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

(11) **EP 3 815 811 A1**

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

(43) Date of publication:
05.05.2021 Bulletin 2021/18

(21) Application number: **19827277.5**

(22) Date of filing: **21.06.2019**

(51) Int Cl.:
B21K 1/22 *(2006.01)* ***B21D 22/16*** *(2006.01)*
B21D 53/10 *(2006.01)* ***B21J 1/04*** *(2006.01)*
B21J 1/06 *(2006.01)* ***B21J 5/06*** *(2006.01)*
B21J 5/08 *(2006.01)* ***C21D 9/00*** *(2006.01)*

(86) International application number:
PCT/JP2019/024806

(87) International publication number:
WO 2020/004286 (02.01.2020 Gazette 2020/01)

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

(30) Priority: **28.06.2018 JP 2018123686**

(71) Applicant: **Toa Forging Co., Ltd.**
Mie-gun, Mie 510-8122 (JP)

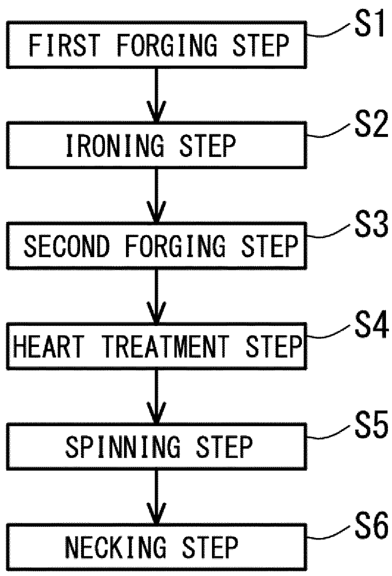
(72) Inventors:
- **IKEDA Toshio**
Mie-gun Mie 510-8122 (JP)
- **KIMURA Moritoshi**
Mie-gun Mie 510-8122 (JP)
- **WATANABE Yutaka**
Mie-gun Mie 510-8122 (JP)

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

(54) METHOD FOR MANUFACTURING HOLLOW ENGINE VALVE

(57) A method for manufacturing a hollow engine valve, by which method the surface condition of an inner surface making up a hollow is made fine and the volume of the hollow is increased, is provided. The method for manufacturing includes a forging step (S3) of obtaining an intermediate part (7) by a forging process, the intermediate part having a cylindrical portion (8B) and a semi-umbrella-shaped portion (9B) continuous with an axial end of the cylindrical portion; a heat treatment step (S4) of keeping the intermediate part at a given heating temperature for a temperature-keeping time (t2) determined in accordance with a wall-thickness (t) of the cylindrical portion (8B), to soften the intermediate part; a spinning step (S5) of drawing the cylindrical portion of the heat-treated intermediate part in an axial direction by a spinning process; and a necking step (S6) of reducing the diameter of the cylindrical portion drawn in the axial direction, by a drawing process to form a shank (2) and an umbrella-shaped portion (3).

FIG1



EP 3 815 811 A1

Description

TECHNICAL FIELD

[0001] The present invention relates to a method for manufacturing a hollow engine valve and relates specifically to a method for manufacturing a hollow engine valve having a shank, an umbrella-shaped portion continuous with an axial end of the shank, and a hollow formed in such a way as to extend from the shank to the umbrella-shaped portion.

BACKGROUND ART

[0002] A conventional method for manufacturing a hollow engine valve has been known, according to which an intermediate part is manufactured by a forging process, the intermediate part having a cylindrical portion and a semi-umbrella-shaped portion continuous with an axial end of the cylindrical portion, and the cylindrical portion of the intermediate part is spun and then is drawn to reduce the diameter of the cylindrical portion to manufacture the hollow engine valve (see claim 5, paragraph [0023], etc., of Patent Literatures 1).

CITATIONS LIST

PATENT LITERATURE

[0003] Patent Literature 1: WO 2011/104903 A

SUMMARY OF THE INVENTION

TECHNICAL PROBLEMS

[0004] However, according to the conventional method for manufacturing the hollow engine valve, the intermediate part obtained by the forging process is subjected to the heat treatment of keeping the intermediate part at the given heating temperature for the temperature-keeping time that is determined based on reference documents, materials, etc., and workers' experience, and the cylindrical portion of the heat-treated intermediate part is subjected to the spinning process. Therefore, drawing the cylindrical portion of the intermediate part becomes difficult during the spinning process in some cases. In such a case, the machined surface of the cylindrical portion of the intermediate part, that is, the outer peripheral surface of the cylindrical portion has a surface condition different from that of the inner peripheral surface of the cylindrical portion, the inner peripheral surface not being brought into contact with a machining tool. Specifically, the inner peripheral surface of the cylindrical portion of the intermediate part, that is, the inner surface making up the hollow of the hollow engine valve develops surface roughness, which deteriorates the surface condition of the inner surface. This reduces the strength of the hollow engine valve. In a case where metallic sodium is put into the hollow of the hollow engine valve for a cooling purpose, the metallic sodium has lower flowability in the hollow, thus exerting a lower cooling function.

[0005] These problems become conspicuous, in particular, when a hard-to-work austenitic heat-resistant material, such as nickel-base superalloy and austenitic stainless steel, is machined.

[0006] Now, to reduce the weight of the hollow engine valve, it is necessary to increase the volume of the hollow. However, according to the conventional method for manufacturing the hollow engine valve, because the intermediate part obtained by the forging process is subjected to the heat treatment of keeping the intermediate part at the given heating temperature for the temperature-keeping time that is determined based on reference documents, materials, etc., and workers' experience, and the cylindrical portion of the heat-treated intermediate part is subjected to the spinning process, as described above, drawing the cylindrical portion of the intermediate part becomes difficult during the spinning process and during the drawing process as well. For this reason, the intermediate part must be drawn deeply with a mold to apply a greater pressure up to the bottom end side of the cylindrical portion of the intermediate part. Such a process leads to a tendency that the umbrella-shaped portion of the hollow engine valve readily collapses at the outer periphery side of the hollow, making it impossible to increase the volume of the hollow of the umbrella-shaped portion.

[0007] The present invention has been conceived in view of the above circumstance, and it is therefore an object of the invention to provide a method for manufacturing a hollow engine valve by which the surface condition of an inner surface making up a hollow is made fine and the volume of the hollow is increased.

SOLUTIONS TO PROBLEMS

[0008] The present invention is summarized as follows.

1. A method for manufacturing a hollow engine valve having a shank, an umbrella-shaped portion continuous with an axial end of the shank, and a hollow formed in such a way as to extend from the shank to the umbrella-shaped portion is provided. The method for manufacturing includes a forging step of obtaining an intermediate part by a forging process, the intermediate part having a cylindrical portion and a semi-umbrella-shaped portion continuous with an axial end of the cylindrical portion; a heat treatment step of keeping the intermediate part at a given heating temperature for a temperature-keeping time determined in accordance with a wall-thickness of the cylindrical portion, to soften the intermediate part; a spinning step of drawing the cylindrical portion of the heat-treated intermediate part in an axial direction by a spinning process; and a necking step of reduc-

ing the diameter of the cylindrical portion by a drawing process, the cylindrical portion being drawn in the axial direction, to form the shank and the umbrella-shaped portion.

2. According to the method for manufacturing the hollow engine valve described in 1., the intermediate part is made of an austenitic heat-resistant material, and, at the heat treatment step, the intermediate part is kept heated at temperatures ranging from 1000°C to 1100°C and then is cooled with water.

3. According to the method for manufacturing the hollow engine valve described in 2., at the heat treatment step, the intermediate part heated to a heating temperature is kept at the heating temperature such that a 1 mm portion of a wall-thickness of the cylindrical portion is kept at the heating temperature for a temperature-keeping time of 3 to 8 minutes.

4. According to the method for manufacturing the hollow engine valve described in 2. or 3., at the heat treatment step, the intermediate part is cooled with water by submerging the intermediate part into cooling water stirred in a container or cooling water circulated to a container.

5. According to the method for manufacturing the hollow engine valve described in 4., a temperature of the cooling water ranges from 15°C to 35°C.

6. According to the method for manufacturing the hollow engine valve described in any one of 1. to 5., at the spinning step, a machining roller is moved in an axial direction relative to the cylindrical portion as a peripheral arcuate surface of the machining roller is pressed at a given cutting depth against an outer peripheral surface of the cylindrical portion, to draw the cylindrical portion in the axial direction. A radius of curvature of the peripheral arcuate surface of the machining roller is 3 to 5 times a wall-thickness of the cylindrical portion not subjected to a spinning process yet. During the spinning process, a straight line connecting one end to the other end of an arc formed at a point of contact between the peripheral arcuate surface of the machining roller and the outer peripheral surface of the cylindrical portion on a section along the axial direction of the cylindrical portion is tilted at a tilt angle of 5 degrees to 7 degrees against the axial direction of the cylindrical portion.

7. According to the method for manufacturing the hollow engine valve described in any one of 1. to 6., in the hollow engine valve, surface roughness Ra of an inner surface making up the hollow is from 4.0 to 22.0.

8. According to the method for manufacturing the hollow engine valve described in any one of 1. to 7., at the forging step, an arcuate surface is formed on a bottom end side of an inner peripheral surface of the cylindrical portion of the intermediate part. At the necking step, when the cylindrical portion is at an upper side as the semi-umbrella-shaped portion is at a lower side, a part of the cylindrical portion, the part being above the arcuate surface in an axial direction of the cylindrical portion, is subjected to a drawing process.

9. According to the method for manufacturing the hollow engine valve described in any one of 1. to 8., at the spinning step, the cylindrical portion of the intermediate part is subjected to a spinning process, using a machining roller. The machining roller is supported rotatably by a support member via front and rear bearings arranged across the machining roller along of an axial direction of the machining roller.

ADVANTAGEOUS EFFECTS OF INVENTION

[0009] The method for manufacturing the hollow engine valve according to the present invention includes the forging step of obtaining the intermediate part by the forging process, the intermediate part having the cylindrical portion and the semi-umbrella-shaped portion continuous with the axial end of the cylindrical portion; the heat treatment step of keeping the intermediate part at a given heating temperature for a temperature-keeping time determined in accordance with a wall-thickness of the cylindrical portion, to soften the intermediate part; the spinning step of drawing the cylindrical portion of the heat-treated intermediate part in the axial direction by the spinning process; and the necking step of reducing the diameter of the cylindrical portion by the drawing process, the cylindrical portion being drawn in the axial direction, to form the shank and the umbrella-shaped portion. In this manner, the intermediate part obtained by the forging process is softened by the heat treatment. As a result, the cylindrical portion of the intermediate part is drawn easily during the spinning process and the drawing process. The spinning process and the drawing process thus offer excellent processing performance. This inhibits development of surface roughness on the inner surface making up the hollow of the hollow engine valve, thus achieving a fine surface condition. Hence, a reduction in the strength of the hollow engine valve is suppressed. In the case where metallic sodium is put into the hollow of the hollow engine valve for a cooling purpose, the metallic sodium flows smoothly in the hollow to exert an effective cooling function. Because the drawing process offers excellent processing performance, the mold can be adjusted easily in height at mold-clamping in the drawing process to prevent the collapse of the umbrella-shaped portion at the outer periphery side of the hollow. This allows an increase in the volume of the hollow of the hollow engine valve.

[0010] The intermediate part is made of the austenitic heat-resistant material, and, at the heat treatment step, the intermediate part is kept heated at temperatures ranging from 1000°C to 1100°C and then is cooled with water. In this case, the intermediate part is subjected to a solution heat treatment to be softened effectively.

[0011] At the heat treatment step, the intermediate part heated to the heating temperature is kept at the heating temperature such that the 1 mm portion of the wall-thickness of the cylindrical portion is kept at the heating temperature for the temperature-keeping time of 3 to 8 minutes. In this case, the temperature-keeping time for keeping the intermediate part at the heating temperature can be made relatively short to suppress development of an oxide film on the surface of the intermediate part subjected to the heat treatment.

