ratio leads to an increase in resistance during wire drawing, the increase in resistance during wire drawing is suppressed and the problem of breakage of the wire becomes less likely to occur, by making the length of bearing portion 6d shorter and making the surface roughness smaller as described above.

[0035] Furthermore, the reduction angle of corner portion 7a may become greater with increasing distance from first side 7b 1 and second side 7b2 and toward a tip 7a1 of corner portion 7a. Tip 7a1 of corner portion 7a refers to a portion of corner portion 7a having a greatest distance from center 7c.

[0036] By setting the shape as described above, tip 7a1 of corner portion 7a has a largest area reduction ratio and the wire is easily processed up to tip 7a1 of corner portion 7a. In addition, in a process for manufacturing the irregularly-shaped die, processing of corner portion 7a becomes easier and the accuracy of corner portion 7a can be easily improved.

(Diamond Particle Size)

[0037] In order to make the R of corner portion 7a smaller, and further to make the surface roughness Sa of bearing portion 6d smaller, diamond that constitutes polycrystalline diamond 5 must have a small particle size. Polycrystalline diamond (sintered diamond) 5 having an average particle size of equal to or less than 500 nm is used. Furthermore, the average particle size of diamond is related to the surface roughness of the wire, and when the average particle size of diamond exceeds 500 nm, the surface roughness of the wire becomes coarse.

[0038] In order to achieve a high-accuracy and long-life die, the average particle size of diamond is more preferably equal to or less than 300 nm, and most preferably equal to or less than 100 nm. Smaller average particle size of diamond is more preferable. However, the cost of ultrafine diamond particles is high on industrial production, and thus, the average particle size of diamond is preferably equal to or more than 5 nm.

[0039] In order to measure the average particle size of the diamond particles, a photograph of polycrystalline diamond 5 is taken at arbitrary three locations within a range of 5 μm $\times$ 5 μm using a scanning electron microscope. Individual diamond particles are extracted from the taken image and the extracted diamond particles are subjected to a binarization process, thereby calculating an area of each diamond particle. A diameter of a circle having the same area as the area of each diamond particle is defined as the particle size of the diamond particle. An arithmetic average value of the diamond particle sizes (diameters of the circles) is defined as the average particle size.

(Binder)

[0040] Polycrystalline diamond 5 may include a binder. A ratio of the binder in the polycrystalline diamond is preferably equal to or less than 5 volume%. In order to achieve a high-accuracy and long-life die, the ratio of the binder is more preferably equal to or less than 3 volume%, and it is most preferable that polycrystalline diamond 5 should include no binder.

[0041] In order to measure the ratio of the binder, a photograph of polycrystalline diamond 5 is taken at arbitrary three locations within a range of 5 μm × 5 μm using the scanning electron microscope as described in the paragraph of "(Diamond Particle Size)" above. The taken image is read using the Adobe Photoshop or the like, a threshold value that matches the original image is calculated through contour tracing, and black and white conversion is performed using the threshold value. An area of the binder displayed in white as a result of the black and white conversion can be calculated. The diamond particles are displayed in gray and a grain boundary is displayed in black. The area ratio of the binder is defined as the volume ratio of the binder.

(Material)

[0042] In the example above, the wire is processed using diamond 1. However, in the irregularly-shaped die, bearing portion 6d may be made of a hard material other than diamond 1.

[0043] Examples of the material of bearing portion 6d include cubic boron nitride (CBN) or cemented carbide. The material of bearing portion 6d can be determined depending on a material of a wire to be processed.

(Method for Manufacturing Irregularly-Shaped Diamond Die 10)

[0044] As a material of irregularly-shaped diamond die 10, sintered diamond is prepared. The sintered diamond is processed into a cylindrical shape, and then, a pilot hole is bored therein by a laser processing method. Next, coarse processing is performed by an electrical discharge processing method. Next, finishing processing is performed by lapping processing. Details of the lapping processing method is as follows.

1) A stainless wire having a rectangular cross-sectional shape smaller than a cross-sectional shape of a processing hole, with each corner portion thereof rounded, is produced by a rolling processing method or the like.
2) A longer side of the stainless wire is brought into contact with one side of the die hole and moved in a reciprocating manner for finishing processing, while supplying a diamond slurry. The remaining three sides are also subjected to finishing processing by the same method. During lapping processing, the stainless wire mainly processes bearing portion 6d. By adjusting an amount of lapping of reduction portion 6c, the surface roughness of the reduction portion can also be adjusted.

(Method for Producing Irregularly-Shaped Wire)

[0045] Fig. 13 is a plan view of processing holes of three diamond dies, for illustrating a method for producing an irregularly-shaped wire according to the embodiment.

[0046] In the first stage, a wire 100 is first processed using a processing hole 107, in order to produce an irregularly-shaped wire by processing wire 100. As a result, wire 100 is processed into a shape close to a rectangular shape.

[0047] In the second stage, the wire drawing process is performed using processing hole 7. As a result, the vicinity of the center of a portion forming a side, of a cross section of the wire, is deformed and wire 100 is processed to elongate toward corner portion 7a. Wire 100 is shaped to be pointed toward corner portion 7a.