[0012] At the heat treatment step, the intermediate part is cooled with water by submerging the intermediate part into cooling water stirred in a container or cooling water circulated to a container. In this case, a rise in the temperature of the cooling water is curbed, and therefore the intermediate part can be cooled effectively and rapidly at the heat treatment step.

[0013] The temperature of the cooling water ranges from 15°C to 35°C. In this case, the intermediate part can be cooled effectively and rapidly at the heat treatment step.

[0014] At the spinning step, the machining roller is moved in the axial direction relative to the cylindrical portion as the peripheral arcuate surface of the machining roller is pressed at the given cutting depth against the outer peripheral surface of the cylindrical portion, to draw the cylindrical portion in the axial direction, the radius of curvature of the peripheral arcuate surface of the machining roller is 3 to 5 times the wall-thickness of the cylindrical portion not subjected to the spinning process yet, and, during the spinning process, the straight line connecting one end to the other end of the arc formed at the point of contact between the peripheral arcuate surface of the machining roller and the outer peripheral surface of the cylindrical portion on the section along the axial direction of the cylindrical portion is tilted at the tilt angle of 5 degrees to 7 degrees against the axial direction of the cylindrical portion. In this case, the radius of curvature of the peripheral arcuate surface of the machining roller is determined as the estimated maximum and minimum of the cutting depth are taken into consideration. As a result, the cylindrical portion of the intermediate part can be drawn effectively through the spinning process.

[0015] In the hollow engine valve, the surface roughness Ra of the inner surface making up the hollow is from 4.0 to 22.0. In this case, the surface condition of the inner surface making up the hollow of the hollow engine valve is extremely fine.

[0016] At the forging step, the arcuate surface is formed on the bottom end side of the inner peripheral surface of the cylindrical portion of the intermediate part. At the necking step, when the cylindrical portion is at the upper side as the semi-umbrella-shaped portion is at the lower side, the part of the cylindrical portion, the part being above the arcuate surface in the axial direction of the cylindrical portion, is subjected to the drawing process. In this case, the maximum outer diameter of the hollow of the hollow engine valve is made substantially equal to the inner diameter of the opening of the cylindrical portion of the intermediate part obtained by the forging process. As a result, the volume of the hollow of the hollow engine valve can be further increased.

[0017] At the spinning step, the cylindrical portion of the intermediate part is subjected to the spinning process, using the machining roller. The machining roller is supported rotatably by the support member via the front and rear bearings arranged across the machining roller along the axial direction of the machining roller. In this case, the machining roller is prevented from leaning forward. The cylindrical portion of the intermediate part is therefore spun effectively.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The present invention will be described by citing exemplary embodiments that do not limit the invention. In the following description, the exemplary embodiments will be explained specifically with reference to the accompanying drawings, and, in some of the drawings, the same reference signs denote the same components.

FIG. 1 is an explanatory view of a method for manufacturing a hollow engine valve according to an example.

FIG. 2 is explanatory view of the method for manufacturing the hollow engine valve according to the example, in which (a) shows a vertical sectional view of a raw material, (b) shows a vertical sectional view of an intermediate part obtained at a first forging step, and (c) shows a vertical sectional view of the intermediate part having been subjected an ironing step.

FIG. 3 is explanatory view of the method for manufacturing the hollow engine valve, in which (a) shows a vertical sectional view of the intermediate part having been subjected a second forging step, (b) shows a vertical sectional view of the intermediate part having been subjected a spinning step, and (c) shows a vertical sectional view of the hollow engine valve obtained at a necking step.

FIG. 4 is an explanatory view of a heat treatment step according to the example.

FIG. 5 is an explanatory view of the heat treatment step.

FIG. 6 is an explanatory view of the spinning step.

FIG. 7 is an explanatory view of the necking step, in which a vertical sectional view of the intermediate part right before being subjected to a drawing process is shown at the left of a center line while a vertical sectional view of the hollow engine valve having been subjected to the drawing process is shown at the right of the center line.

FIG. 8 is an explanatory view of another form of the necking step.

FIG. 9 is explanatory view of a surface condition of the hollow engine valve according to the example, in which (a) shows a processed image of a vertical section of a principle part of the intermediate part having been subjected to the spinning step, and (b) shows a processed image of a vertical section of a principle part of the hollow engine valve.

FIG. 10 is explanatory view of a surface condition of a hollow engine valve according to a comparative example, in which (a) shows a processed image of a vertical section of the principle part of the intermediate part having been subjected to the spinning step, and (b) shows a processed image of a vertical section of the principle part of the hollow engine valve.

FIG. 11 is a table showing results of tests of the method for manufacturing the hollow engine valve, the tests being conducted in test examples 1 to 7.

FIG. 12 is a table showing results of tests of the method for manufacturing the hollow engine valve, the tests being conducted in test examples 8 to 13.

FIG. 13 is a table showing results of tests of the method for manufacturing the hollow engine valve, the tests being conducted in test examples 14 to 19 and the comparative example.

FIG. 14 is an explanatory view of another form of the spinning step.

FIG. 15 is an enlarged view of a principle part of components shown in FIG. 14.

FIG. 16 is table showing results of tests of the spinning step conducted in test examples, in which (a) shows results of tests conducted in test examples 20 to 24 and (b) shows results of tests conducted in test examples 25 to 27.

DESCRIPTION OF EMBODIMENTS

[0019] What is described herein includes examples and exemplary explanations of an embodiment of the present invention. The description is made for the purpose of providing examples and explanations that allow readers to readily understand the principle and conceptual features of the present invention most effectively. The description is not intended for giving structural details of the invention to an extent that they exceed details necessary for basic understanding of the present invention. It is intended to let those who are skilled in the art to understand how some features of the invention are embodied in practical applications by referring to drawings and explanations.

[0020] A method for manufacturing a hollow engine valve according to an embodiment is a method for manufacturing a hollow engine valve (1) having a shank (2), an umbrella-shaped portion (3) continuous with an axial end of the shank (2), and a hollow (4) formed in such a way as to extend from the shank (2) to the umbrella-shaped portion (3). The method for manufacturing includes a forging step (S3) of obtaining an intermediate part (7C) by a forging process, the intermediate part (7C) having a cylindrical portion (8B) and a semi-umbrella-shaped portion (9B) continuous with an axial end of the cylindrical portion (8B); a heat treatment step (S4) of keeping the intermediate part at a given heating temperature for a temperature-keeping time (t2) determined in accordance with a wall-thickness (t) of the cylindrical portion (8B), to soften the intermediate part (7C); a spinning step (S5, S5') of drawing the cylindrical portion (8B) of the heat-treated intermediate part (7C) in an axial direction by a spinning process; and a necking step (S6) of reducing the diameter of the cylindrical portion (8B) by a drawing process, the cylindrical portion (8B) being drawn in the axial direction, to form the shank (2) and the umbrella-shaped portion(3) (see, for example, FIGS. 1 to 3).

[0021] The method for manufacturing the hollow engine valve according to the embodiment is carried out, for example, in a mode in which the intermediate part (7C) is made of an austenitic heat-resistant material, and, at the heat treatment step (S4), the intermediate part (7C) is kept heated at temperatures ranging from 1000°C to 1100°C (preferably, from 1030°C to 1070°C, more preferably, from 1040°C to 1060°C) and then is cooled with water (see, for example, FIGS. 11 to 13). The austenitic heat-resistant material is provided as, for example, nickel-base superalloy, such as NCF 751 or Inconel 751 (registered trademark), stainless steel, such as SUS 304, and heat-resistant steel, such as SUH 35 and SUH 38.

[0022] In the above mode, for example, at the heat treatment step (S4), the intermediate part (7C) heated to a heating temperature is kept at the heating temperature such that a 1 mm portion of the wall-thickness (t) of the cylindrical portion (8B) is kept at the heating temperature for a temperature-keeping time (t2) of 3 to 8 minutes (preferably, 4 to 6 minutes) (see, for example, FIGS. 11 to 13). In this case, for example, the wall-thickness (t) of the cylindrical portion (8B) of the intermediate part (7C) ranges from 1 mm to 3 mm, and, at the heat treatment step (S4), the intermediate part (7C) heated to the heating temperature is kept at the heating temperature for a temperature-keeping time of 3 to 24 minutes (preferably, 4 to 18 minutes, more preferably, 5 to 15 minutes).

[0023] In the above mode, for example, at the heat treatment step (S4), the intermediate part (7C) is cooled with water by submerging the intermediate part (7C) into cooling water (23) stirred in a container (22) or cooling water (23) circulated to a container (22) (see, for example, FIG. 5). In this case, for example, the temperature of the cooling water ranges from 15°C to 35°C (preferably, from 20°C to 30°C) (see, for example, FIGS. 11 to 13).

[0024] According to the method for manufacturing the hollow engine valve according to the embodiment, for example, at the spinning step (S5'), a machining roller (132) is moved in an axial direction relative to the cylindrical portion (8B) as a peripheral arcuate surface (132a) of the machining roller (132) is pressed at a given cutting depth (d) against the outer peripheral surface of the cylindrical portion (8B), to draw the cylindrical portion (8B) in the axial direction, as shown in FIGS. 14 and 15. In this case, for example, the radius of curvature (R) of the peripheral arcuate surface (132a) of the machining roller (132) is 3 to 5 times the wall-thickness (t) of the cylindrical portion (8B) not subjected to a spinning process yet. During the spinning process, a straight line (L1) connecting one end (p1) to the other end (p2) of an arc formed at a point of contact between the peripheral arcuate surface (132a) of the machining roller (132) and the outer peripheral surface of the cylindrical portion (8B) on a section along the axial direction of the cylindrical portion (8B) is tilted at a tilt angle (θ1) of 5 degrees to 7 degrees against the axial direction of the cylindrical portion (8B).

[0025] The method for manufacturing the hollow engine valve according to the embodiment is carried out, for example, in a mode in which, in the hollow engine valve (1), the surface roughness Ra of an inner surface making up the hollow (4) is from 4.0 to 22.0 (preferably, 4.0 to 12.0, more preferably, from 4.0 to 8.0 and, still more preferably, from 4.0 to 6.0) (see, for example, FIG. 9). The surface roughness (Ra) is measured as an arithmetic mean roughness. The surface roughness (Ra) represents the surface roughness that results after the necking step is over.

[0026] The method for manufacturing the hollow engine valve according to the embodiment is carried out, for example, in a mode in which, at the forging step (S3), an arcuate surface (17) is formed on the bottom end side of the inner peripheral surface of the cylindrical portion (8B) of the intermediate part (7C), and, at the necking step (S6), when the cylindrical portion (8B) is at the upper side as the semi-umbrella-shaped portion (9B) is at the lower side, a part of the cylindrical portion(8B), the part being above the arcuate surface (17) in the axial direction of the cylindrical portion (8B), is subjected to the drawing process (see, for example, FIG. 8). In this case, for example, the maximum outer diameter (D1') of the hollow (4) of the hollow engine valve (1) is made equal to the inner diameter (D2) of an opening of the cylindrical portion (8B) of the intermediate part (7C) obtained at the forging step (S3).

[0027] To be exact, the above expression "made equal" means "made substantially equal", and therefore connotes a difference of about ±5%.

[0028] The method for manufacturing the hollow engine valve according to the embodiment is carried out, for example, in a mode in which, at the spinning step (S5, S5'), the cylindrical portion (8B) of the intermediate part (7C) is subjected to the spinning process, using a machining roller (32, 132), and the machining roller (32, 132) is supported rotatably by a support member (35, 135) via front and rear bearings (34, 134) arranged across the machining roller (32,132) along the axial direction of the machining roller (see, for example, FIGS. 6 and 14).

[0029] The method for manufacturing the hollow engine valve according to the embodiment is carried out, for example, in a mode in which the method for manufacturing includes a first forging step (S1) of subjecting a solid columnar raw material (6) to the forging process to obtain an intermediate part (7A) having a cotyloid wide-diameter portion (8A) and a columnar portion (9A) continuous with an axial end of the cotyloid wide-diameter portion (8A), the axial end being reduced in diameter, and an ironing step (S2) of shaping the cotyloid wide-diameter portion (8A) into the cylindrical portion (8B) by an ironing process, and the forging step (S3) mentioned above is a second forging step (S3) of shaping the columnar portion (9A) into the semi-umbrella-shaped portion (9B) by the forging process (see, for example, FIGS. 1 to 3).

[0030] Reference signs for constituent elements placed in parentheses in the above description of the embodiment correspond to reference signs for constituent elements of an example, which will be described later.

EXAMPLE

[0031] An example of the present invention will hereinafter be described specifically with reference to drawings.

(1) Configuration of Hollow Engine Valve

[0032] A hollow engine valve 1 according to the example includes a shank 2 and an umbrella-shaped portion 3 continuous with an axial end of the shank 2, as shown in FIG. 3(c). A hollow 4 is formed in such a way as to extend from the shank 2 to the umbrella-shaped portion 3. The maximum outer diameter D1 of the hollow 4 is made slightly smaller than the inner diameter D2 (see FIG. 3(a)) of an opening of a cylindrical portion 8B of an intermediate part 7C obtained at a forging step S3, which will be described later. In the hollow engine valve 1, the surface roughness Ra of an inner surface making up the hollow 4 is about 4.0 (see FIG. 9).

(2) Method for Manufacturing Hollow Engine Valve

[0033] As shown in FIG. 1, a method for manufacturing a hollow engine valve according to the example includes a first forging step S1, an ironing step S2, a second forging step S3, a heat treatment step S4, a spinning step S5, and a necking step S6.

[0034] As shown in FIGS. 2(a) and 2(b), the first forging step S1 is a step of subjecting a solid columnar raw material 6 made of a nickel-base superalloy to a hot forging process to obtain an intermediate part 7A. This intermediate part 7A has a cotyloid wide-diameter portion 8A and a columnar portion 9A continuous with an axial end of the cotyloid wide-diameter portion 8A. At the first forging step S1, a mold 11 and a mold 12 are used. The mold 11 has a protrusion 11a for forming the inner wall of the cotyloid wide-diameter portion 8A, and the mold 12, which holds the raw material 6, has a recession 12a for forming the outer wall of the cotyloid wide-diameter portion 8A.

[0035] As shown in FIGS. 2(b) and 2(c), the ironing step S2 is carried out mainly as a step of shaping the cotyloid wide-diameter portion 8A of the intermediate part 7A into the cylindrical portion 8B by a cold ironing process to obtain an intermediate part 7B. The outer diameter of the cylindrical portion 8B is made substantially equal to that of the columnar portion 9A. At the ironing step S2, a mold 14 and a mold 15 are used. The mold 14 has a through-hole 14a for ironing the cotyloid wide-diameter portion 8A while the mold 15 has a projection 15a for applying a pressure to the columnar portion 9A.

[0036] As shown in FIG. 2(c) and FIG. 3(a), the second forging step S3 is carried out mainly as a step of subjecting the columnar portion 9A of the intermediate part 7B to the hot forging process to obtain the intermediate part 7C as a semi-umbrella-shaped portion 9B, which is a semi-finished form of the umbrella-shaped portion 3. This means that the intermediate part 7C obtained at the second forging step S3 has the cylindrical portion 8B and the semi-umbrella-shaped portion 9B continuous with an axial end of the cylindrical portion 8B. On the bottom end side of the inner peripheral surface of the cylindrical portion 8B, an arcuate surface 17 is formed. At the second forging step S3, a mold 18, a mold 19, and a pin 20 are used. The mold 18 has a protrusion 18a for applying a pressure to the bottom of the columnar portion 9A, the mold 19 has a through-hole 19a that holds the columnar portion 9A and cylindrical portion 8B on their outer periphery, and the pin 20 is inserted into the through-hole 19a to come in contact with the bottom end of the cylindrical portion 8B.

[0037] The wall-thickness t of the cylindrical portion 8B of the intermediate part 7C obtained at the second forging step S3 is determined to be about 2 mm.

[0038] The heat treatment step S4 is a step of subjecting the intermediate part 7C to a solution heat treatment at a given heating temperature for a temperature-keeping time t2 determined in accordance with a wall-thickness t of the cylindrical portion 8B, to soften the intermediate part 7C. As shown in FIG. 4, at the heat treatment step S4, the intermediate part 7C is heated to a given heating temperature T1 (e.g., 1050°C), is kept at the heating temperature T1, and then is cooled with water. Specifically, the intermediate part 7C having an ordinary temperature T2 (e.g., 20°C) is heated to the heating temperature T1 in a given temperature-increasing time t1 (e.g., 5 minutes) and is kept at the heating temperature T1 for a given temperature-keeping time t2 (e.g., 10 minutes). Subsequently, the intermediate part 7C is cooled rapidly to the ordinary temperature T2 in a given cooling time t3 (e.g., 10 seconds). The temperature-keeping time t2 is the time for keeping a 1 mm portion of the wall-thickness t of the cylindrical portion 8B of the intermediate part 7C at the heating temperature for about 5 minutes.

[0039] In the above process of cooling with water, cooling water 23, such as tap water, held in a container 22 is used, as shown in FIG. 5. A nozzle 25 connected to a pump 24 and capable of jetting water is disposed in the container 22. The nozzle 25 is disposed such that water jetted out of the nozzle 25 stirs the cooling water 23. Because of this arrangement, even if a number of intermediate parts 7C (e.g., 20 to 30 intermediate parts 7C) are put in the container 22, the temperature of the cooling water 23 is kept within a range of 20°C to 30°C.

[0040] As shown in FIGS. 3(a) and 3(b), the spinning step S5 is a step of drawing the cylindrical portion 8B of the heat-treated intermediate part 7C in the axial direction by a cold spinning process to reduce the thickness of the cylindrical portion 8B, thereby obtain an intermediate part 7D. At the spinning step S5, as shown in FIG. 6, a chuck mechanism 31 and a machining roller 32 are used. The chuck mechanism 31 grips the semi-umbrella-shaped portion 9B and allows the intermediate part 7C to rotate around its axis, and the machining roller 32 has its outer peripheral surface pressed against the outer peripheral surface of the cylindrical portion 8B. A support shaft 33 extending in the axial direction of the machining roller 32 is supported rotatably on both surfaces of the machining roller 32 by a support member 35, via bearings 34. In other words, the machining roller 32 is supported rotatably by the support member 35 via the front and rear bearings 34 arranged across the machining roller 32 along the axial direction of the machining roller 32. The support member 35 is caused to move in the radial direction and axial direction of the cylindrical portion 8B by a moving mechanism (not depicted). The machining roller 32 is provided as a single roller or may be provided as a plurality of rollers.

[0041] At the spinning step S5, a holding pin 37 is inserted in the cylindrical portion 8B of the intermediate part 7C such that the holding pin 37 has its front end brought into contact with the bottom end of the cylindrical portion 8B but not into contact with the inner peripheral surface of the cylindrical portion 8B. In other words, at the spinning step S5, no tool is in contact with the inner peripheral surface of the cylindrical portion 8B of the intermediate part 7C.

[0042] The wall-thickness of the cylindrical portion 8B of the intermediate part 7C obtained at the second forging step S3 may develop irregularity. In such a case, however, subjecting the cylindrical portion 8B to the spinning process eliminates its wall-thickness irregularity. When a swaging process is adopted in place of the spinning process, however, the swaging process hardly eliminates the wall-thickness irregularity of the cylindrical portion 8B.

[0043] As shown in FIGS. 3(b) and 3(c), the necking step S6 is a step of gradually reducing the diameter of the cylindrical portion 8B, which is drawn in the axial direction, through a plurality of stages (e.g., 9 stages) of cold drawing process to form the shank 2 and the umbrella-shaped portion 3, that is, a step of obtaining the hollow engine valve 1. Specifically, a part of cylindrical portion 8B that is other than the bottom end side, the part being reduced in diameter, forms the shank 2, while the bottom end side of the cylindrical portion 8B, the bottom end side being reduced in diameter, and the semi-umbrella-shaped portion 9B jointly form the umbrella-shaped portion 3. At the necking step S6, a mold 38 and a S3 39 are used. The mold 38 holds the semi-umbrella-shaped portion 9B of the intermediate part 7D, and the mold 39 has a molding hole 39a for drawing the cylindrical portion 8B. A plurality of molds 39 different in the diameter of the molding hole 39a are used respectively in the plurality of stages of drawing process.

[0044] At the necking step S6, as shown in FIG. 7, a part of the cylindrical portion 8B of the intermediate part 7D in its axial direction, the part including an arcuate surface 17, is subjected to the drawing process. Specifically, at mold-clamping in the final stage (e.g., 9th stage) of drawing process, the lower end face of the mold 39 is located below the upper end of the arcuate surface 17 of the cylindrical portion 8B of the intermediate part 7D before execution of the final stage of drawing process. In FIG. 7, the level of the upper end of the arcuate surface 17 is indicated by a single-dot chain line.

(3) Effects of Example

[0045] The method for manufacturing the hollow engine valve according to the example includes the forging step S3 of obtaining the intermediate part 7C having the cylindrical portion 8B and the semi-umbrella-shaped portion 9B continuous with the axial end of the cylindrical portion 8B; the heat treatment step S4 of keeping the intermediate part 7C at a given heating temperature for a temperature-keeping time t2 determined in accordance with a wall-thickness t of the cylindrical portion 8B, to soften the intermediate part 7C; the spinning step S5 of drawing the cylindrical portion 8B of the heat-treated intermediate part 7C in the axial direction by the spinning process; and the necking step S6 of reducing the diameter of the cylindrical portion 8B by the drawing process, the cylindrical portion 8B being drawn in the axial direction, to form the shank 2 and the umbrella-shaped portion 3. In this manner, the intermediate part 7C obtained by the forging process is softened by the heat treatment. As a result, the cylindrical portion 8B of the intermediate part 7C is drawn easily during the spinning process and the drawing process. The spinning process and the drawing process thus offer excellent processing performance. This inhibits development of surface roughness on the inner surface making up the hollow 4 of the hollow engine valve 1, thus achieving a fine surface condition. Hence, a reduction in the strength of the hollow engine valve 1 is suppressed. In a case where metallic sodium is put into the hollow 4 of the hollow engine valve 1 for a cooling purpose, the metallic sodium flows smoothly in the hollow 4 to exert an effective cooling function. Because the drawing process offers excellent processing performance, the mold 39 can be adjusted easily in height at mold-clamping in the drawing process to prevent the collapse of the umbrella-shaped portion 3 at the outer periphery side of the hollow 4. This allows an increase in the volume of the hollow 4 of the hollow engine valve 1.

[0046] According to the example, the intermediate part 7C is made of a nickel-base superalloy, and, at the heat treatment step S4, the intermediate part 7C is heated to 1050°C, is kept at 1050°C, and then is cooled with water. In this manner, the intermediate part 7C is subjected to the solution heat treatment to soften the intermediate part 7C effectively.

[0047] According to the example, at the heat treatment step S4, the intermediate part 7C heated to the heating temperature is kept at the heating temperature such that the 1 mm portion of the wall-thickness t (a specific example of the wall-thickness t is 2 mm) of the cylindrical portion 8B is kept at the heating temperature for the temperature-keeping time t2 of 5 minutes (a specific example of the temperature-keeping time t2 is 10 minutes). As a result, the temperature-keeping time t2 for keeping the intermediate part 7C at the heating temperature can be made relatively short to suppress development of an oxide film on the surface of the intermediate part 7C subjected to the heat treatment.

[0048] According to the example, at the heat treatment step S4, the intermediate part 7C is cooled with water by submerging the intermediate part 7C into the cooling water 23 stirred in the container 22. In this process, a rise in the temperature of the cooling water 23 is curbed, and therefore the intermediate part 7C can be cooled effectively and rapidly at the heat treatment step S4. Because the temperature of the cooling water 23 is kept within the range of 20°C to 30°C in the example, the intermediate part 7C can be cooled effectively and rapidly at the heat treatment step S4.