[0048] In the third stage, wire 100 is processed using a processing hole 207 of an irregularly-shaped die for finishing processing. As a result, a portion closer to corner portion 7a, of the cross section of wire 100, is deformed more greatly than the side portion and wire 100 is processed to have such a shape that wire 100 is also in contact with processing hole 207 at corner portion 7a having a small R.

[0049] One irregularly-shaped die may be used or a plurality of irregularly-shaped dies may be used in each of the first to third stages. In order to improve the accuracy, the number of irregularly-shaped dies can be increased depending on the wire and the size of the R of corner portion 7a.

[0050] The wire to be subjected to wire drawing can be various types of metals such as copper, silver, iron, gold, and aluminum.

(Examples)

[0051] Wire drawing using Combination 1 to Combination 3 of irregularly-shaped dies was evaluated.

[0052] In each of Combination 1 to Combination 3, wire drawing is performed using three irregularly-shaped dies.

(1) Material of Diamond Dies

[0053] Combination 1 to Combination 3 of irregularly-shaped dies are all made of the same material. The irregularly-shaped dies are substantially made of only diamond and are made of polycrystalline diamond having an average particle size of 50 nm.

(2) Specifications of Diamond Dies

[0054] In each of Combination 1 to Combination 3, the first to third irregularly-shaped dies have the following specifications.

(2-1) First Irregularly-Shaped Die

[0055] In Combination 1 to Combination 3, the first irregularly-shaped die is the same.

[0056] In each of Combination 1 to Combination 3, a side of the first irregularly-shaped die is not provided with a portion that is convex toward a center as shown in Figs. 4 to 11, and the specifications are as follows.

Reduction angle: 16 degrees
Length of bearing: 10 μm
Surface roughness of bearing: Sa 0.021 μm
Distance between facing sides of bearing portion: 109 μm
Radius R of corner portion: 30 μm

(2-2) Second Irregularly-Shaped Die

[0057] (2-2-1) In Combination 1, the specifications of the second irregularly-shaped die are as follows (Fig. 5).

Reduction angle: 15 degrees (this applies to both the side portion and the R portion)
Length of bearing portion 6d: 10 μm
Surface roughness of bearing portion 6d: Sa 0.025 μm
Distance L1 of bearing portion 6d: 90 μm
Distance L2 of bearing portion 6d: 98 μm
Radius R of corner portion 7a: 10 μm

[0058] (2-2-2) In Combination 2, the specifications of the second irregularly-shaped die are as follows (Figs. 5 and 11).

Reduction angle: 15 degrees (side 7b1, 7b2)
Reduction angle: 15 to 18 degrees (R portion of corner portion 7a). The reduction angle is 15 degrees at a boundary portion between side 7b1, 7b2 and corner portion 7a, and gradually becomes greater toward tip 7a1, and is 18 degrees at tip 7a1.
Length of bearing portion 6d: 10 μm
Surface roughness of bearing portion 6d: Sa 0.025 μm
Distance L1 of bearing portion 6d: 90 μm
Distance L2 of bearing portion 6d: 98 μm
Radius R of corner portion 7a: 10 μm

[0059] (2-2-3) In Combination 3, a side of the second irregularly-shaped die is not provided with a portion that is convex toward a center as shown in Figs. 4 to 11, and the specifications are as follows.

Reduction angle: 17 degrees
Length of bearing portion: 10 μm
Surface roughness of bearing portion: Sa 0.020 μm
Distance between facing sides of bearing portion: 91 μm
Radius R of corner portion: 7 μm

(2-3) Third Irregularly-Shaped Die

[0060] In each of Combination 1 to Combination 3, a side of the third irregularly-shaped die is not provided with a portion that is convex toward a center as shown in Figs. 4 to 11, and the specifications are as follows.

Reduction angle: 16 degrees
Length of bearing portion: 10 μm
Surface roughness of bearing portion: Sa 0.018 μm
Distance between facing sides of bearing portion: 80 μm
Radius R of corner portion: 7 μm

(3) Wire Before Wire Drawing Process

[0061] The specifications of a wire to be subjected to the wire drawing process are as follows.

Material: pure copper
Wire diameter (before wire drawing): ϕ 130 μm

(4) Wire After Wire Drawing Process

[0062] A state of the wire subjected to the wire drawing process was as follows.

(4-1) Combination 1

(4-1-1) Wire diameter

[0063] The wire diameters at measurement points 1 to 3 are as follows.