[0049] According to the example, in the hollow engine valve 1, the surface roughness Ra of the inner surface making up the hollow 4 is 4.0. Because of this surface roughness value, the surface condition of the inner surface making up the hollow 4 of the hollow engine valve 1 is extremely fine.

[0050] According to the example, at the spinning step S5, the cylindrical portion 8B of the intermediate part 7C is subjected to the spinning process, using the machining roller 32, and the machining roller 32 is supported rotatably by the support member 35 via the front and rear bearings 34 arranged across the machining roller 32 along the axial direction of the machining roller 32. In this arrangement, the machining roller 32 is prevented from leaning forward. The cylindrical portion 8B of the intermediate part 7C is therefore spun effectively.

[0051] According to the example, the method for manufacturing the hollow engine valve includes the first forging step S1 of subjecting the solid columnar raw material 6 to the forging process to obtain the intermediate part 7A having the cotyloid wide-diameter portion 8A and the columnar portion 9A continuous with the axial end of the cotyloid wide-diameter portion 8A, the axial end being reduced in diameter, the ironing step S2 of shaping the cotyloid wide-diameter portion 8A into the cylindrical portion 8B by the ironing process, and the second forging step S3 of shaping the columnar portion 9A into the semi-umbrella-shaped portion 9B by the forging process. By this method for manufacturing, the cylindrical portion 8B with a relatively small wall-thickness can be formed easily by applying a relatively small pressure.

(4) Test Examples 1 to 19 and Comparative Example

[0052] Results of tests of the method for manufacturing the hollow engine valve, the tests being conducted in test examples 1 to 19 and a comparative example, will then be described with reference to FIGS. 11 to 13. In the test examples 1 to 19, the hollow engine valve has been manufactured through the first forging step S1, the ironing step S2, the second forging step S3, the heat treatment step S4, the spinning step S5, and the necking step S6 in the same manner as by the above method for manufacturing the hollow engine valve according to the example. In the comparative example, on the other hand, the heat treatment step S4 has been omitted from the steps S1 to S6 to manufacture the hollow engine valve through the rest of the steps. Then, the surface conditions of variations of the hollow engine valve obtained by variations of the method for manufacturing adopted in the test examples 1 to 19 and the comparative example have been checked and the processing performance of the spinning process in the test examples and comparative example has been checked as well, after which a comprehensive evaluation has been made.

[0053] In the test examples 1 to 7, a raw material made of nickel-base superalloy containing nickel of about 50% is used. In the test examples 8 to 13, a raw material made of nickel-base superalloy containing nickel of about 80% is used. In the test examples 14 to 19 and the comparative example, a raw material made of nickel-base superalloy containing nickel of about 30% is used. At the heat treatment step in each of the test examples 1 to 19, the heating time, the temperature-keeping time, the cooling method, and the number of intermediate parts to be processed, etc., are changed. In the test examples 1 to 17, the intermediate part is cooled with water by submerging the intermediate part in the cooling water that is not stirred. In the test examples 18 and 19, on the other hand, the intermediate part is cooled with water by submerging the intermediate part in the cooling water being stirred. In the test examples 1 to 16, one intermediate part is submerged in the cooling water to be cooled therein. In the test examples 17 to 19, on the other hand, 10 to 20 intermediate parts are submerged in the cooling water to be cooled therein.

[0054] As a result, a variation of the hollow engine valve produced by a variation of the method for manufacturing adopted in the comparative example have developed conspicuous roughness of the inner surface making up the hollow, and the surface roughness Ra of the inner surface is measured at about 22.0 (see FIG. 10). In addition, the rate of drawing of the material is low during the spinning process. The processing performance of the spinning process is therefore observed to be extremely low.

[0055] In contrast, variations of the hollow engine valve produced by variations of the method for manufacturing adopted in the test examples 1, 2, 6, 9, and 11 have developed minor roughness of the inner surface making up the hollow but the surface condition of the inner surface is found to be better than that in the comparative example. Variations of the hollow engine valve produced by variations of the method for manufacturing adopted in the test examples 3 to 5, 7, 8, 10, and 12 to 19 have developed no roughness of the inner surface making up the hollow, thus offering the inner surface with an extremely fine surface condition. A variation of the hollow engine valve produced by a variation of the method for manufacturing adopted in the test example 19, in particular, have developed less oxide film on the inner surface making up the hollow.

[0056] Variations of the method for manufacturing adopted in the test examples 1 to 15 and 17 have led to slight inferiority in the rate of drawing of the material during the spinning process but have offered processing performance higher than that in the comparative example. Variations of the method for manufacturing adopted in the test examples 16, 18, and 19 have led to the higher rate of drawing of the material during the spinning process, thus offering extremely high processing performance.

[0057] According to the variations of the method for manufacturing adopted in the test examples 18 and 19, even when a number of intermediate parts are submerged in the cooling water all at once, they are cooled effectively. This is because that the intermediate parts are cooled in the cooling water that is being stirred to curb a rise in its temperature. The variation of the method for manufacturing adopted in the test example 19 have led to less development of an oxide film on the inner surface making up the hollow of the hollow engine valve. This is because that the temperature-keeping time t2 is 10 minutes, which is extremely short. This leads to a conclusion that composition reformation necessary for the spinning process is achieved by keeping the intermediate part 7C obtained by the forging step S3 at the heating temperature such that a 1 mm portion of the wall-thickness t of the cylindrical portion 8B is kept at the heating temperature for the temperature-keeping time t2 of about 5 minutes.

<Another Spinning Step>

[0058] Another spinning step S5' will then be described. The substantially same constituent elements as included in the above spinning step S5 will be denoted by the same reference signs and will be omitted in further description.

(1) Spinning Step

[0059] As shown in FIGS. 3(a) and 3(b), the spinning step S5' is a step of drawing the cylindrical portion 8B of the heat-treated intermediate part 7C in the axial direction by the cold spinning process to reduce the wall-thickness of the cylindrical portion 8B, thereby obtain the intermediate part 7D. At the spinning step S5', as shown in FIG. 14, a chuck mechanism 131 and a machining roller 132 are used. The chuck mechanism 131 grips the semi-umbrella-shaped portion 9B and allows the intermediate part 7C to rotate around its axis, and the machining roller 132 has its peripheral arcuate surface 132a pressed against the outer peripheral surface of the cylindrical portion 8B. The machining roller 132 is supported rotatably by a support shaft 133 (i.e., support member 135) extending in the axial direction of the machining roller 132, via front and rear bearings 134 (thrust bearings 134) arranged across the machining roller 132 along its axial direction. The support member 135 is caused to move in the radial direction and axial direction of the cylindrical portion 8B by a moving mechanism (not depicted).

[0060] The machining roller 132 is provided as a single roller or may be provided as a plurality of rollers. In FIG. 14, a part of the cylindrical portion 8B that is above a center line of the cylindrical portion 8B indicates a wall-thickness (e.g., 1.65 mm) before execution of the spinning process, while a part of the cylindrical portion 8B that is below the center line indicates a wall-thickness (e.g., 1.0 mm) after execution of the spinning process.

[0061] At the spinning step S5', as shown in FIG. 15, the machining roller 132 is moved in a machining direction P along the axial direction of the cylindrical portion 8B as the peripheral arcuate surface 132a of the machining roller 132 is pressed at a given cutting depth d against the outer peripheral surface of the cylindrical portion 8B. This process is repeated to draw the cylindrical portion 8B in the axial direction. At the spinning step S5', the cutting depth d and the number of times of movement in the direction P, in which the cylindrical portion 8B is drawn, are not specified and therefore may be determined freely. At the spinning step S5', the peripheral arcuate surface 132a usually experiences a reaction smaller than the cutting depth d during the spinning process.

[0062] The radius of curvature R of the peripheral arcuate surface 132a of the machining roller 132 is determined to be 3 to 5 times the wall-thickness t of the cylindrical portion 8B not subjected to the spinning process yet. During the spinning process, a straight line L1 connecting one end p1 to the other end p2 of an arc formed at a point of contact between the peripheral arcuate surface 132a of the machining roller 132 and the outer peripheral surface of the cylindrical portion 8B on a section along the axial direction of the cylindrical portion 8B is tilted at a tilt angle θ1 of 5 degrees to 7 degrees against the axial direction of the cylindrical portion 8B. In this configuration, the radius of curvature R of the peripheral arcuate surface 132a of the machining roller 132 is determined as the estimated maximum and minimum of the cutting depth d are taken into consideration. As a result, the cylindrical portion 8B of the intermediate part 7C can be drawn effectively through the spinning process.

[0063] Usually, the above one end p1 is defined as a point at which, on the section along the axial direction of the cylindrical portion 8B, a straight line L2 passing through the center of the radius of curvature R of the peripheral arcuate surface 132a of the machining roller 132 and being perpendicular to the axis of the cylindrical portion 8B intersects the outer peripheral surface of the cylindrical portion 8B during the spinning process. At the spinning step S5, the radius of curvature R and the tilt angle θ1 of the machining roller 32 are determined to be equal to the radius of curvature R and the tilt angle θ1 of the machining roller 132 that are adopted at the spinning step S5'.

(2) Test Examples 20 to 27

[0064] Results of tests of the spinning process, the tests being conducted in test examples 20 to 27, will then be described with reference to FIG. 16. In the test examples 20 to 27, the intermediate part 7C having been subjected to the first forging step S1, the ironing step S2, the second forging step S3, and the heat treatment step S4 (test example 19) is spun several times until the wall-thickness t=1.65 mm of the cylindrical portion 8B is reduced to 1 mm. In the test examples 20 to 24, the cutting depth d of the machining roller 132 against the cylindrical portion 8B is determined to be 0.15 mm. In the test examples 25 to 27, the cutting depth d of the machining roller 132 against the cylindrical portion 8B is determined to be 0.1 mm. The surface condition of the intermediate part 7D having been subjected to the spinning process has been checked, and an evaluation has been made based on the surface condition and the number of times of spinning of the intermediate part 7D.

[0065] In the test examples 20 to 27, a general-purpose numerically-controlled (NC) lathe is used in a setup such that the rotating speed of the intermediate part 7C is 1200 rpm and that the feed rate of the machining roller 132 is 0.13 mm/s.

[0066] In the test examples 21 to 23, 25, and 26, the machining roller 132 is adopted under the condition that the radius of curvature R of the peripheral arcuate surface 132a of the machining roller 132 is 3 to 5 times the wall-thickness t of the cylindrical portion 8B not subjected to the spinning process yet and that the straight line L1 is tilted at the tilt angle θ1 of 5 degrees to 7 degrees against the axial direction of the cylindrical portion 8B. As a result, in the test examples 21 to 23, the intermediate part 7D with a smooth and fine surface condition has been obtained, and the number of times of spinning is 10, which indicates the excellent processing performance of the spinning process. In the test examples 25 and 26, the intermediate part 7D with a smooth and fine surface condition has been obtained, and the number of times of spinning is 13, which also indicates the excellent processing performance.

[0067] In the test example 20, on the other hand, the machining roller 132 is adopted under the condition that the radius of curvature R of the peripheral arcuate surface 132a of the machining roller 132 is about 1.8 times the wall-thickness t of the cylindrical portion 8B not subjected to the spinning process yet and that the straight line L1 is tilted at the tilt angle θ1 of 9 degrees against the axial direction of the cylindrical portion 8B. As a result, in the test example 20, the intermediate part 7D with a slightly rough surface condition has been obtained, but the number of times of spinning is 10, indicating the excellent processing performance.

[0068] In the test example 24, the machining roller 132 is adopted under the condition that the radius of curvature R of the peripheral arcuate surface 132a of the machining roller 132 is about 6 times the wall-thickness t of the cylindrical portion 8B not subjected to the spinning process yet and that the straight line L1 is tilted at the tilt angle θ1 of 4.5 degrees against the axial direction of the cylindrical portion 8B. As a result, in the test example 24, the intermediate part 7D with a smooth and fine surface condition has been obtained, but the number of times of spinning has been increased to 16.