Measurement point 1: 80.1 μm in length and 80.0 μm in width
Measurement point 2: 80.0 μm in length and 80.2 μm in width
Measurement point 3: 80.2 μm in length and 80.1 μm in width
Average value: 80.1 μm

(4-1-2) Magnitude of resistance during wire drawing: 1.7 N

(4-1-3) Size of corner R: R 7 μm

(4-1-4) Surface roughness of wire

[0064]

Measurement point 1: Sa 0.030 μm
Measurement point 2: Sa 0.033 μm
Measurement point 3: Sa 0.035 μm
Average value: Sa 0.033 μm

(4-2) Combination 2

(4-2-1) Wire diameter

[0065]

Measurement point 1: 79.8 μm in length and 80.1 μm in width
Measurement point 2: 79.9 μm in length and 79.8 μm in width
Measurement point 3: 80.1 μm in length and 79.9 μm in width
Average value: 79.9 μm

(4-2-2) Magnitude of resistance during wire drawing: 1.75 N

(4-2-3) Size of corner R: R 7 μm

(4-2-4) Surface roughness of wire

[0066]

Measurement point 1: Sa 0.033 μm
Measurement point 2: Sa 0.027 μm
Measurement point 3: Sa 0.032 μm
Average value: Sa 0.031 μm

(4-3) Combination 3

(4-3-1) Wire diameter

[0067]

Measurement point 1: 79.6 μm in length and 79.8 μm in width
Measurement point 2: 79.6 μm in length and 79.5 μm in width
Measurement point 3: 79.8 μm in length and 79.6 μm in width
Average value: 79.7 μm

(4-3-2) Magnitude of resistance during wire drawing: 2.0 N

(4-3-3) Size of corner R: R 12 μm

(4-3-4) Surface roughness of wire

[0068]

Measurement point 1: Sa 0.026 μm
Measurement point 2: Sa 0.036 μm
Measurement point 3: Sa 0.034 μm
Average value: Sa 0.032 μm

(5) Method for Measuring Wire Subjected to Wire Drawing Process

[0069] The wire diameter was obtained by measuring the length and width of the wire subjected to wire drawing at arbitrary three points (measurement points 1 to 3), using an electronic micrometer.

[0070] The size of the corner R was measured by cutting the wire subjected to wire drawing at arbitrary three locations to obtain the cut cross sections, and observing these cross sections using a laser microscope (VK-X series shape analysis laser microscope manufactured by Keyence Corp.).

[0071] The surface roughness of the wire was obtained by observing the wire subjected to wire drawing at arbitrary three points using the laser microscope (VK-X series shape analysis laser microscope manufactured by Keyence Corp.), and measuring the surface roughness Sa at these three points.

(6) Evaluation

[0072] According to these measurement results, the best result was obtained in Combination 2. The second best result was obtained in Combination 1. It can be seen that since Combination 3 is a conventional combination, Combination 3 is lower in wire quality than Combinations 1 and 2.

[0073] It should be understood that the embodiment and examples disclosed herein are illustrative and non-restrictive in every respect. The scope of the present invention is defined by the terms of the claims, rather than the description above, and is intended to include any modifications within the scope and meaning equivalent to the terms of the claims.

REFERENCE SIGNS LIST

[0074] 1 diamond; 2 case; 3 sintered alloy; 4 support ring made of an alloy; 5 polycrystalline diamond; 6 hole inner surface; 6a bell portion; 6b approach portion; 6c reduction portion; 6c1 tangent line; 6d bearing portion; 6e back relief portion; 6f exit portion; 7 processing hole; 7a corner portion; 7b1 first side; 7b2 second side; 7c center; 7d central axis; 10 irregularly-shaped diamond die.

Claims

1. An irregularly-shaped die for producing an irregularly-shaped wire, wherein

a processing hole having a bearing portion is provided,
a first side and a second side that face each other are provided in a bearing cross section of the bearing portion perpendicular to a wire draw-

ing direction, and
each of the first side and the second side has a shape that is convex toward a center side of the processing hole in the bearing cross section.

2. The irregularly-shaped die according to claim 1, wherein
a maximum distance between the first side and the second side is more than 100% and equal to or less than 150% of a minimum distance.

3. The irregularly-shaped die according to claim 1 or 2, wherein

a reduction portion is provided upstream of the bearing portion in the wire drawing direction,
the first side and the second side are provided in a reduction cross section of the reduction portion perpendicular to the wire drawing direction and the bearing cross section,
a corner portion of the processing hole is provided at an end of each of the first side and the second side in the reduction cross section, and
an opening angle of reduction of the corner portion is different from an opening angle of reduction of each of the first side and the second side.

4. The irregularly-shaped die according to claim 3, wherein
the opening angle of reduction of the corner portion is greater than the opening angle of reduction of each of the first side and the second side.

5. The irregularly-shaped die according to claim 4, wherein
the opening angle of reduction of the corner portion becomes greater with increasing distance from the first side and the second side and toward a tip of the corner portion.

6. A method for producing an irregularly-shaped wire, wherein
a wire is processed using a first irregularly-shaped die, the irregularly-shaped die as recited in claim 1 or 2, and a second irregularly-shaped die in this order.

7. A method for producing an irregularly-shaped wire, wherein
a wire is processed using a first irregularly-shaped die, the irregularly-shaped die as recited in claim 3, and a second irregularly-shaped die in this order.

FIG.1

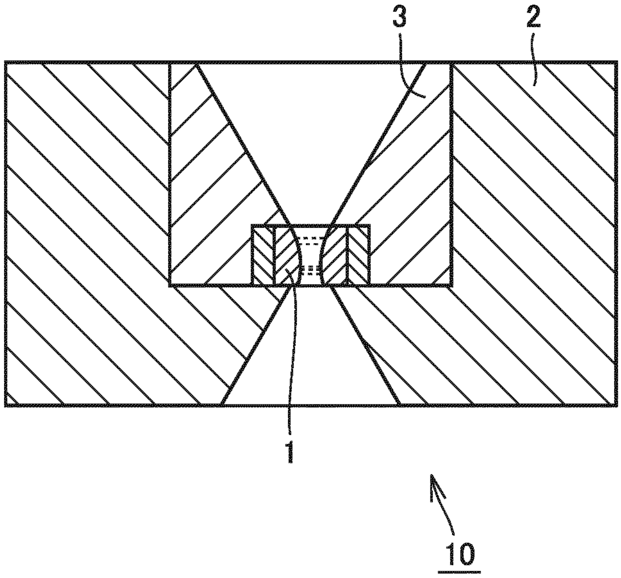


FIG.2

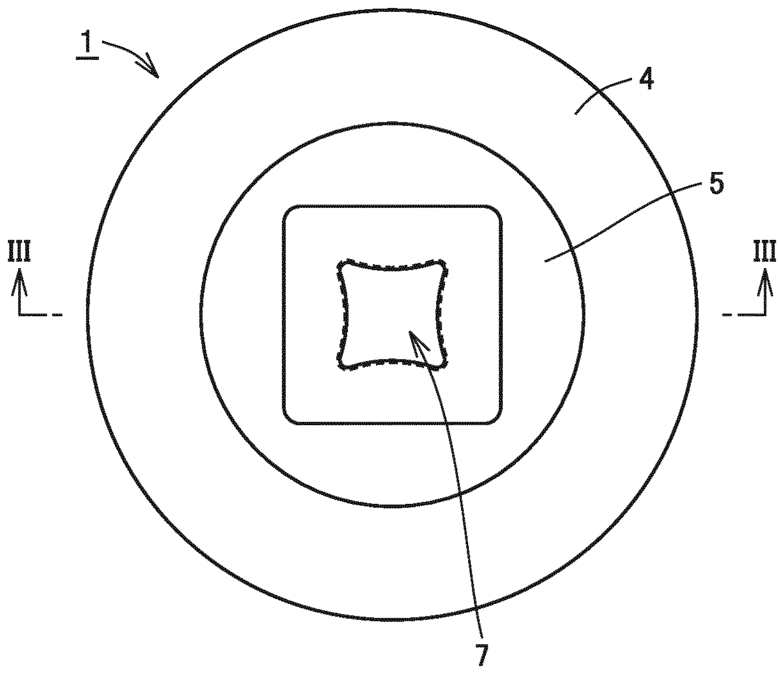


FIG.3

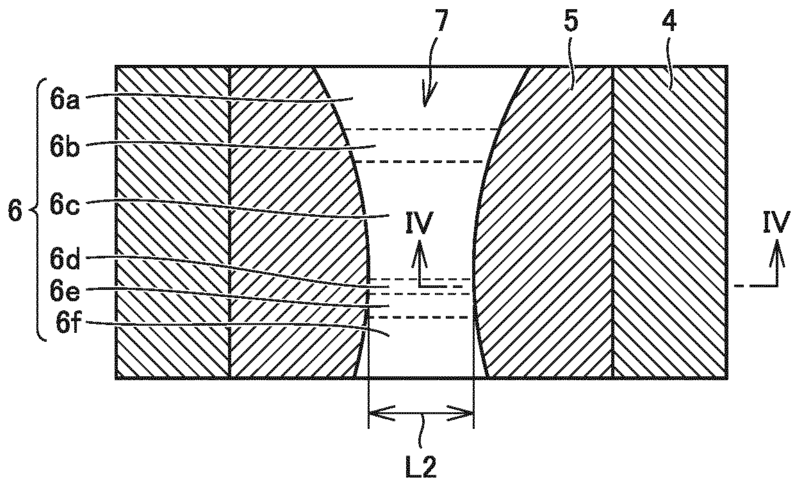


FIG.4

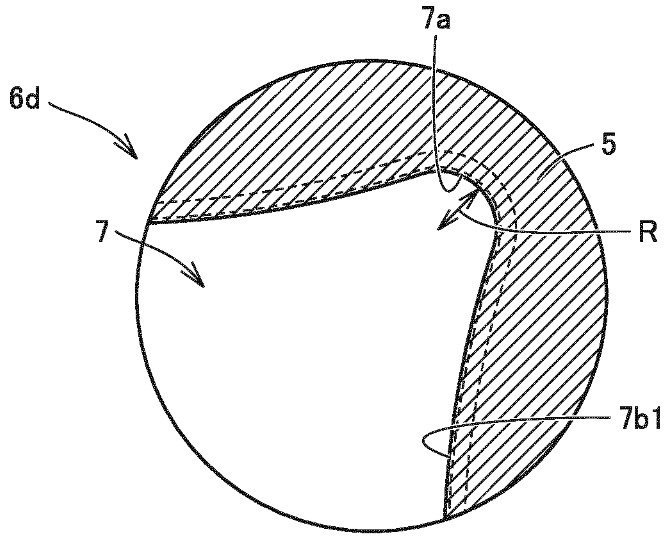


FIG.5

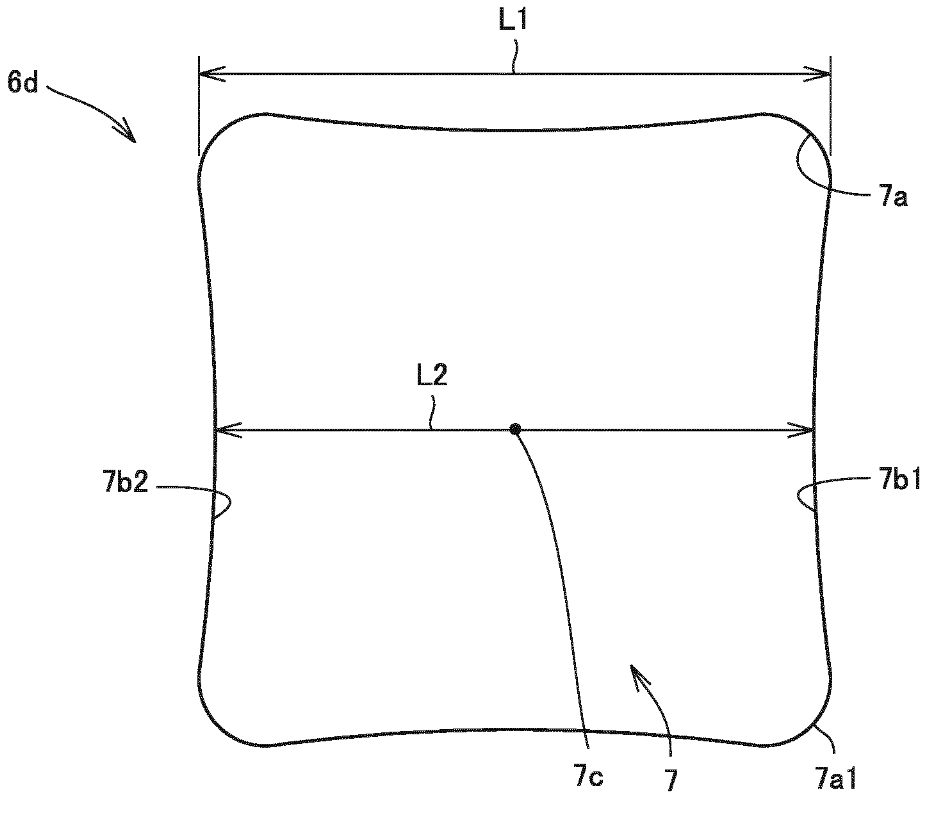


FIG.6

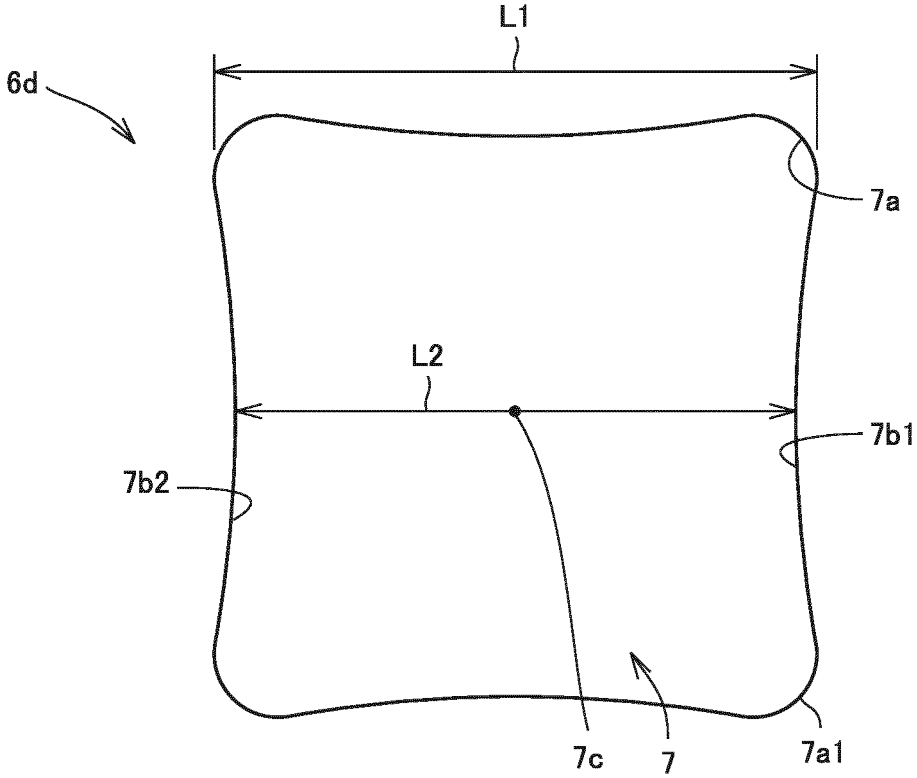


FIG.7

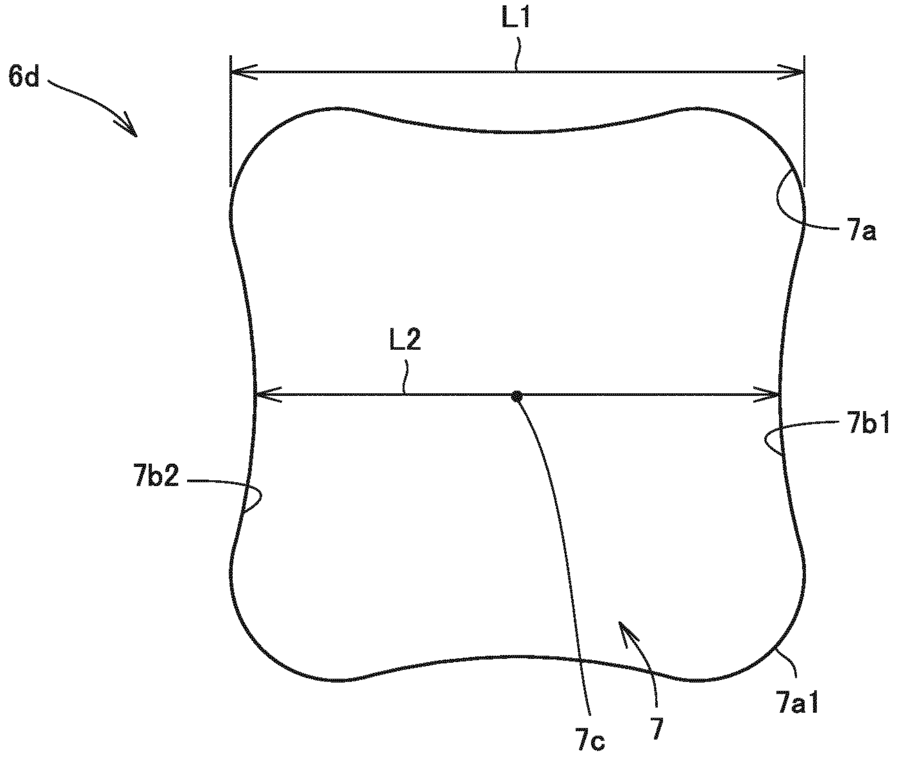


FIG.8

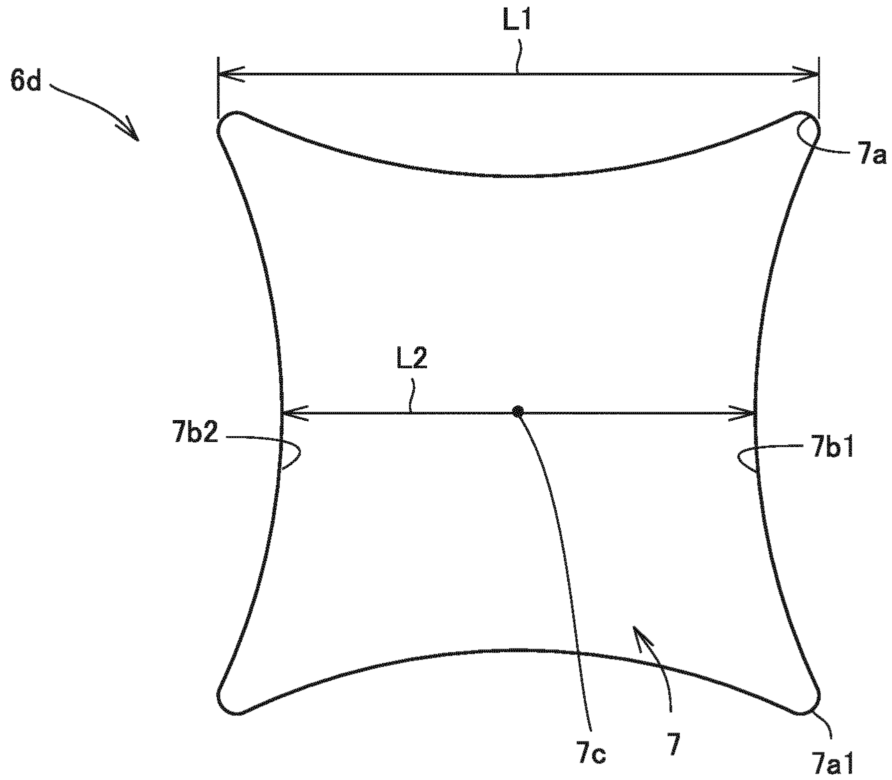


FIG.9

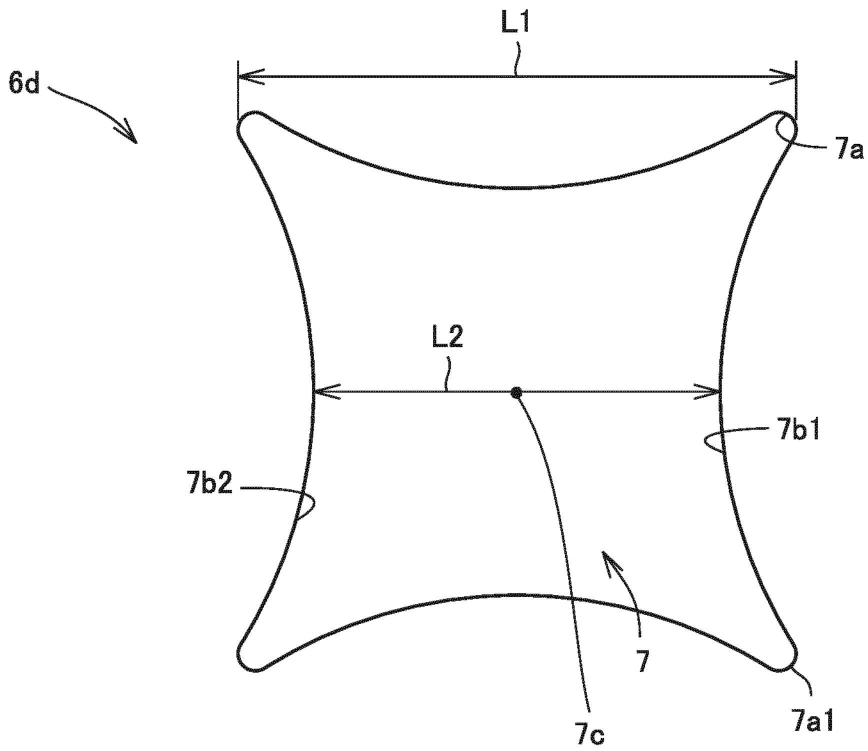


FIG.10

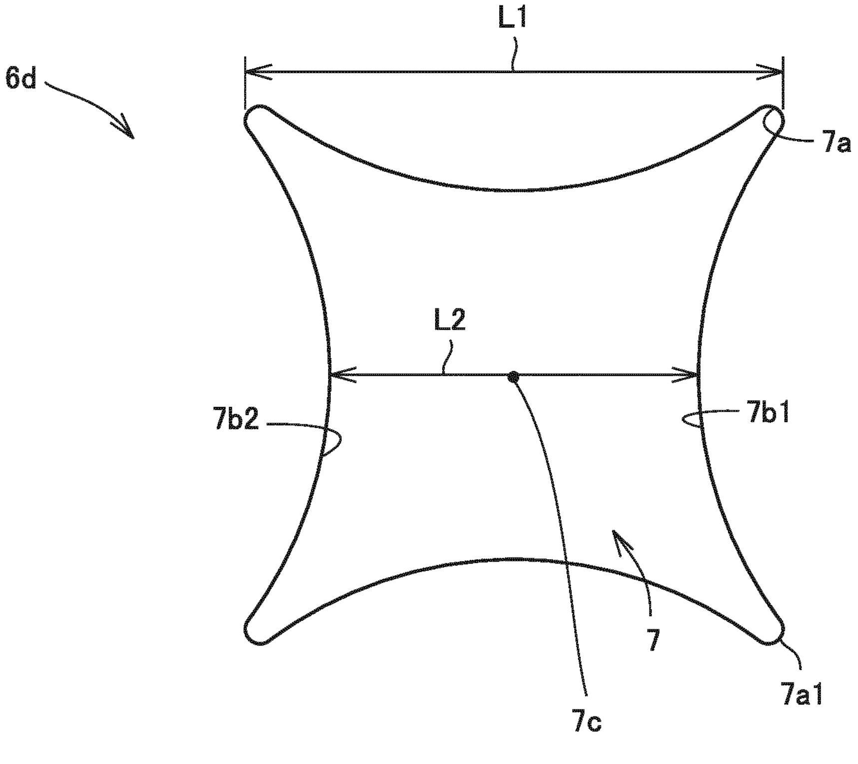