[0069] In the test example 27, the machining roller 132 is adopted under the condition that the radius of curvature R of the peripheral arcuate surface 132a of the machining roller 132 is 5 times the wall-thickness t of the cylindrical portion 8B not subjected to the spinning process yet and that the straight line L1 is tilted at the tilt angle θ1 of 4.5 degrees against the axial direction of the cylindrical portion 8B. As a result, in the test example 27, the intermediate part 7D with a smooth and fine surface condition has been obtained, but the number of times of spinning has been increased to 20.

[0070] The present invention is not limited to the above example. The example may be modified into various forms within the scope of the present invention, according to intended purposes and applications. In the example, the hot forging process, the cold forging process, the cold spinning process, the cold ironing process, etc., have been described. Processes included in the example are, however, not limited to these processes and may be selected properly from a hot, warm, and cold processes. Each of these processes may be carried out once or several times.

[0071] In the example, the intermediate part 7C made of the austenitic heat-resistant material (specifically, nickel-base superalloy) has been described. Another intermediate part 7C, however, may also be adopted, the intermediate part 7C being made of, for example, a martensitic heat-resistant material, such as SUH3 and SUH11. In such a case, a heat treatment appropriate for the martensitic heat-resistant material making up the intermediate part 7C is carried out at the heat treatment step S4.

[0072] According to the example, the intermediate part 7A having the cotyloid wide-diameter portion 8A is formed by the forging process, and the cotyloid wide-diameter portion 8A is shaped into the cylindrical portion 8B by the ironing process to obtain the intermediate part 7B having the cylindrical portion 8B. Another method for manufacturing, however, may be adopted, according to which, for example, the intermediate part 7B having the cylindrical portion 8B is obtained by the forging process without forming the cotyloid wide-diameter portion 8A.

[0073] According to the example, water jetted out of the nozzle 25 stirs the cooling water 23 in the container 22. Another configuration, however, may be adopted, in which, for example, rotating stir vanes or stir screws stir the cooling water 23 in the container 22. Still another configuration may also be adopted, in which, for example, a circulation channel is connected to the container 22 to circulate the cooling water 23 to the container 22. In this configuration, a rise in the temperature of the cooling water 23 is curbed, and therefore the intermediate part 7C can be cooled effectively and rapidly at the heat treatment step S4.

[0074] The example has been described as the mode in which the machining roller 132 having the peripheral arcuate surface 132a with the radius of curvature R that is 3 to 5 times the wall-thickness t of the cylindrical portion 8B not subjected to the spinning process yet is used at the spinning steps S5 and S5'. A different machining roller 132, however, may be used, the machining roller 132 having the peripheral arcuate surface 132a with the radius of curvature R that is less than 3 times or more than 5 times the wall-thickness t of the cylindrical portion 8B not subjected to the spinning process yet.

[0075] The example has been described as the mode in which the machining roller 132 configured to have the straight line L1 tilted at the tilt angle θ1 of 5 degrees to 7 degrees against the axial direction of the cylindrical portion is used at the spinning steps S5 and S5'. A different machining roller 132, however, may be used, the machining roller 132 being configured to have the straight line L1 tilted at the tilt angle θ1 of less than 5 degrees or more than 7 degrees against the axial direction of the cylindrical portion 8B.

[0076] In the example, the necking step S6 of subjecting the part of the cylindrical portion 8B of the intermediate part 7D, the part including the arcuate surface 17, in the axial direction to the drawing process has been described. Another form of the necking step S6, however, may be adopted, according to which, as shown in FIG. 8, when the cylindrical portion 8B of the intermediate part 7D is at the upper side while the semi-umbrella-shaped portion 9B is at the lower side, the part of cylindrical portion 8B that is above the arcuate surface 17 in the axial direction is subjected to the drawing process. In this case, at mold-clamping in the drawing process, the lower end face of the mold 39 is located above the upper end of the arcuate surface 17 of the cylindrical portion 8B of the intermediate part 7D before execution of the drawing process. In FIG. 8, the level of the upper end of the arcuate surface 17 is indicated by a single-dot chain line. In this arrangement, the maximum outer diameter D1' of the hollow 4 of the hollow engine valve 1 can be made equal to the inner diameter D2 of the opening of the cylindrical portion 8B of the intermediate part 7D obtained at the forging step S3 (see FIG. 3(a)). As a result, the volume of the hollow 4 of the hollow engine valve 1 can be further increased.

[0077] In the example, the machining roller 32 supported on its both sides via the front and rear bearings 34 has been described. A different machining roller 32 supported on its one side only, however, may be adopted. At the spinning step S5, the machining roller 32 may be replaced with a machining spatula or both the machining roller 32 and the machining spatula may be used.

INDUSTRIAL APPLICABILITY

[0078] The present invention is used preferably as a technique for manufacturing a hollow engine valve that is light in weight and superior in heat resistance.

REFERENCE SIGNS LIST

[0079]

1	Hollow engine valve
2	Shank
3	Umbrella-shaped portion
4	Hollow
7C	Intermediate part
8B	Cylindrical portion
9B	Semi-umbrella-shaped portion
17	Arcuate surface
22	Container
23	Cooling water
32, 132	Machining roller
33	Support shaft
34, 134	Bearing
35, 135	Support member
39, 139	Mold
S3	Second forging step
S4	Heat treatment step
S5, S5'	Spinning step
S6	Necking step
T1	Heating temperature
t2	Temperature-keeping time

Claims

1. A method for manufacturing a hollow engine valve having a shank, an umbrella-shaped portion continuous with an axial end of the shank, and a hollow formed in such a way as to extend from the shank to the umbrella-shaped portion, the method for manufacturing comprising:

   a forging step of obtaining an intermediate part by a forging process, the intermediate part having a cylindrical portion and a semi-umbrella-shaped portion continuous with an axial end of the cylindrical portion;
   a heat treatment step of keeping the intermediate part at a given heating temperature for a temperature-keeping time determined in accordance with a wall-thickness of the cylindrical portion, to soften the intermediate part;
   a spinning step of drawing the cylindrical portion of the heat-treated intermediate part in an axial direction by a spinning process; and
   a necking step of reducing a diameter of the cylindrical portion by a drawing process, the cylindrical portion being drawn in the axial direction, to form the shank and the umbrella-shaped portion.

2. The method for manufacturing the hollow engine valve according to claim 1, wherein
   the intermediate part is made of an austenitic heat-resistant material, and
   at the heat treatment step, the intermediate part is kept heated at temperatures ranging from 1000°C to 1100°C and then is cooled with water.

3. The method for manufacturing the hollow engine valve according to claim 2, wherein at the heat treatment step, the intermediate part heated to a heating temperature is kept heated at the heating temperature such that a 1 mm portion of a wall-thickness of the cylindrical portion is kept heated at the heating temperature for a temperature-keeping time of 3 to 8 minutes.

4. The method for manufacturing the hollow engine valve according to claim 2 or 3, wherein at the heat treatment step, the intermediate part is cooled with water by submerging the intermediate part into cooling water stirred in a container or cooling water circulated to a container.

5. The method for manufacturing the hollow engine valve according to claim 4, wherein a temperature of the cooling water ranges from 15°C to 35°C.

6. The method for manufacturing the hollow engine valve according to any one of claims 1 to 5, wherein at the spinning step, a machining roller is moved in an axial direction relative to the cylindrical portion as a peripheral arcuate surface of the machining roller is pressed at a given cutting depth against an outer peripheral surface of the cylindrical portion, to draw the cylindrical portion in the axial direction,
   a radius of curvature of the peripheral arcuate surface of the machining roller is 3 to 5 times a wall-thickness of the cylindrical portion not subjected to a spinning process yet, and
   during the spinning process, a straight line connecting one end to the other end of an arc formed at a point of contact between the peripheral arcuate surface of the machining roller and the outer peripheral surface of the cylindrical portion on a section along

the axial direction of the cylindrical portion is tilted at a tilt angle of 5 degrees to 7 degrees against the axial direction of the cylindrical portion.

7. The method for manufacturing the hollow engine valve according to any one of claims 1 to 6, wherein in the hollow engine valve, surface roughness Ra of an inner surface making up the hollow is from 4.0 to 22.0.

8. The method for manufacturing the hollow engine valve according to any one of claims 1 to 7, wherein at the forging step, an arcuate surface is formed on a bottom end side of an inner peripheral surface of the cylindrical portion of the intermediate part, and at the necking step, when the cylindrical portion is at an upper side as the semi-umbrella-shaped portion is at a lower side, a part of the cylindrical portion, the part being above the arcuate surface in an axial direction of the cylindrical portion, is subjected to a drawing process.

9. The method for manufacturing the hollow engine valve according to any one of claims 1 to 8, wherein at the spinning step, the cylindrical portion of the intermediate part is subjected to a spinning process, using a machining roller, and
the machining roller is supported rotatably by a support member via front and rear bearings arranged across the machining roller along an axial direction of the machining roller.