FIG.11

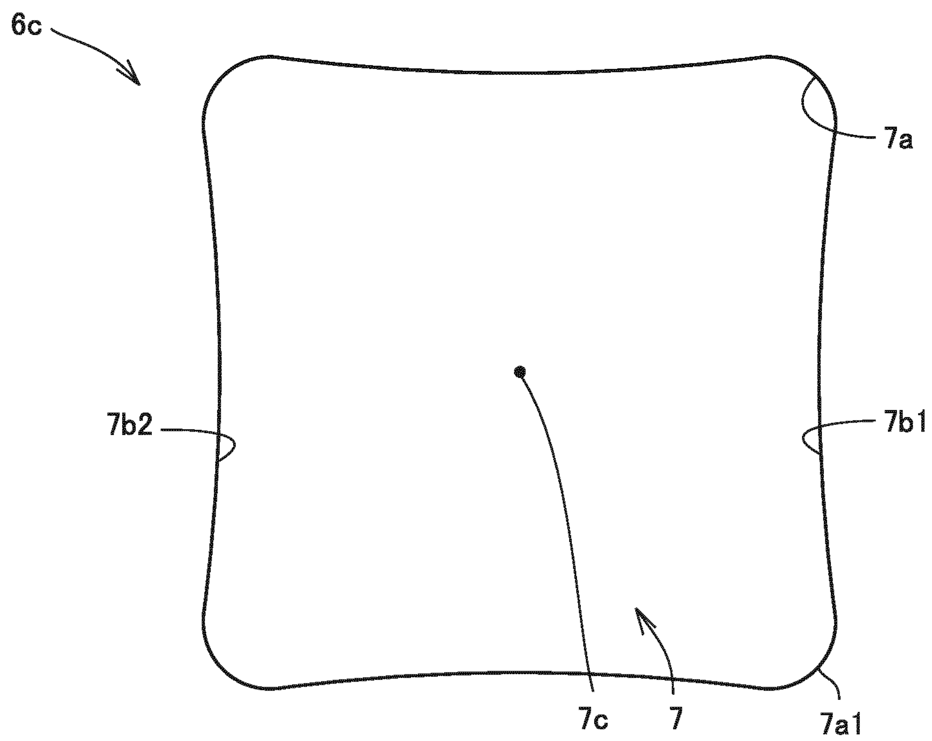


FIG.12

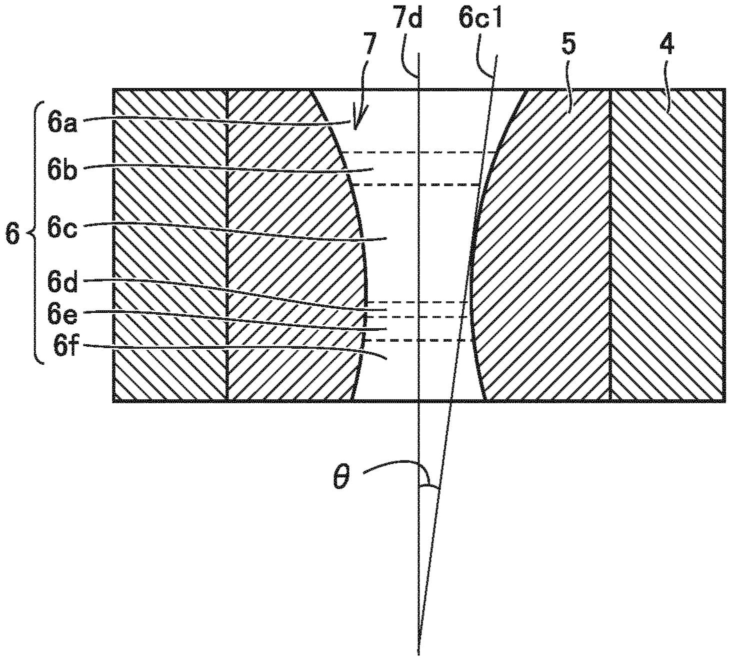
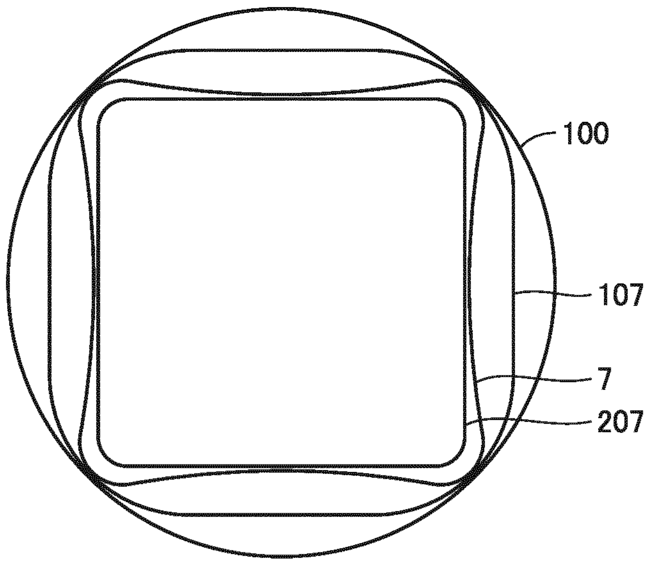


FIG.13



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/041556

A. CLASSIFICATION OF SUBJECT MATTER

B21C 3/02(2006.01)i; ***B21C 1/00***(2006.01)i
FI: B21C3/02 B; B21C3/02 K; B21C1/00 B

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)

B21C3/02; B21C1/00

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 1971-203