FIG.1

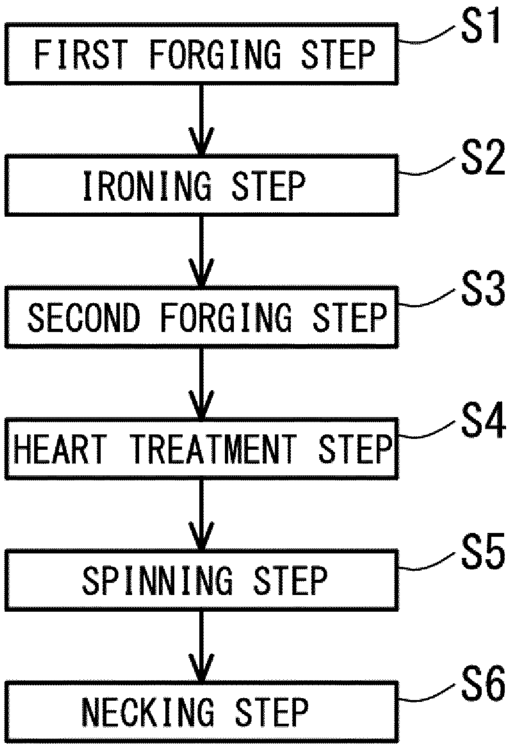

FIRST FORGING STEP
S1
IRONING STEP
S2
SECOND FORGING STEP
S3
HEART TREATMENT STEP
S4
SPINNING STEP
S5
NECKING STEP
S6

FIG.2

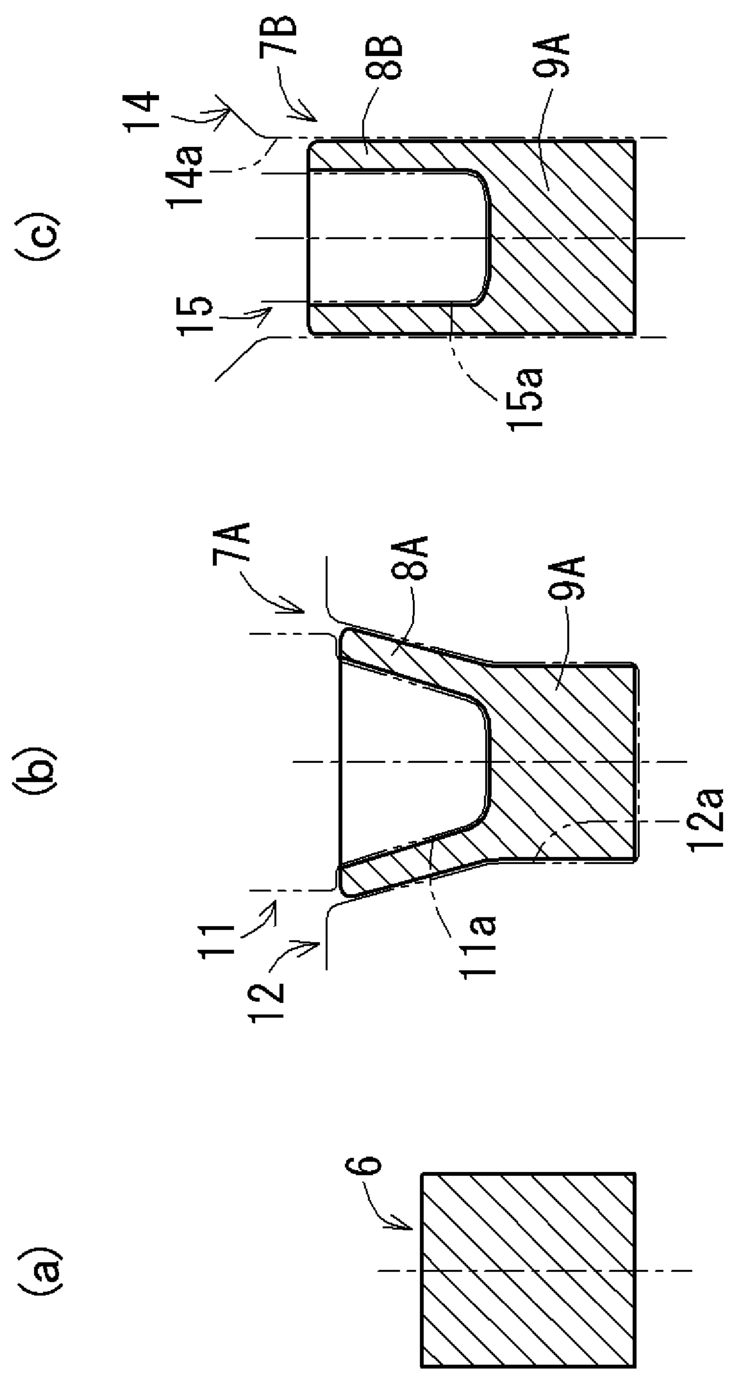


FIG.3

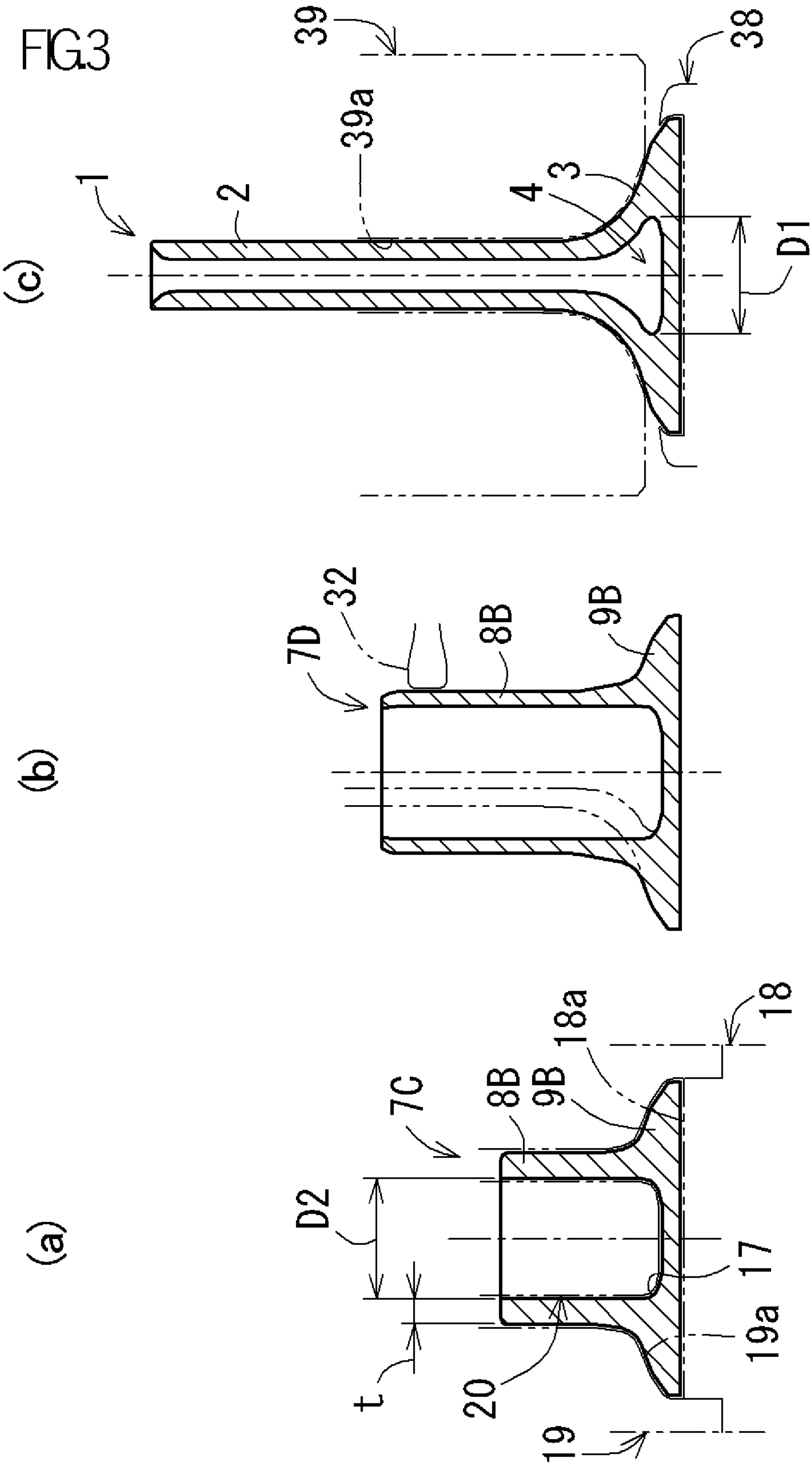


FIG.4

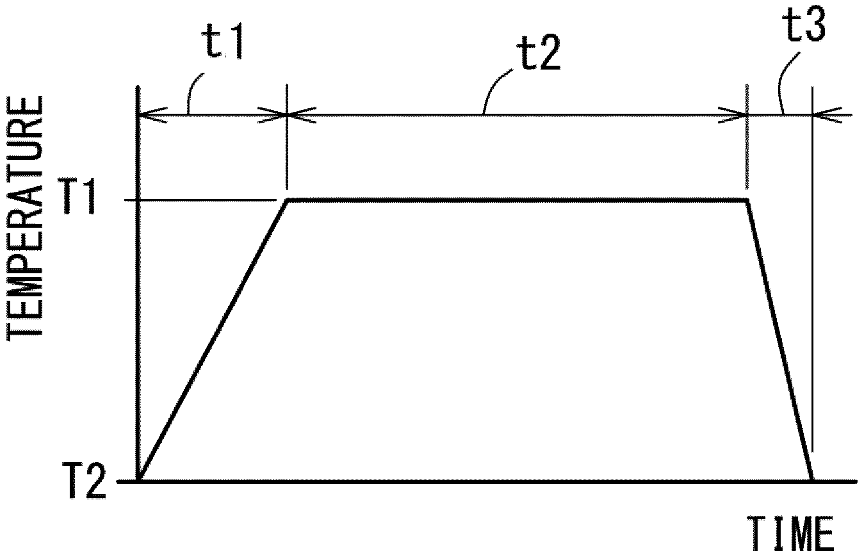


FIG.5

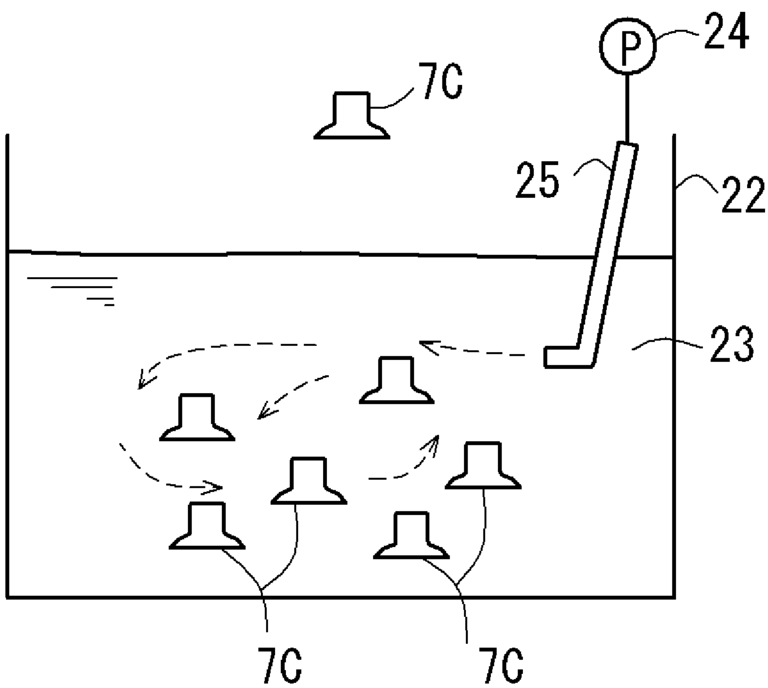


FIG.6

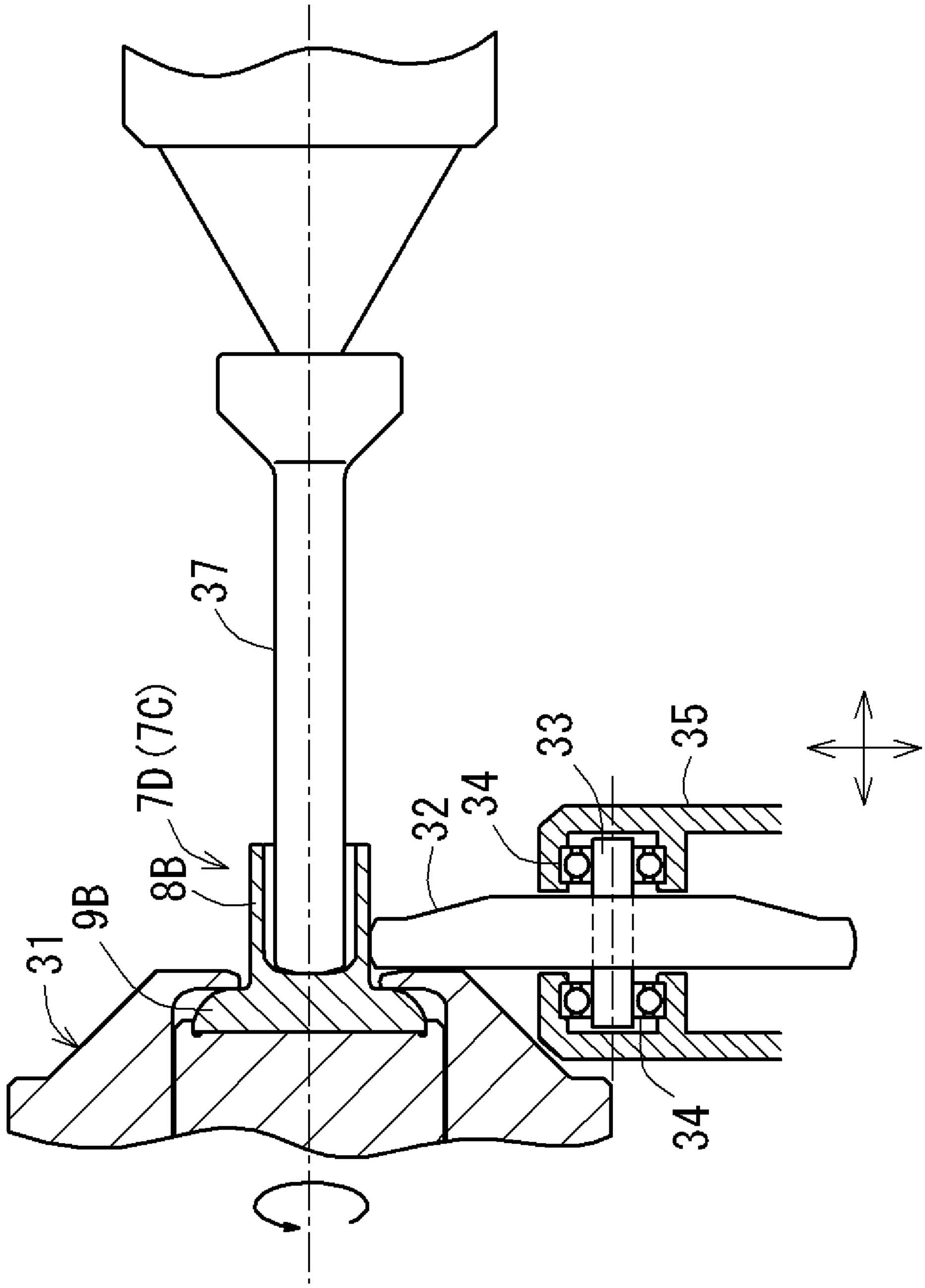


FIG.7

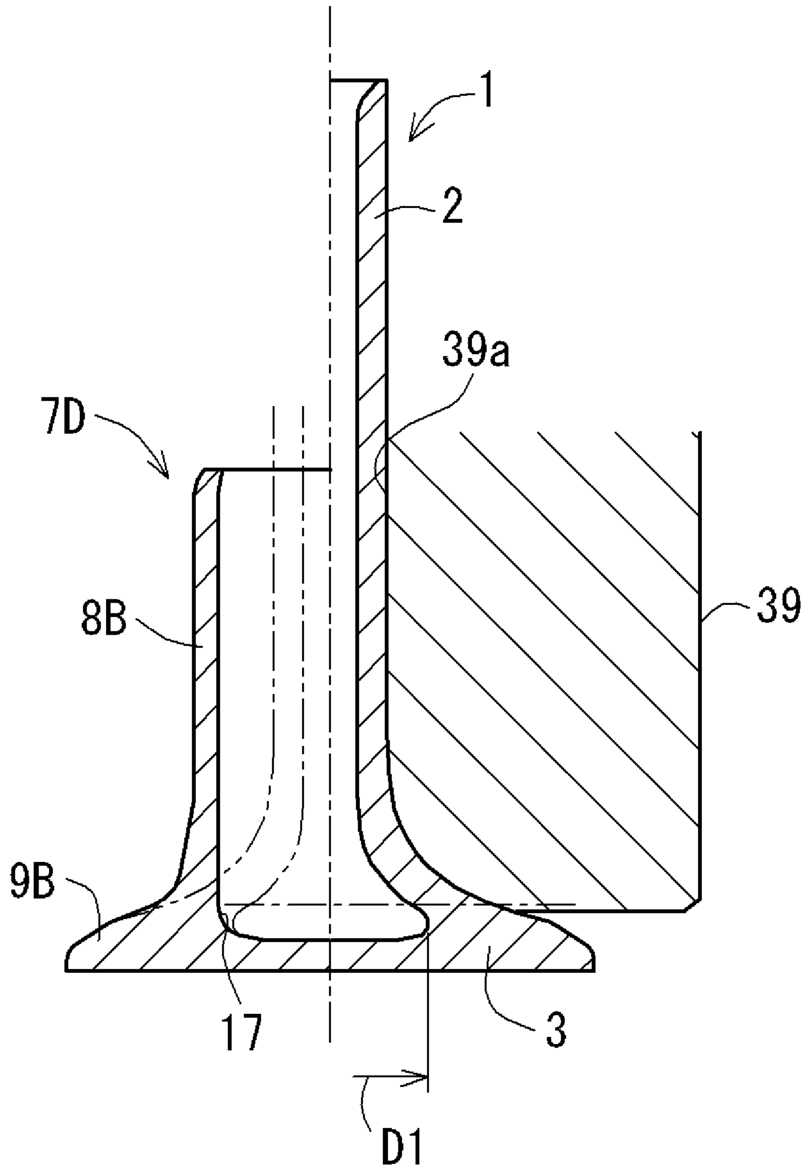


FIG.8

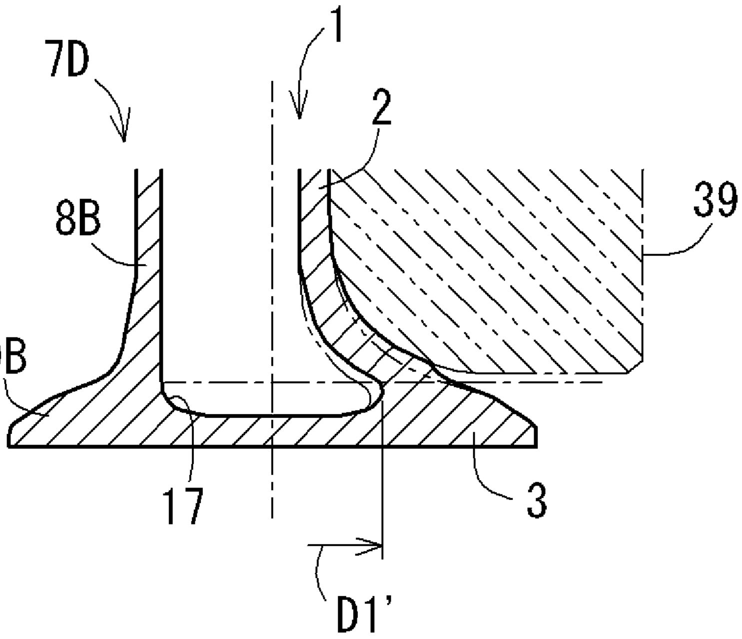
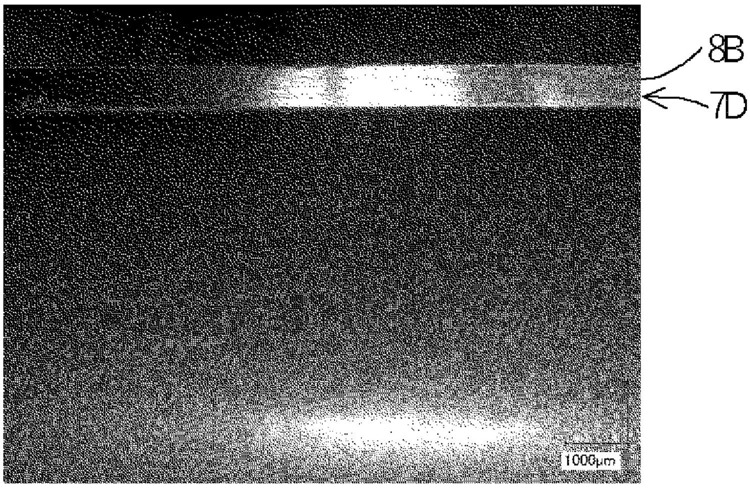


FIG.9

(a)



(b)

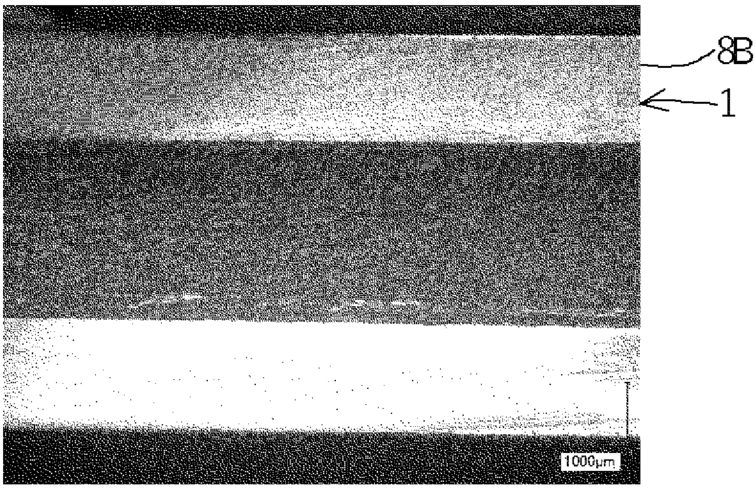
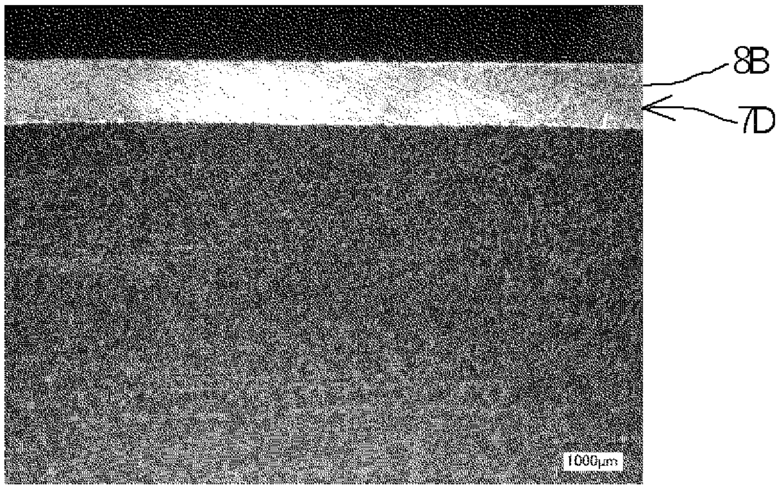


FIG.10

(a)



(b)

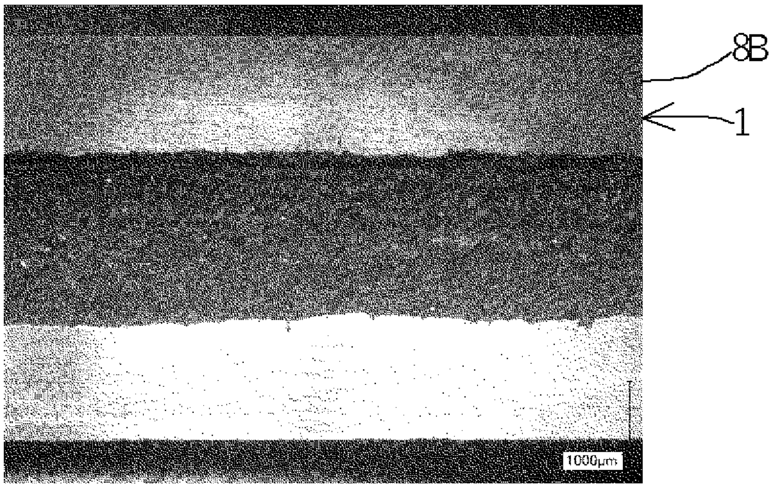


FIG.11