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.
X	JP 2008-149324 A (SANYO METAL INDUSTRIES CORP.) 03 July 2008 (2008-07-03) paragraphs [0048]-[0076], fig. 1-15	1-2, 6
Y		1-7
X	JP 2002-263727 A (NIPPON STEEL CORP.) 17 September 2002 (2002-09-17) paragraphs [0002]-[0004], [0029]-[0038], fig. 10, 13	1-2, 6
Y		1-7
Y	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 042198/1981 (Laid-open No. 156215/1982) (SUMITOMO METAL INDUSTRIES, LTD.) 01 October 1982 (1982-10-01), specification, p. 2, line 6 to p. 5, line 15, fig. 1-3	1-7
Y	JP 2005-254311 A (ALLIED MATERIAL CORP.) 22 September 2005 (2005-09-22) paragraphs [0014]-[0018], fig. 1-7	3-5, 7

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

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Date of the actual completion of the international search	Date of mailing of the international search report
06 January 2023	**24 January 2023**

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office (ISA/JP) **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	 Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/041556

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2008-149324 A	03 July 2008	(Family: none)	
JP 2002-263727 A	17 September 2002	(Family: none)	
JP 57-156215 U1	01 October 1982	(Family: none)	
JP 2005-254311 A	22 September 2005	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2021184040 A **[0001]**
- JP 2018123513 A **[0002] [0003]**