	MATERIAL	HEATING TEMPERATURE	HEATING TIME	COOLING METHOD	NUMBER OF INTERMEDIATE PART TO BE PROCESSED	WATER TEMPERATURE	SURFACE CONDITION	MOLDABILITY	COMPREHENSIVE EVALUATION
TEST EXAMPLE 1	NICKEL-BASE SUPERALLOY (NICKEL CONTENT 50%)	1100°C	30 MIMUTES	COOLING WITH WATER	ONE	20 to 40°C	△	△	△
TEST EXAMPLE 2		1080°C	20 MIMUTES	COOLING WITH WATER	ONE	20 to 40°C	△	△	△
TEST EXAMPLE 3		1060°C	20 MIMUTES	COOLING WITH WATER	ONE	20 to 40°C	○	△	○
TEST EXAMPLE 4		1050°C	20 MIMUTES	COOLING WITH WATER	ONE	20 to 40°C	○	△	○
TEST EXAMPLE 5		1040°C	20 MIMUTES	COOLING WITH WATER	ONE	20 to 40°C	○	△	○
TEST EXAMPLE 6		1060°C	40 MIMUTES	COOLING WITH WATER	ONE	20 to 40°C	△	△	△
TEST EXAMPLE 7		1050°C	30 MIMUTES	COOLING WITH WATER	ONE	20 to 40°C	○	△	○

◎;BEST
○;FINE
△;ACCEPTABLE
×;NOT ACCEPTABLE

FIG.12

	MATERIAL	HEATING TEMPERATURE	HEATING TIME	COOLING METHOD	NUMBER OF INTERMEDIATE PART TO BE PROCESSED	WATER TEMPERATURE	SURFACE CONDITION	MOLDABILITY	COMPREHENSIVE EVALUATION
TEST EXAMPLE 8	NICKEL-BASE SUPERALLOY (NICKEL CONTENT 80%)	1080°C	60 MIMUTES	COOLING WITH WATER	ONE	20 to 40°C	○	△	○
TEST EXAMPLE 9		1065°C	30 MIMUTES	COOLING WITH WATER	ONE	20 to 40°C	△	△	△
TEST EXAMPLE 10		1100°C	60 MIMUTES	COOLING WITH WATER	ONE	20 to 40°C	○	△	○
TEST EXAMPLE 11		1060°C	40 MIMUTES	COOLING WITH WATER	ONE	20 to 40°C	△	△	△
TEST EXAMPLE 12		1080°C	60 MIMUTES	COOLING WITH WATER	ONE	20 to 40°C	○	△	○
TEST EXAMPLE 13		1080°C	90 MIMUTES	COOLING WITH WATER	ONE	20 to 40°C	○	△	○

◎;BEST
○;FINE
△;ACCEPTABLE
×;NOT ACCEPTABLE

FIG.13

	MATERIAL	HEATING TEMPERATURE	HEATING TIME	COOLING METHOD	NUMBER OF INTERMEDIATE PART TO BE PROCESSED	WATER TEMPERATURE	SURFACE CONDITION	MOLDABILITY	COMPREHENSIVE EVALUATION
TEST EXAMPLE 14	NICKEL-BASE SUPERALLOY (NICKEL CONTENT 30%)	1080°C	30 MIMUTES	COOLING WITH WATER	ONE	20 to 40°C	○	△	○
TEST EXAMPLE 15		1065°C	30 MIMUTES	COOLING WITH WATER	ONE	20 to 40°C	○	△	○
TEST EXAMPLE 16		1050°C	20 MIMUTES	COOLING WITH WATER	ONE	20 to 40°C	○	○	◎
TEST EXAMPLE 17		1050°C	30 MIMUTES	COOLING WITH WATER	10 to 20	20 to 50°C	○	△	○
TEST EXAMPLE 18		1050°C	30 MIMUTES	COOLING WITH WATER PLUS PUMPING	10 to 20	20 to 30°C	○	◎	◎
TEST EXAMPLE 19		1050°C	10 MIMUTES	COOLING WITH WATER PLUS PUMPING	10 to 20	20 to 30°C	◎	◎	◎
COMPARATIVE EXAMPLE		—	—	—	—	—	×	×	×

◎;BEST
○;FINE
△;ACCEPTABLE
×;NOT ACCEPTABLE

FIG.14

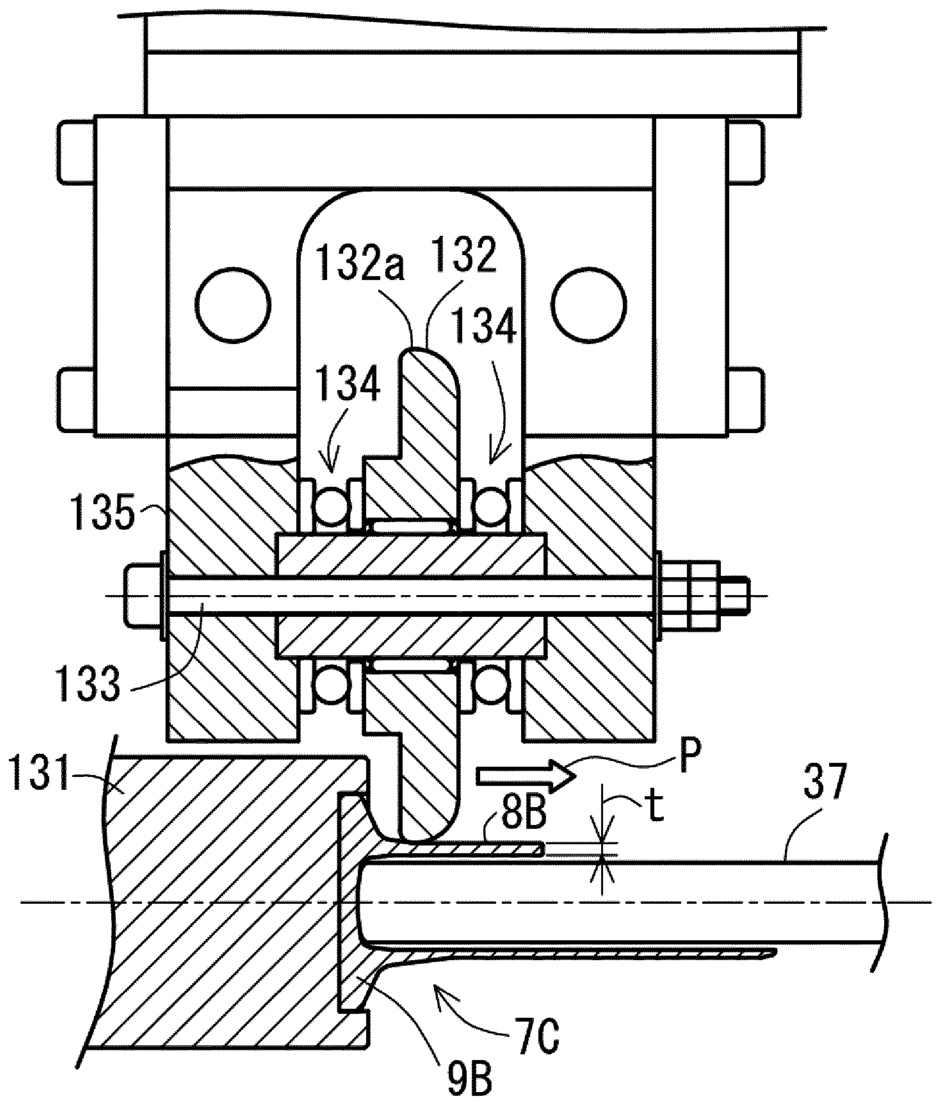


FIG.15

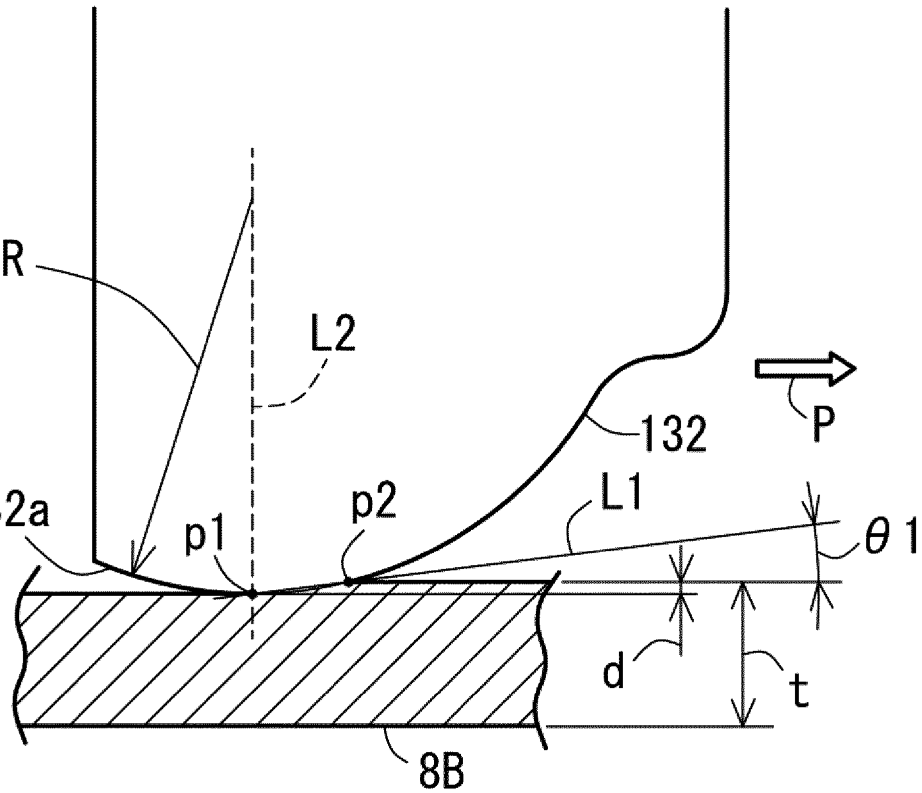


FIG.16

(a)

CUTTING DEPTH d:0.15 mm

	TEST EXAMPLE 20	TEST EXAMPLE 21	TEST EXAMPLE 22	TEST EXAMPLE 23	TEST EXAMPLE 24
RADIUS OF CURVATURE R (mm)	3	5	7	8.25	10
ANGLE θ1 (°)	9	7	6	5	4.5
SURFACE CONDITION	SLIGHTLY ROUGH	SMOOTH AND FINE	SMOOTH AND FINE	SMOOTH AND FINE	SMOOTH AND FINE
NUMBER OF TIMES OF SPINNING	10	10	10	10	16
EVALUATION	△	◎	◎	◎	○

◎;BEST
○;FINE
△;ACCEPTABLE

(b)

CUTTING DEPTH d:0.1 mm

	TEST EXAMPLE 25	TEST EXAMPLE 26	TEST EXAMPLE 27
RADIUS OF CURVATURE R (mm)	5	7	8.25
ANGLE θ1 (°)	6	5	4.5
SURFACE CONDITION	SMOOTH AND FINE	SMOOTH AND FINE	SMOOTH AND FINE
NUMBER OF TIMES OF SPINNING	13	13	20
EVALUATION	◎	◎	○

◎;BEST
○;FINE
△;ACCEPTABLE

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2019/024806

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. B21K1/22(2006.01)i, B21D22/16(2006.01)i, B21D53/10(2006.01)i, B21J1/04(2006.01)i, B21J1/06(2006.01)i, B21J5/06(2006.01)i, B21J5/08(2006.01)i, C21D9/00(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)
Int.Cl. B21K1/22, B21D22/16, B21D53/10, B21J1/04, B21J1/06, B21J5/06, B21J5/08, C21D9/00

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	1971-2019
Registered utility model specifications of Japan	1996-2019
Published registered utility model applications of Japan	1994-2019

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	JP 2012-197718 A (MITSUBISHI HEAVY INDUSTRIES, LTD.) 18 October 2012, paragraphs [0003], [0025], [0031]-[0033], [0064], fig. 1, 5, 6 & US 2014/0033533 A1, paragraphs [0003], [0042], [0048]-[0050], [0081], fig. 1, 5, 6 & EP 2690262 A1 & CN 103403305 A & KR 10-2013-0116943 A	1-9
Y	JP 11-117020 A (DAIDO STEEL CO., LTD.) 27 April 1999, paragraphs [0013]-[0014] (Family: none)	1-9

☒ 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
03 September 2019 (03.09.2019)	17 September 2019 (17.09.2019)

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

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

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2019/024806

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 4-193912 A (AISAN INDUSTRY CO., LTD.) 14 July 1992, page 2, upper right column, line 3 to upper right column, line 20, page 4, upper right column, line 1 to upper right column, line 9 (Family: none)	1-9
Y	JP 2003-1366 A (TOYOTA CENTRAL R&D LABS., INC.) 07 January 2003, paragraphs [0021], [0028], fig. 4 (Family: none)	1-9
Y	CN 102728690 A (XI AN AEROSPACEMOTOR MACHINE FACTORY) 17 October 2012, paragraph [0024], fig. 3 (Family: none)	9
Y	CN 106180341 A (HARBIN INSTITUTE TECHNOLOGY) 07 December 2016, paragraphs [0007], [0015]-[0025], fig. 1-3 (Family: none)	9

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

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

- WO 2011104903 A **[0003]**